Feasibility of strategic ornithological compensatory measures in the Scottish context

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Feasibility of strategic ornithological compensatory measures in the Scottish context

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Executive Summary

1. The Scottish Government have set out goals for significant offshore wind capacity to be developed as part of their Net Zero policies. The scale of proposed and planned development has the potential to adversely affect seabird populations protected under the Habitats Regulations. Should developments or plans proceed where adverse effects are concluded, there is an obligation to deliver compensatory measures to offset for impacts. Recent policy and legislative changes mean that, in future, compensation could be delivered strategically across multiple offshore wind projects.
2. To ensure that strategic compensatory measures can be delivered effectively and with maximum positive benefit to seabirds, there is a need to assess which measures have ecological and practical feasibility within Scotland. The Scottish Government scoped out a list of potential measures which were evaluated in this project. The project was structured around two work packages which assessed the proposed measures; the first to evaluate their ecological feasibility and the second to evaluate their practical feasibility.
3. For each proposed measure, we identified corresponding conservation actions. The term 'compensatory measure' is a broad term which could include either a single or a suite of coordinated actions that must deliver a compensatory response, i.e. counteracting a given population level impact. Here, we use a more specific term, 'conservation action', which refers to management interventions that have potential to lead to population level gains and/or recovery for a seabird species (e.g. by improving productivity or survival). Consequently, conservation actions have potential to be used as compensatory measures subject to meeting various tests, both relating to efficacy and other factors such as additionality.
4. Measures that corresponded to clear conservation actions were assessed through a systematic literature review process and evaluated on their ecological feasibility, using a qualitative approach, and enabling the comparison of their relative ecological feasibility. Where conservation actions were not readily identifiable from the initial proposed measures, scoping reviews were conducted to identify and evaluate potential conservation actions. Additionally, bycatch mitigation was explored through a targeted review.
5. The conservation actions with the highest ecological feasibility scores (a composite score including ecological effect and accounting for strength of the evidence base) were, in descending order: Mammalian predator eradication and/or management, End of the Gannet harvest at Sula Sgeir; Avian predator management; Fishery closure or enhanced management of prey fisheries; Reduction of disturbance (at sea); Reduction of disturbance (at colony); and Sandeel fishery closure. All conservation actions were assessed for their practical feasibility, excluding Reduction of disturbance (at sea). The latter was excluded due to there being a consensus that, at this time, there is insufficient evidence to have confidence that this action could lead to a meaningful scale of compensation.

6. For measures assessed via scoping and targeted reviews, we identify a list of potential conservation actions and provide a high-level state-of-the-art review that considers key relevant recent papers and reports. Measures include: Management of supporting habitats; Reducing disease spread; Habitat management; Changes in large gull management; and Bycatch mitigation in longline fisheries. The last measure was also included for the practical feasibility assessments.
7. Practical feasibility assessments included: identifying the steps required to implement each action; ecological benefits anticipated in Scotland for the different seabird species and other wildlife; research and monitoring recommendations; and key considerations including barriers and potential solutions to these.
8. Sandeel fishery closure and fishery closure or enhanced management of prey fisheries had medium levels of ecological efficacy and low–medium overall feasibility scoring. Both actions can indirectly benefit seabirds through an increase in prey availability. However, quantifying the impact and benefit is challenging as prey fish are limited by other non-fishery factors as well. They should both be considered as a measure to enhance ecosystem resilience. Key considerations include international aspects, potential socio-economic impacts, and potential for displacement.
9. The end of the Gannet harvest at Sula Sgeir had a low–medium level of ecological efficacy and a low–medium overall feasibility scoring. It also proved to be the conservation action were there was lowest uncertainty of its benefits. Benefits will likely be stronger for the North Rona and Sula Sgeir SPA colonies. However, limited benefit is expected to Gannet populations more widely in Scotland, though this is yet to be fully understood. This action would require local community cooperation for its implementation, which may be challenging given its cultural heritage to the Ness community.
10. Mammalian predator eradication and/or management had a medium level of ecological efficacy and a high overall feasibility scoring. A key issue for this action is the requirement for biosecurity in perpetuity, leading to an ongoing long-term commitment for its continued success. Avian predator management, on the other hand, had a low–medium level of ecological efficacy and a low overall feasibility score. The low score mainly reflects the high uncertainty and paucity of evidence regarding its potential benefit for seabirds and that this is highly context-specific depending on the specific management intervention and the location. This action is relatively low-cost but may not be scalable, limiting its application for strategic compensation.
11. Reducing disturbance at colonies had a medium level of ecological efficacy and a low–medium overall feasibility scoring. Seabirds at colonies can be disturbed by on-land activities, by sea, or via Unmanned Aerial Vehicles (UAVs) and management will need to be conducted accordingly. A key consideration with this action is that there are already existing laws and guidance for minimising disturbance on wildlife, especially at SPAs, so additionality issues would need considering.
12. Bycatch mitigation in longline fisheries had a medium level of ecological efficacy and a medium overall feasibility scoring. This action would likely require international coordination to deliver. Quantifying overall population level benefits, as well as

apportioning benefits to individual SPAs, is not possible with high confidence due to wide confidence intervals around bycatch rates (arising from currently low monitoring effort) and difficulty linking bycaught birds to specific SPAs.

13. Conservation actions varied with regards to their application, benefits to different seabird species, monitoring strategies, key considerations, and evidence regarding their ecological feasibility. Actions ranged from broad-scale interventions, affecting extensive areas and regions, to targeted actions implemented at one or more sites. Moreover, some actions benefited species directly, while others were some steps removed from providing a population level response. For conservation actions acting more indirectly, it is hard to quantify population-level responses, meaning that uncertainty is often high. Therefore, comparisons between actions should be taken with caution.
14. An overall qualitative assessment of the practical feasibility for seven conservation actions were produced. Ranked from least to most feasible (in the context of strategic compensation): Avian predator management (low); Reduction of disturbance at seabird colonies (low); End of the Gannet harvest at Sula Sgeir (low–medium); Sandeel fishery closure (low–medium); Fishery closure or enhanced management of prey fisheries (low–medium); Bycatch mitigation of longline fisheries (medium); and Mammalian predator eradication and/or management (high). It should be noted, however, that the overall assessment score is highly dependent on how component criteria are weighted. Additionally, significant uncertainties remain for some actions and, therefore, evaluations may change in the future as more evidence becomes available.
15. Several general recommendations are provided, these include: developing guidance for how strategic compensation measures should be evaluated; developing a framework for evaluating more indirect measures where it is technically challenging to relate these to seabird population responses; work to scope out additional compensation options for categories of potential compensation that are least developed; and developing an integrative approach to compensatory measures that accounts for, and works to support, adaptation in seabird populations to the impacts of climate change.

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The following annexes are available as supplementary files.

Annex 1: **Systematic literature review methods**. Detailed general methods for the systematic literature reviews along with detailed methods for the seven systematic literature reviews. [Word document]

Annex 2: **Systematic literature review - search information**. Information on time and dates when each search string was used, as well as the total records obtained, total records saved, and unique records of each search. [Excel file]

Annex 3: **Systematic literature review - complete reference lists for each review**. Each file contains the full list of the references saved from the systematic literature searches. It also shows at what screening stage each reference was eliminated. Within the zip file there is an individual Excel document dedicated to each conservation action. [Zip file containing Excel files]

Annex 4: **Systematic literature review - complete data extracted from records that were assessed at the full-text level and for final assessment**. Within the zip file, there is an individual Excel document dedicated to each conservation action. [Zip file containing Excel files]

1 Results summary

The following pages summarise the key findings of this report using tables, figures, and fact sheets. This starts with a table summarising high-level evaluations for several general aspects across all measures, followed by more detailed summaries of key sections. For detailed information please refer to the corresponding sections of the report.

1.1 Summary for all compensatory measures considered in the review

Table 1 provides an overview of all compensatory measures considered within the report with very high-level findings presented. Note that these measures are being considered specifically within the context of strategic compensatory measures and with current knowledge. We have not evaluated the measures in terms of their use for wider conservation purposes which would require consideration of different criteria with consequent changes in scoring.

Results summary

Table 1. Summary findings across all potential compensatory measures considered in the report. Measures are ordered as per Table 4. Costs are a very high-level relative estimate of direct costs of implementing measures only and have high uncertainty (i.e. these do not include any indirect costs, e.g. to loss of earnings etc resulting from the implementation of a measure). For measures not considered in the practical feasibility assessments (section 7), overall feasibility was not assessed, however we score these qualitatively in terms of their potential as compensatory measures.

Compensatory measure	Type of review	Type of measure	Key considerations	Ecological efficacy	Costs	Overall feasibility or potential as compensatory measures
Sandeel fishery closure	Systematic	General – indirect	Requires international cooperation. Additionality issues.	Low–medium	£	Low–medium
Fishery closure or enhanced management of prey fisheries	Systematic	General – indirect	Requires international cooperation. Additionality issues.	Low–medium	££	Low–medium
End of the Gannet harvest at Sula Sgeir	Systematic	Site – direct	Community support is imperative.	Low–medium	£	Low–medium
Mammalian predator eradication and/or management	Systematic	Site – direct	High costs. Long-term funding is essential (for biosecurity). Unintended ecological consequences.	Medium	£££	High
Avian predator management	Systematic	Site – direct	Requires site-specific baseline ecological knowledge. Ethical concerns and potential for opposition.	Low–medium	£	Low

Compensatory measure	Type of review	Type of measure	Key considerations	Ecological efficacy	Costs	Overall feasibility or potential as compensatory measures
Reduction of disturbance (at colony)	Systematic	Site – direct	Effectiveness is difficult to quantify. Additionality issues.	Low–medium	£	Low–medium
Reduction of disturbance (at sea)	Systematic	General – indirect	Effectiveness is difficult to quantify. Insufficient evidence of benefit.	Low–medium	££	Low
Manage supporting habitats that relate to prey availability for seabirds	Scoping	General – indirect	Effectiveness is difficult to quantify. Insufficient data. Limited range of habitats that can be created or restored. Requires further research on ecological feasibility.	N/A	£££	Medium
Reducing disease spread (including HPAI)	Scoping	General – indirect	Applicability is highly site-specific. Health and safety-related issues for both birds and humans. Requires further research on ecological feasibility.	N/A	££	Low–medium
Habitat management (terrestrial breeding colonies)	Scoping	Site – direct	Highly site-specific; difficulties in obtaining permits at certain sites. Effectiveness is difficult to quantify.	N/A	£	Low–medium

Compensatory measure	Type of review	Type of measure	Key considerations	Ecological efficacy	Costs	Overall feasibility or potential as compensatory measures
			Requires further research on ecological feasibility.			
Bycatch mitigation of longline fisheries	Targeted	General – direct	Requires international cooperation. Additionality issues.	Medium (though not quantified via systematic review)	£	Medium
Large gull management	Scoping	General – direct	Potential for opposition. Practical feasibility to deliver at scale. Requires further research on ecological feasibility.	N/A	££	Low–medium

1.2 Systematic literature reviews assessing ecological feasibility summary

Compensatory measures that corresponded to clearly defined and specific conservation actions were assessed through systematic literature reviews. All compensatory measures were scored on ecological efficacy and confidence in the evidence. Results are summarised below in Table 2 and in Figure 1.

Table 2. Summary of the ecological feasibility for those compensatory measures assessed via systematic literature reviews. Links are provided to the corresponding document sections providing the underlying detailed information. It is also noted whether the measures were assessed for practical feasibility. Measures are in reverse order of ecological efficacy scores, from highest to lowest. For colour coding, see key below table.

Compensatory measure	Ecological efficacy (0 – 25)	Confidence in evidence (3 – 15)	Report section	Main ecological considerations (brief conclusions)	Assessed for practical feasibility?
Mammalian predator eradication and/or management	12.8	10	5.4	Reducing predation from invasive mammals will increase productivity and, in some cases, adult survival of several seabird species. However, the degree of this effect will depend on the seabird species, the mammalian predator that is being eradicated/controlled, the success of post-management biosecurity measures, and external factors. Evidence is strongest for the eradication of invasive mammals on islands, which can lead to population recovery or re-establishment. Predator control (reducing abundance) has similar benefits. Predator exclusion is most effective for reducing predation by medium-sized mammalian predators.	**Yes**
End of the Gannet harvest at Sula Sgeir	9.4	11	5.3	Ending (or reducing) the traditional harvest of Gannet chicks at Sula Sgeir would lead to increases in breeding success. This should lead to an increase in the population growth rate for Sula Sgeir with potentially small benefits for nearby colonies (through emigration/immigration).	**Yes**
Avian predator management	8	8	5.5	To some degree, the management of avian predators can have a beneficial effect on seabird populations during the breeding season, albeit to varying degrees. The effectiveness of such management actions is heavily	**Yes**

Compensatory measure	Ecological efficacy (0 – 25)	Confidence in evidence (3 – 15)	Report section	Main ecological considerations (brief conclusions)	Assessed for practical feasibility?
				influenced by factors such as the avian predator involved, the nesting ecology of the target seabird species, and most importantly, the management action. Therefore, effects of avian predator management will be highly species- and site-specific.	
Fishery closure or enhanced management of prey fisheries (Sprat, Herring, and Mackerel)	6.9	10	5.2	Prey fisheries management can benefit seabird populations. However, prey availability to seabirds is determined by many different factors, with fisheries one amongst these. Whether a population level benefit can be anticipated following changes in fisheries management for a seabird species will require careful consideration of the specific ecological context, and it will rarely be possible to confidently form quantitative predictions on the level of benefit (if any).	**Yes**; assessed jointly with 'Sandeel fishery closure'
Reduction of disturbance (at colony)	5.2	8	5.6	The impact of disturbance at seabird colonies is highly species- and site-specific. There is relatively little evidence to appraise the potential benefit of reducing disturbance at colonies, though most studies found a beneficial effect. However, disturbance is hard to measure and relate to population level impacts, especially as responses are not always visible (e.g. stress), and behavioural studies are difficult to translate into effects on demography to understand population level impacts.	**Yes**
Reduction of disturbance (at sea)	5.7	8	5.7	There is evidence that vessel presence and activity lead to behavioural responses in marine birds. However, few	No

Compensatory measure	Ecological efficacy (0 – 25)	Confidence in evidence (3 – 15)	Report section	Main ecological considerations (brief conclusions)	Assessed for practical feasibility?
				studies have gone on to link this to population level impacts. As such, at this stage, we advise that there is not sufficient evidence to be able to progress as a potential strategic compensatory measure.	
Sandeel fishery closure	5	8	5.2	Sandeel fishery closures may lead to increased Sandeel abundance and, consequently, Kittiwake productivity and/or survival. However, evidence suggests that Sandeel abundance and availability is largely driven by processes other than fisheries, so there is significant uncertainty around benefit around this. This conservation action is best considered as a resilience-building measure that may assist Kittiwake in coping with additional pressures, such as climate change.	**Yes**; assessed jointly with 'fishery closure or enhanced management of prey fisheries'

Ecological efficacy colour-code. See 3.1.2.2.2 for scoring information.

No effect	Low	Low – Medium	Medium	Medium – High	High

Confidence in evidence colour-code. See 3.1.2.2.3 for scoring information.

Very low	Low	Medium	High	Very high

Results summary

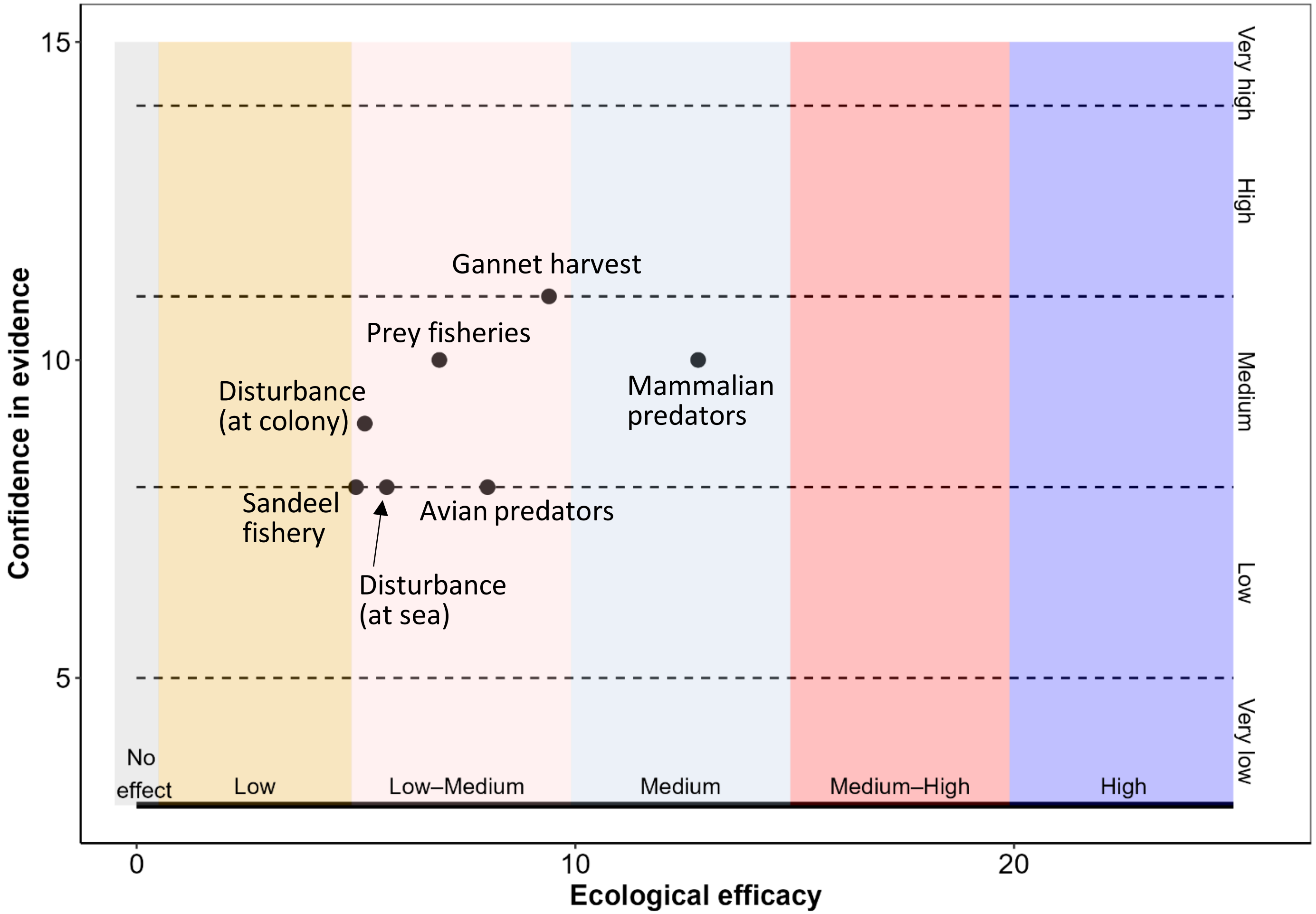

Figure 1. Ecological efficacy and confidence in evidence of the seven compensatory measures assessed through a systematic literature review process.

1.3 Scoping and targeted reviews summary

For compensatory measures that did not correspond to clearly defined and specific conservation actions, scoping reviews were used to identify conservation actions that may have potential as compensatory measures. In one case (bycatch mitigation in longline fisheries) a targeted review was used to summarise the evidence for a measure that had recently been reviewed outwith this study. Table 3 provides a qualitative assessment of the potential of the conservation actions identified.

Table 3. Summary of conservation actions identified for the five compensatory measures assessed through scoping or targeted reviews. Potential was assessed qualitatively only (colour scale is as for Table 2, though scoring is not directly comparable).

Compensatory measure	Species most likely to benefit	Identified conservation actions	Potential (low – medium – high)	Assessed for practical feasibility?
Managing supporting habitats that relate to prey availability for seabirds	Species most reliant on forage fish (auks and terns)	Habitat creation (e.g. seagrass)	Medium	No
		Protection of spawning and nursery habitat	Medium	
Reducing disease spread (e.g. HPAI)	Most species	Carcass collection during disease outbreaks	Low–medium	No
		Managing standing water	Low–medium	
		Vaccination of wild birds	Low	
		Rehabilitation of sick birds	Low–medium	
Habitat management	Kittiwake and other cliff-nesting species	Construction of coastal defence structures to reduce impact from storm events	Low	No
	Burrow-nesting species, especially Puffin and Manx Shearwater	Water management to reduce flooding of burrow nesting seabirds	Low	

Compensatory measure	Species most likely to benefit	Identified conservation actions	Potential (low – medium – high)	Assessed for practical feasibility?
	Puffin and other ground-nesting species	Vegetation management to improve breeding habitat quality	Low–medium	
Bycatch mitigation in longline fisheries	Gannet and Fulmar	Bycatch mitigation in longline fisheries	High	**Yes**
Large gull management	Large gulls	Reduce level of licensed control	Low–medium	No
		SPA designation of non-traditional colonies	Medium	
		Establishing artificial colonies	Low–medium	
		Translocation of eggs/chicks from non-traditional to traditional or artificial colonies	Low	

1.4 Practical feasibility summary fact sheets

Compensatory measures deemed ecologically feasible and potentially practically feasible, were assessed for practical feasibility. The following fact sheets provide a summary of the findings. However, we strongly encourage readers to refer to the corresponding report sections to gain a full understanding of how these conclusions were reached and to understand the caveats around these.

The ‘type of measure’ section (at bottom of fact sheets) uses the following classification:

- General: actions that act over a wide area, and
- Site: actions applied at one or more sites;
- Direct: where action benefits the species directly (e.g. predator management), and
- Indirect: actions that are some steps removed from seabird population response (e.g. reducing fishing may increase prey abundance which may then lead to population level responses in seabird populations).

Sandeel fishery closure

Action: Sandeel fishery closure

Ecological aspects (WP1 and WP2)

Species that may benefit
With low certainty: Kittiwake, Guillemot, Razorbill, and Puffin.

→

Increased:

- foraging efficiency,
- diet quality,
- chick provisioning and parental care,
- productivity, and
- survival

in a mid- to long-term.

Scalable?
No. Would apply to a wide geographical area.

Scale and degree of population benefit
Over several years prey-base could increase. Subsequently, increases in seabird productivity and survival may be observable.
Effects will be observable at local, regional, and national levels, especially in the east and north-east of Scotland, where fisheries are active (beyond the previously closed area covering a large part of the east region).

Other ecological benefits

- Enhance ecosystem resilience, and overall ecosystem stability.
- Increase in populations of other species foraging on Sandeel.

Risk of not doing
Risk assessed as low–medium, as fishery pressure is low compared to historical levels.

Practical aspects (WP2)

Other benefits

- Increase of tourism and recreational opportunities.
- Benefit to pelagic fisheries.

Implementation time
Implementation could take a few years.

Government intervention? Yes (lead).

Key considerations

- *International political opposition*, as quota is shared with other countries.
- *Displacement* of fisheries to other fish species and/or regions.
- *Socio-economic impacts* to those involved with affected fisheries.
- *Lag effects* for seabird population responses from changes in fisheries management may limit ability to detect a subsequent population level response.
- Increase of tourism and recreational opportunities.
- Benefit to pelagic fisheries.

**This measure was evaluated prior to the announcement of a Sandeel fishery closure in Scottish Waters in early 2024.*

Uncertainties
The abundance of Sandeel is not only regulated by industrial fisheries, but also by predatory fish populations, competition for food sources, and changes in environmental conditions. Consequently, predicting the response of Sandeel populations to fishery closures, is highly challenging. It is even more challenging to quantify and predict the broader effects of fishery closures on the demography of the predator species themselves (i.e. seabirds). Implementation could take a few years.

Type of measure: General – indirect

Ecological efficacy: Low–medium

Overall feasibility: Low–medium

Fishery closure or enhanced management of prey fisheries

Action: Fishery closure or enhanced management of prey fisheries, focused on Sprat and Herring

Ecological aspects (WP1 and WP2)

Species that may benefit
With low certainty, but likely: Kittiwake, Guillemot, Razorbill, Puffin, terns, Red-throated Diver, Fulmar, Shag, skuas.

Likely minimal benefit: Large gulls and Gannet.

→

Increased:
- foraging efficiency,
- diet quality,
- chick provisioning and parental care,
- productivity, and
- survival

in a mid- to long-term.

Scalable? No. Limited to a wide geographical area.

Scale and degree of population benefit
Over several years prey-base could increase. Subsequently, increases in seabird productivity and survival may be observable.
Effects will be observable at local, regional, and national levels, especially in the North Sea.
There is considerable uncertainty in the scale of benefits, but these could be moderate.

Other ecological benefits
- Enhance ecosystem resilience, and overall ecosystem stability.
- Increased populations of species feeding on Sprat and Herring.

Risk of not doing
Risk assessed as low–medium, as fishery pressure is low compared to historical levels.

Practical aspects (WP2)

Other benefits
- Increase of tourism and recreational opportunities.
- Benefit to other fishing industries.

Potential management options
- Total Allowable Catches (TAC)
- Limits of time at sea
- Full and/or regional closures
- Partial and/or temporal closures
- Fishing gear restrictions

Government intervention? Yes (lead).

Key considerations
- *International political opposition*, as quota is shared with other countries.
- *Displacement* of fisheries to other fish species and/or regions.
- *Socio-economic impacts* to those involved with affected fisheries.
- *Lag effects* for seabird population responses from changes in fisheries management may limit ability to detect a subsequent population level response.

Implementation time
Evidence base and existing preparatory work is limited compared to Sandeel, so likely to take several years.

Uncertainties
The abundance of prey fish is not only regulated by industrial fisheries, but also by predatory fish populations, competition for food sources, and changes in environmental conditions. Consequently, predicting the response of prey fish populations to fisheries management interventions, is highly challenging. It is even more challenging to quantify and predict the broader effects of changes in fisheries management on the demography of the predator species themselves (i.e. seabirds).

Type of measure: General – indirect

Ecological efficacy: Low–medium

Overall feasibility: Low–medium

End of the Gannet harvest at Sula Sgeir

Action: End the harvest of Gannet chicks ('guga') at Sula Sgeir

Ecological aspects (WP1 and WP2)

Species that may benefit
With high certainty: Gannet.

With very low certainty: Fulmar, Leach's Petrel, and European Storm Petrel.

Increased:

- productivity in the short-term;
- population size in the mid-term; and
- natal dispersal increasing populations at other colonies long-term.

Scalable? No. Sula Sgeir is the only site in the UK with an active harvest.

Scale and degree of population benefit
Benefits would primarily be for Gannet from North Rona and Sula Sgeir SPA, with medium to high responses in the short- to mid-term, but lower benefit in the long-term (once the population approaches carrying capacity).
Low to moderate benefits may accrue to other colonies in north-west Scotland.
No significant benefit is expected to Gannet more widely in Scotland.

Other ecological benefits

- Overall decrease in disturbance on the island.

Risk of not doing
Risk appears to be low. However, recent impacts of HPAI are not fully accounted for in this assessment.

Practical aspects (WP2)

Loss of cultural heritage
The Gannet harvest has been a long-lasting tradition dating back several centuries. As such, it holds significant cultural value for the Ness community. If the harvest were to stop completely, there is a possibility that this practice could not resume due to loss of traditional knowledge.

Government intervention? Likely (not lead).

Key considerations

- *Lack of community support* could make it politically and logistically difficult to implement.
- *Long-term ecological benefits* may be overestimated if harvest rates were to continue to decline.
- Ending the harvest without *community support* could undermine existing community goodwill and trust that took years to develop, this is essential to other ongoing and future conservation schemes.

Uncertainties
The effects on other species may be limited but is not known. There is potential for both positive and negative impacts. Positive from reduced disturbance (e.g. petrels) and negative if Gannet expansion displaces other breeding birds (e.g. Fulmar).

Implementation time
Ending the harvest can, theoretically, be implemented immediately, as long as community has been consulted and an agreement has been reached.
Dialogue with the community from the outset is imperative.

Type of measure: Site – direct

Ecological efficacy: Low–medium

Overall feasibility: Low–medium

Mammalian predator eradication and/or management

Actions: Predator eradication (islands) and predator control or exclusion (mainland colonies and islands)

Ecological aspects (WP1 and WP2)

Species that may benefit

With high certainty: Puffin, burrow- (e.g. Manx Shearwater and storm petrels) and ground-nesting species (e.g. terns and waders).

With low certainty/localised cases only: Guillemot, Razorbill, large gulls.

→

Increased:

- productivity,
- survival (some cases)

in the short-term;

- recruitment rates,
- population recovery,
- reestablishment, and
- distribution expansion

in the mid- to long-term.

Main mammalian predators in Scotland

- Rodents; Brown and Black Rat – Eradication.
- Medium-sized mammals; Mink, Fox, and feral/domestic Cat – Control and/or exclusion.

Scale and degree of population benefit

Most candidate sites are to the north and west of Scotland with fewer potential sites to the east.
Population level responses can be significant, but this will be site-, predator- and species-specific.

Evidence

There is more evidence to show higher success rates on uninhabited islands, followed by inhabited islands, and then at mainland sites.

Scalable? Yes.

Other ecological benefits

- Enhance ecosystem recovery, resilience, and stability.
- Increase populations of other animal and plant species, especially those native or endemic.

Risk of not doing

Risk is high – without eradication, population declines are likely to continue. Risk for further spread of predators to other sites.

Practical aspects (WP2)

Biosecurity

Eradication must be supported by long-term biosecurity. This will involve:

- conducting preventative measures to minimise risk of reinvasion;
- regular monitoring at sites; and
- rapid response in the case of predator detection.

Government intervention? No, but could be beneficial.

Key considerations

- A forthcoming *ban* on the most widely used *rodenticides* may pose significant risk to the viability of future eradication projects.
- The *costs* of eradication attempts are significant and could increase where initial eradication/control is unsuccessful. Long-term funding is required to maintain biosecurity, and for control/exclusion for ongoing action/maintenance.
- *Unintended ecological consequences* from poisoning and trapping of non-targeted species. Potential for pesticide-resistance to develop.
- At inhabited sites, *support from resident communities* is crucial.
- Potential for *opposition* by animal rights groups in some cases.

Uncertainties

The potential gains for individual species cannot by predicted with confidence.
Highest uncertainty where species are absent with reestablishment not guaranteed post-eradication.

Implementation time

It will take several years to initialise and plan successful programmes.
Biosecurity is required in perpetuity.

Type of measure: Site – direct

Ecological efficacy: Medium

Overall feasibility: High

Avian predator management

Actions: Diversionary feeding, removal of targeted or non-targeted nests, eggs, or individuals, and deterrence.

Ecological aspects (WP1 and WP2)

Species that may benefit
With high certainty: ground-nesting species, like terns.

With low certainty: Guillemot, Razorbill, Puffin, large gulls, Kittiwake, Fulmar.

Decreased
- disturbance, and
- predation rates in the short-term.

Increased:
- body condition,
- productivity, and
- survival in the short- to mid-term.

Scalable? Yes.

Scale and degree of population benefit
The degree of benefit will range from no to moderate effects depending on species, site, management intervention and whether predation occurs on eggs, chicks, or adults.

Risk of not doing
Risk is medium – impacts of avian predators may increase in absence of management.

Main avian predators in Scotland
- White-tailed Eagle
- Golden Eagle
- Peregrine Falcon
- Large gulls
- Great skua
- Corvids

Other ecological benefits
- Potential for increasing populations of other species also affected by avian predation.

Practical aspects (WP2)

Benefits of each management action
- Diversionary feeding – useful when both prey and predator are of conservation concern. Adaptable as can be stopped at any time.
- Removal – targeted removal is more efficient than large scale culling.
- Deterrence – non-lethal method. Quick and easy to implement at low costs.

Government intervention? No, but could be beneficial.

Key considerations
- *Good baseline knowledge* on existing predator impacts is required to design measures effectively, which is lacking for most sites.
- Certain actions will only be feasible at more *accessible sites*.
- Essential to consider the *conservation status of predators*.
- *Ethical concerns* and *opposition* by animal welfare groups could increase difficulty of implementing management.
- Managements could cause *undesired ecological effects*.
- A combination of different management types could result in an increase in *effectiveness*.

Uncertainties
The level of avian predation and/or disturbance at seabird colonies has not been well studied in Scotland.
The potential management interventions have rarely been trialled for seabirds. Consequently, there is uncertainty regarding their potential benefits. The effects are likely to be highly site- and context-specific.

Implementation time
A few years of preparatory work but could then be put in place quickly (depending on the specific management action).

Type of measure: Site – direct

Ecological efficacy: Low–medium

Overall feasibility: Low

Reduction of disturbance (at colony)

Actions: Reduction of disturbance at colony on land, at sea, and by Unmanned Aerial Vehicles (UAVs)

Ecological aspects (WP1 and WP2)

Species that may benefit
Depends on source of disturbance.

Decreased:
- stress,
- predation, and
- flush rates in a short-term.

Increased:
- parental care,
- body condition,
- energy allocation efficiency,
- productivity, and
- survival, in short-term. And
- survival, and
- population size in mid- to -long term.

Scale and degree of population benefit
As a site-based measure, benefits will primarily be to the sites with high existing disturbance.
Effects will range from negligible to moderate, dependent on the effectiveness of management actions.

Scalable? Yes, though management will need to be specific for each site.

Other ecological benefits
- Decreased disturbance on most species at the colonies.
- Increased populations of other animal and plant species impacted by disturbance.

Risk of not doing
Risk is low–medium, most for colonies with existing high disturbance.

Practical aspects (WP2)

List of potential management actions
- Minimum approach distances to seabirds
- Reduce number of visitors
- Provide paths and signage
- Wardening
- Fences
- Educational programmes
- UAV regulation

Key considerations
- Need to consider *additionality* issues given existing laws and guidance on minimising disturbance to wildlife.
- *Effectiveness* of reducing disturbance is difficult to quantify.
- Enforcing certain management measures may not be *politically* feasible and may only act as guidance.
- Risk of *affecting local conservation efforts*, education, local economy, and reduce appreciation for wildlife.

Uncertainties
The population level impacts of human disturbance are not well understood, limiting our ability to predict the impact of reducing disturbance.
Many regulations and management measures are already in place for key seabird colonies in Scotland, so the scale of additional benefit is uncertain.

Implementation time
Will depend on specific action, but likely a few years.

Government intervention? No, but could be beneficial.

Type of measure: Site – direct

Ecological efficacy: Low–medium

Overall feasibility: Low–medium

Bycatch mitigation in longline fisheries

Action: Applying mitigation measures in the floated demersal longline fleet operating in Scottish Waters

Ecological aspects (WP1 and WP2)

Species that may benefit
With high certainty: Fulmar.

With medium certainty: Gannet.

With low certainty: Great Shearwater and Great Skua.

Increased:

- survival,
- population size, and
- potential to arrest population declines

in a medium- to long-term.

Scalable? No. Would be a fleet wide measure.

Scale and degree of population benefit
Benefits are most likely to Gannet and Fulmar populations to the west and north of Scotland, with no significant benefits likely to east coast populations.
For Gannet there may be small to moderate benefits.
For Fulmar there are likely to be strong effects.

Other ecological benefits

- Reduction bycatch of other bird species.
- Enhanced ecosystem resilience.

Risk of not doing
Risk is medium–high, bycatch is one of the biggest threats to certain seabird populations (especially Fulmar).

Practical aspects (WP2)

List of potential bycatch mitigation options

- *Operational adaptations*: changing timing of gear deployment.
- *Gear adaptations*: bird-scaring lines, increasing sink-rates, and use of swivel-hooks.
- *Management changes*: spatial and seasonal closures.

Government intervention? Yes (lead).

Key considerations

- Bycatch could only be significantly reduced if non-UK registered vessels were included as this is a large component of the fleet.
- Need to consider *additionality* issues, given existing commitments around bycatch minimisation.
- *Apportioning* benefits to individual SPAs would be difficult.
- *Quantifying population level benefits is not possible* with high confidence due to wide confidence intervals around bycatch rates (arising from currently low monitoring effort).
- *Compliance* and *monitoring* arrangements would need to be put in place to ensure compliance with mitigation requirements.

Implementation time
Full implementation could take a few years, but bycatch mitigation programme could likely be put into place within a year.

Uncertainties
There is high uncertainty in current bycatch estimates, so benefits cannot be quantified with confidence.
Several potential mitigation options have been identified. However, few have been trialled within the fishery, leading to uncertainty on which would be most effective.
The UK registered fleet is in the minority, so overall bycatch rates cannot be significantly reduced by targeting UK registered vessels alone.

Type of measure: General – direct

Ecological efficacy: Medium

Overall feasibility: Medium

2 Introduction

The Scottish Government has set out goals to reduce carbon emissions across the Scottish economy over the coming decades, with a net zero emissions target by 2045. A key part of the Government's strategy for decarbonising the economy is by supporting the development of sustainable offshore energy production. In the medium term it is anticipated that as much as 11 GW of offshore wind farm (OWF) capacity could be delivered by 2030 (Scottish Government, 2020b), which would also contribute towards the UK Government's target of 50 GW of total installed capacity by 2030 (outlined in the British Energy Security Strategy) (UK Government, 2022). The ScotWind leasing round led to lease option agreements for 20 potential OWFs (17 in the initial announcement in January 2022 and a further three sites announced in August 2022) totalling a potential capacity of 27.6 GW. A further 13 OWFs with a total potential capacity of 5.5 GW have been offered initial agreements for leases by Crown Estate Scotland (Crown Estate Scotland, 2023) under the Sectoral Marine Plan for Innovation and Targeted Oil and Gas (INTOG) Decarbonisation (Scottish Government, 2022b).

The Habitats Regulation Appraisal (HRA) for the Sectoral Marine Plan for Offshore Wind Energy, which underpins the ScotWind leasing round, was unable to conclude that there would be No Adverse Effect on Site Integrity (NAEOSI). This uncertainty stems from the current understanding around the potential scale of in combination impacts on protected seabird populations (i.e. those originating from Special Protection Areas; SPAs) and the need for precaution given the level of uncertainty on the scale of impact (Scottish Government, 2019). The plan-level Appropriate Assessment was able to conclude NAEOSI, but only with a number of mitigation measures applied, including the need for project-level HRA. The plan is currently undergoing a review as part of the iterative plan review process, which includes the consideration of outcomes from the ScotWind and INTOG leasing rounds.

It is now anticipated that it is likely that it will not be possible to conclude NAEOSI for some future OWFs in Scottish Waters, and thus, if these developments are to proceed, it would be following the derogation procedure under Article 6(4) of the Habitats Directive. This process has already been implemented for proposed OWFs in English Waters, with Hornsea Project Three and Norfolk Boreas being the first developments to follow this approach. For a development to be consented with a derogation under Article 6(4), three sequential legal tests must be met, the third of which is whether necessary compensatory measures can be secured to offset the assessed impacts for the proposed development.

This third test requires that Scottish Ministers (or the Secretary of State, depending on the applicable legislation) ensure that any necessary compensatory measures are taken for the protection of the overall coherence of the UK site network (NatureScot, 2024). The general principles to be considered are outlined in the European Commission guidance (European Commission, 2021) (which are transposed into UK guidance (DEFRA, 2021)):

- that compensatory measures deliver for the ecological functions affected by the plan or project;

- that measures are put into place, are fully operational and effective before the damage occurs;
- that the delivery of effective compensation should be verified through adequate monitoring.

To have confidence of these, it is necessary to demonstrate the ecological feasibility of proposed measures which, when simplified, equates to providing a conservation benefit to the impacted SPA feature species that ideally outweighs the assessed impact. Ensuring that appropriate compensatory measures can be put into place ahead of the proposed impact requires confidence in the feasibility of the technical, legal, and financial provisions for implementation. Once measures are put into place then there is a requirement to demonstrate that they are indeed delivering the intended benefit through monitoring.

Compensatory measures for seabirds are some forms of activity or management intervention which may offset the impacts to protected seabirds of one or more OWFs. The term 'compensatory measure' is a broad term which could include e.g. a suite of coordinated actions, but must be measures that deliver a compensatory response, i.e. counteracting a given population level impact. For this report we use a more specific term 'conservation action' when considering candidate options that if assessed to be suitable could be implemented as compensatory measures. This distinction follows international conservation terminology (Salafsky et al., 2008), conservation actions denoting specific management interventions undertaken with the aim of delivering a gain and/or recovery of a habitat or population. Consequently, conservation actions have potential to be used as compensatory measures subject to meeting various tests, both relating to efficacy and other factors such as additionality. Because compensatory measures can be used as a more general term referring to either a single or a potential suite or category of conservation actions, hereafter, we will refer to a conservation action when referring to a specific management effort.

As such, considering compensation options for seabirds starts with understanding threats and pressures acting on seabird populations and the potential conservation actions to either reduce existing pressures on populations (e.g. fisheries bycatch reduction) or by improving existing conditions in some way (e.g. restoration of habitat). The primary threats and most beneficial conservation actions for seabird populations are relatively well understood (for recent reviews see Dias et al. (2019), Johnston et al. (2021), and Young and VanderWerf (2023)), however understanding which conservation actions may be effective compensatory measures, and for which specific colonies, populations, or species, is less straightforward.

To date, compensatory measures for OWFs have occurred on a project-by-project basis, however it is recognised that at least, in some instances, compensatory measures may be best delivered strategically (e.g. see reforms progressed as part of the Offshore Wind Environmental Improvement Package in the UK Energy Act). This is termed 'strategic compensation' (see Glossary and common acronyms for definition of this and other terms). By delivering compensation strategically, the impacts of multiple OWFs (e.g. those under the same sectoral marine plan) can be effectively compensated through coordinated and larger scale conservation actions which may provide greater conservation benefits by fitting with the large spatial scales that seabirds operate at (Oppel et al., 2018). Strategic delivery, usually involving government bodies, also allows for certain types of conservation actions to be delivered that are not in the control of developers (e.g. those requiring a government policy or regulatory response to implement). The purpose of this project is to improve the evidence base around potential strategic compensatory measures for seabird populations. Strategic compensatory measures are here defined broadly to be any compensatory measures that apply to at least two OWFs or are delivered at plan-level.

In the past few years there have been several studies reviewing potential compensatory measures in in the context of Britain and Ireland, both for impacts from OWF and from climate change, e.g. Furness (2021), Pearce-Higgins et al. (2021), and McGregor et al. (2022). However, there remains considerable uncertainty around the feasibility of many of these compensatory measures, both in terms of whether they would be effective (i.e. by delivering meaningful scales of compensation) and in the practicality of implementing them. This project is focussed on better understanding the feasibility of compensatory measures for seabirds in a Scottish context.

2.1 Structure and approach to project

The project is structured into two work packages (WP), which together look at the overall feasibility of a list of compensatory measures collated by the Marine Directorate (Table 4). The first WP evaluates ecological feasibility (WP1) while the second evaluates practical feasibility (WP2). Each WP is sub-divided into several linked component steps (Figure 2).

2.1.1 Ecological feasibility (WP1)

The objective of the first WP (WP1) was to assess the ecological feasibility of the candidate compensatory measures (Table 4). Here, we define ecological feasibility as a combination of the likelihood that a measure is beneficial, i.e. bringing about a population-level benefit to the target seabird species (e.g. an increase in productivity or survival) and the size of effect found across studies (for details see section 3.1.2.2 below).

Some of the proposed compensatory measures (as described in Table 4) correspond directly to a single conservation action (i.e. management intervention). Others represent a suite of possible conservation actions, or their associated conservation actions are undefined or unclear. Therefore, we first identified the conservation actions associated with each compensatory measure. For those measures where conservation actions were clear, we conducted one or more systematic literature reviews (see section 3.1.1) to find, collate and analyse relevant evidence. We then used a qualitative approach to assess their ecological feasibility. This involved assigning scores to each measure on a common continuous scale, enabling the comparison of their relative ecological feasibility (i.e. not just a binary outcome). We also estimated our level of confidence in these scores.

In cases where compensatory measures were broader and unclear, representing a suite of potential conservation actions (defined or undefined), we conducted a scoping review to identify the conservation actions that are likely to provide the most benefit. Additionally, we undertook a targeted review on bycatch mitigation with the aim of summarising the key findings of a recent review to put this in the context of strategic compensation.

Table 4. The original list of compensatory measures collated by Scottish Government, and the associated seabird species that each measure may benefit. Focal species are highlighted in bold, and measures are numbered for convenience. It was also noted that synergies across compensatory measures and delivery may also be considered. The table footnotes are retained (edited) from the original table.

Compensatory Measure	Species that may benefit
1. Sandeel fishery closure[1]	**Kittiwake**
2. Sustainable management of other fishery/shellfish[2] (Not aquaculture)	**Kittiwake**, **large gulls**, **Guillemot, Razorbill, Puffin**, Fulmar, petrels, skuas, **Gannet**,
3. End harvest of chicks-Sula Sgeir[1]	**Gannet**
4. Habitat Management [1,2] (terrestrial breeding colonies)	**Gannet**, **Guillemot, Razorbill, Puffin, gulls,** terns
5. Bycatch mitigation[1,2] (UK and international)	**Gannet,** Fulmar
6. Predator eradication/management[1,2] (i.e. rodents, foxes)	**Guillemot, Razorbill, Puffin, large gulls,** terns
7. Biosecurity (prevention of threats, including HPAI)	**As predator eradication above, plus skuas and Gannet**
8. Diversionary feeding (of gulls/skua/raptors)	**Guillemot, Razorbill, Puffin**
9. Population management interventions[1,2]	**Large gulls**
10. Behavioural Disturbance: reduction/mitigation [1,2] (including shipping and recreation)	**Large gulls, Guillemot, Razorbill, Puffin,** terns, Fulmar
11. Manage supporting habitats (e.g., restrict seaweed removal, litter, seagrass, sandbanks)[2]	**Large gulls,** terns**, Gannet, petrels, Guillemot, Razorbill, Puffin**
12. Disease/environmental event mitigation	**Those spp. affected (i.e. All species potentially affected if HPAI, auks if weather event)**

[1]Taken from Compensatory Measures Workshop, held by Marine Scotland (now the Marine Directorate) and attended by NatureScot, Royal Society for the Protection of Birds, Marine Scotland Science (now Marine Directorate – Science Evidence, Data and Digital) and Marine Scotland.
[2]Taken from Pearce-Higgins et al. (2021). MarPAMM report on Species and habitat climate change adaptation options.

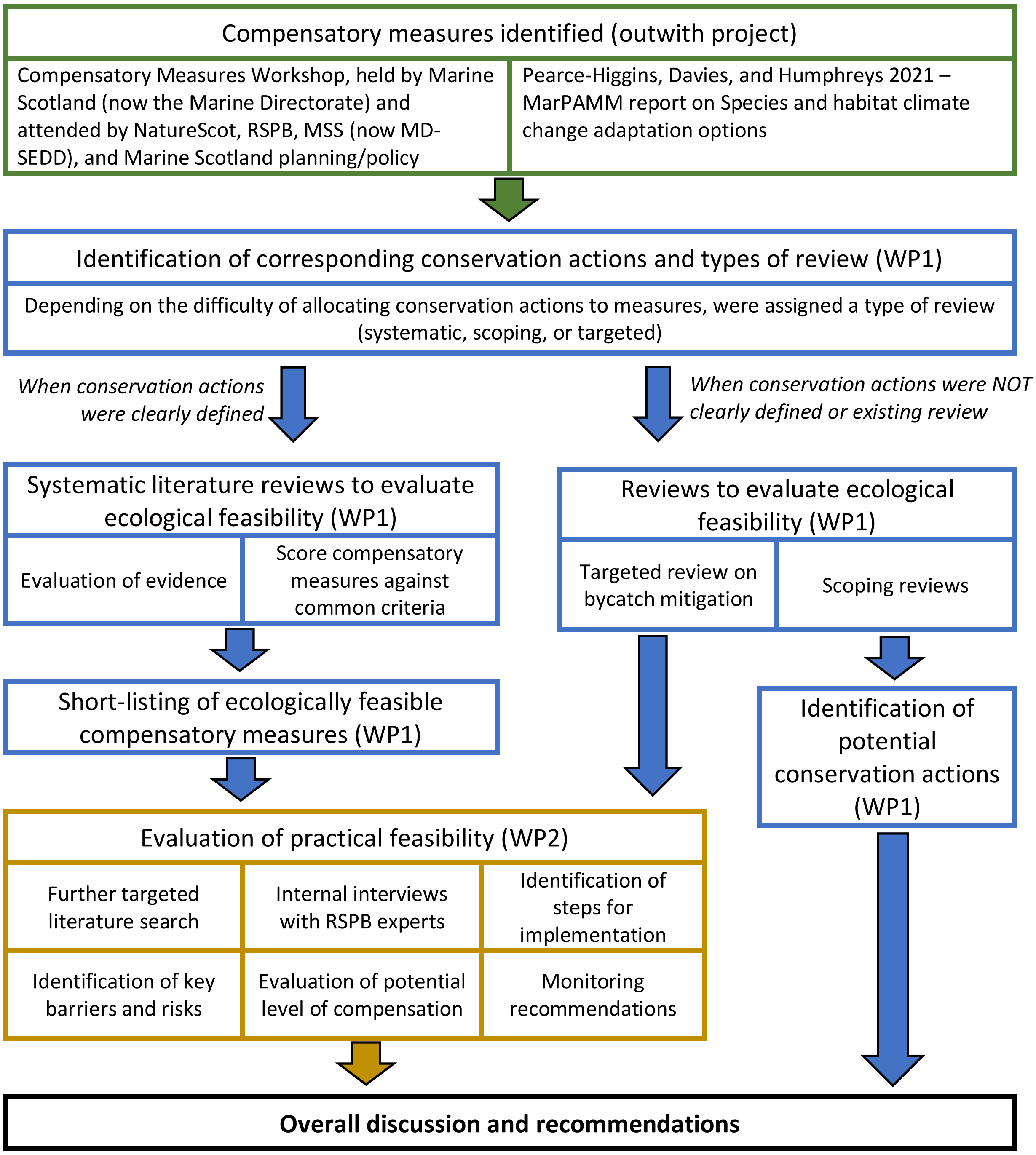

Figure 2. A flow-diagram showing the steps involved in the project. The first step, outlined in green, focuses on the list of potential compensatory measures provided by the Marine Directorate (Table 4). WP1 is outlined in blue, and shows the process taken to identify conservation actions, types of reviews, and criteria used to assess ecological feasibility. WP2, outlined in yellow, shows criteria used to assess practical feasibility. The final step involved an overall discussion and final recommendations. Detailed information can be found within the main text.

2.1.2 Practical feasibility (WP2)

The objective of the second WP (WP2) was to assess the practical feasibility of those conservation actions that were most ecologically feasible. For each conservation action, an implementation plan was developed, outlining the necessary steps required to put an action in place. This section also evaluates the scale and degree of benefit of each action on focal species and other possible benefitting species. Additionally, it provides recommendations for required monitoring efforts to assess progress and the ultimate success of the conservation action and lists potential issues and possible solutions that must be considered prior to implementation.

In this section we also drew on wider RSPB expertise[1] in practical conservation, asking relevant staff (e.g. site managers, scientists, engagement officers) to provide recommendations and comments on the drafts of the practical feasibility chapters. This allowed us to draw on real world examples where conservation actions have previously been implemented and to use expert assessment on whether it could prove effective on focal species. RSPB policy and planning colleagues were also contacted to gain insights into potential technical, political, or legal barriers.

[1] This report is a technical review commissioned by the Scottish Government and authored by RSPB scientists. While wider RSPB colleagues imputed expertise into relevant sections, they did not have an authoring nor editorial role. As a technical review it should not be read to imply policy positions of either the RSPB nor of the Scottish Government around any of the matters considered within.

3 Methods

3.1 Ecological feasibility (WP1)

3.1.1 Refining the scope of the review for each compensatory measure

We began by identifying the conservation actions relating to each compensatory measure listed in Table 4. Subsequently, we sought feedback from the project steering group. This led to a finalised list of review topics, and their associated review type and research questions (steps illustrated in Figure 3).

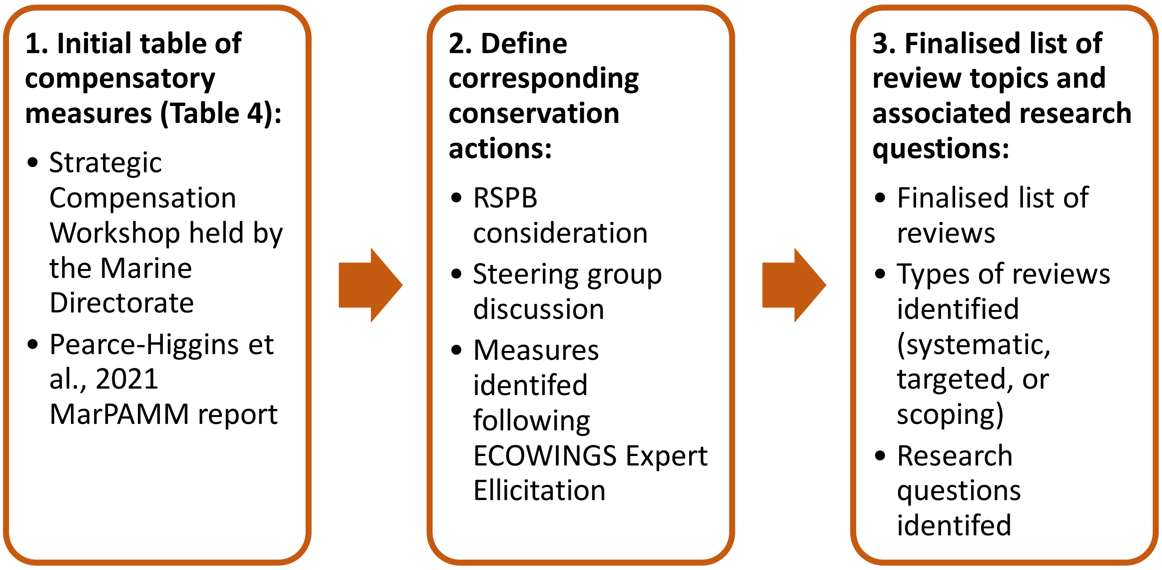

Figure 3. The steps used to move from the initial table of compensatory measures to a finalised list of review topics, associated research questions, and corresponding review types following consideration and discussion with the steering group.

The initial table of compensatory measures (Table 4) was developed outwith this project and provided by the Marine Directorate. This provided 12 short-listed compensatory measures along with a list of the seabird species most likely to benefit from each one. This table was derived from compensatory measures identified in a workshop held by the Marine Directorate (then Marine Scotland) in 2022. The workshop, attended by representatives from different parts of Marine Scotland (now either within the Marine or Offshore Wind Directorates; including Science, Licensing, and Planning functions), NatureScot, and RSPB, focussed on identifying compensatory measures for seabird species in Scotland that could potentially be progressed in a strategic way.

Additionally, conservation actions identified by Pearce-Higgins et al. (2021) were also considered. This study considered two types of actions, those directly targeting the same impact mechanism, (termed ‘counteracting adaptation responses’), e.g. creating new inter-tidal habitat to offset that same type of habitat lost, or indirectly (termed ‘compensatory adaptation responses’), by benefitting a species but not addressing the same impact mechanism. Note, while that report uses the term ‘compensatory adaptation response’ the focus was on compensating (i.e. offsetting) the impacts of climate change on seabird populations, so it was not in the context of how compensation is considered in this study (i.e. compensation under the Habitats Directive). However, as most of the actions identified in that report were general conservation actions (i.e. not specific to climate change), many also have the potential to be considered as options for compensating for OWF impacts.

We then sought to map each of the compensatory measures (Table 4) to conservation actions. Some compensatory measures were more easily allocated to conservation actions than others and, therefore, scored the difficulty of allocating actions to measures on a scale of 1–5 (Table A 1). This was first assessed internally by the project team and was subsequently discussed with the project steering group (meeting held 20th March 2023). Key points arising in this discussion are summarised in Table A 1. We also considered the compensatory measures and associated conservation actions identified by an Expert Elicitation Exercise conducted within the ECOWINGs project (K Searle, personal communication). After identifying the relevant conservation actions for each compensatory measure, and incorporating feedback from the steering group, we designated the type of review to be applied to each measure (described in the 'outcome' column of Table A 1).

Reviews are a ubiquitous evidence synthesis approach undertaken to identify and collate relevant literature, aiming to draw conclusions on specific research questions and/or to summarise the current state of knowledge within a particular topic or research field. There are two main types of reviews, scoping reviews and systematic reviews (Munn et al., 2018), and another less-common type of review, targeted reviews. Here we used the three types of review approaches (summarised in Table 5) depending on how easily the initial list of compensatory measures could be mapped onto conservation actions (for additional information on the review types and rationale behind these see Appendix 2: Description of the different type of reviews considered within the project).

Table 5. Summary of the types of review used in this report with a description of how these are used and how their approaches differ.

Review type	Purpose	When?	Approach
Systematic	Determine whether conservation actions are ecologically effective (scoring approach)	Where one (or a few) specific conservation actions have been identified	1. Undertake literature search 2. Screen literature 3. Summarise key findings and score each study 4. Collate evidence across studies to reach overall conclusions
Scoping	Identify potential conservation actions corresponding to a compensatory measure and summarise which are most likely to be ecologically effective (following a narrative approach)	Where no specific conservation actions have been identified or where many potential actions are identified, with no clearly defined preferred options	1. Undertake literature search and backward search (cited literature) 2. Identify conservation actions identified in each and note any evidence on efficacy 3. Collate evidence across studies to produce list of conservation actions prioritised by likely efficacy
Targeted	Set findings of recent review in context of strategic compensation and supplement with findings from other relevant literature. Determine whether associated conservation actions are ecologically effective	Where a recent detailed review already exists	1. Summarise key findings of recent review placing emphasis on how this translates to strategic compensation 2. Supplement with literature search (non-systematic) 3. Summarise strength of evidence for likely efficacy

Based on the initial 12 compensatory measures, we identified 12 potential reviews to be conducted (Table 6); while the number of reviews remains consistent with the initial count (Table 4), there is not a direct one-to-one correspondence between the original compensatory measures and the final 12 reviews. For example, 'biosecurity' merged with 'predator eradication' while 'predator eradication' itself was split into 'mammalian predator eradication/management' and 'avian predator management'. For each review, the conservation action or review topic were defined along with associated research questions. Of the 12 reviews, seven are systematic reviews, four scoping reviews, and one a targeted review.

Table 6. Finalised scopes for reviews and types of reviews to be used.

Review number	Conservation action	Parent compensatory measure	Review type	Focal species	Secondary species
1	Sandeel fishery closure	Sandeel fishery closure	Systematic	Kittiwake	none
2	Fishery closure or enhanced management of prey fisheries (sprat, herring, mackerel)	Sustainable management of other fishery/shellfish (Not aquaculture)	Systematic	Kittiwake, large gulls, Guillemot, Razorbill, Puffin, Gannet	Fulmar, petrels, skuas
3	End of the Gannet harvest at Sula Sgeir	End harvest of chicks- Sula Sgeir	Systematic	Gannet	none
4	Mammalian predator eradication and/or management	Predator eradication/management and Biosecurity	Systematic	Guillemot, Razorbill, Puffin, gulls	terns
5	Avian predator management	Predator eradication/management and Diversionary feeding (of gulls/skua/raptors)	Systematic	Guillemot, Razorbill, Puffin, large gulls	terns
6	Reduction of disturbance (at colony)	Behavioural Disturbance: reduction/mitigation (Including shipping and recreation)	Systematic	Large gulls, Guillemot, Razorbill, Puffin	terns, Fulmar
7	Reduction of disturbance (at sea)	Behavioural Disturbance: reduction/mitigation (Including shipping and recreation)	Systematic	Guillemot, Razorbill, Puffin	none

Review number	Conservation action	Parent compensatory measure	Review type	Focal species	Secondary species
8	Manage supporting habitats that relate to prey availability for seabirds	Manage supporting habitats (e.g., restrict seaweed removal, litter, seagrass, sandbanks)	Scoping	Large gulls, Gannet, petrels, Guillemot, Razorbill, Puffin	terns
9	Reducing disease spread (including HPAI)	Disease/ Environmental event mitigation	Scoping	All seabird species	none
10	Habitat Management (terrestrial breeding colonies)	Habitat Management (terrestrial breeding colonies)	Scoping	Gannet, Guillemot, Razorbill, Puffin, gulls	terns
11	Bycatch mitigation in longline fisheries	Bycatch mitigation (UK and international)	Targeted	Gannet, Fulmar	none
12	Large gull management (various)	Population management interventions	Scoping	Large gulls (Great Black-backed Gull, Lesser Black-backed Gull, Herring Gull)	none

3.1.2 Systematic review – general methods

We conducted systematic literature reviews where possible (Table 6), to gather available published evidence regarding the impact of the conservation actions on seabirds. At this stage, our main objective was to undertake a comprehensive and unbiased overview of all published and available studies that have, directly or indirectly, tested the effect of the identified conservation actions on the focal seabird species, or, when not possible, proxy species. If performed correctly, a systematic review guarantees to find the most relevant and current knowledge in a thorough, objective, unbiased, and reproducible manner (Kugley et al., 2016).

3.1.2.1 Literature search

Following Foo et al. (2021) and Higgins et al. (2022), for each systematic literature review we undertook the steps shown in Figure 4. An in-depth description of each step can be found in section 1 of Annex 1 (the following is an abridged version of this).

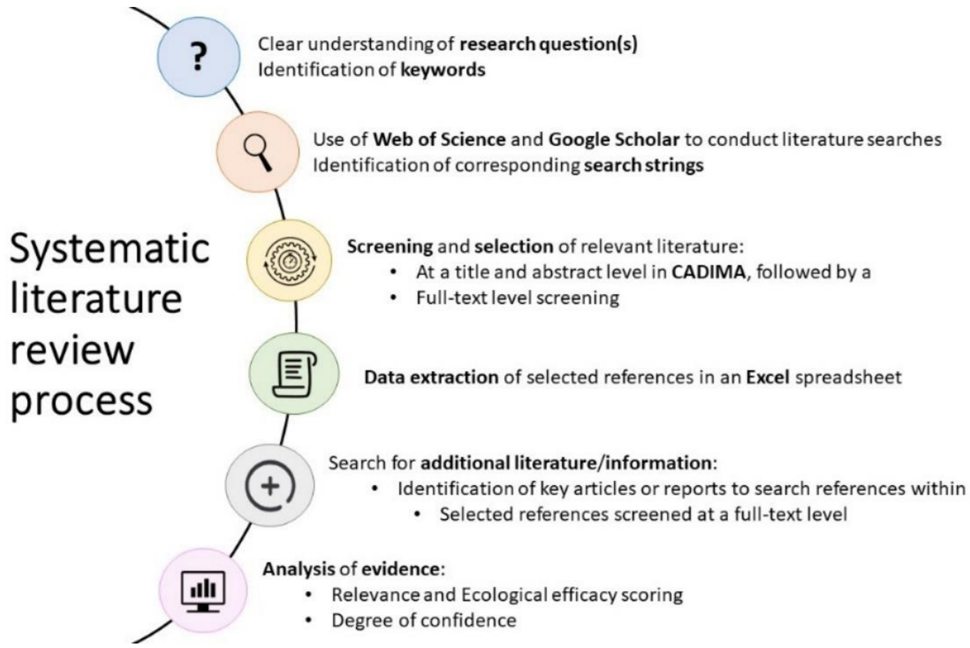

Figure 4. A visual representation illustrating the steps taken to conduct each systematic review.

1. **Defining and identifying the research questions and keywords:** Overall, research questions had the following structure: 'Would 'conservation action/s' benefit species?' In most cases, each systematic review centred on a single research question, but, in some instances, several research questions were addressed within a single review. Keywords varied depending on the scope of the research questions but mostly encompassed synonyms of the conservation action, the focal species, and other key words.
2. **Conducting the literature search:**
    a. Search engines: We conducted the literature search using two complementary search engines, Web of Science (WoS) and Google Scholar (GS).
    b. Search strings: We used a selection of the previously identified keywords to produce appropriate search strings. Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.
3. **Screening and selection of relevant literature:** References obtained from WoS and GS were uploaded and screened in CADIMA (Kohl et al., 2018). After eliminating duplicated records, we screened all references following a pre-defined set of inclusion criteria (Table A 2). References were screened at a title and abstract level, and those that advanced to the next stage were then screened at a full-text level. Inclusion criteria depended on the scope of the topic, but overall, we were looking for studies that tested, either indirectly or directly, the effect of the conservation action on seabirds. Information on the complete reference list obtained during the literature searches, and the level at which each reference was eliminated can be found in Annex 3.

4. **Data extraction**: In a Microsoft Office Excel spreadsheet, we recorded details of all references screened at a full-text level, including initials of reviewer, study title, authors, publication year, document type, whether we had access to the full text, and a summary of the study, including reasons for exclusion (this information can be found in Annex 4).
5. **For those references that were deemed relevant for the final assessment, we also recorded information** on the study species, duration and location of study, note on which seabird demographic parameter was tested, and relevant information regarding the methods, results, and conclusions of the study. Additional information specific to the actions was also extracted if deemed relevant. All this information can be found in Annex 4.
6. **Additional literature**: Making use of expert judgment and subject knowledge of the authors, we identified highly relevant key studies. All references within these studies were scanned to identify any additional relevant references. All newly identified references were screened at full-text level, repeating steps 4 and 5. While this step may decrease the reproducibility of the systematic reviews, we deemed it important to include these references to ensure that project included most of the key literature on the subject.

Steps 3–5 were performed by one of the authors (either CTH or TE). The inclusion/exclusion criteria, however, were agreed on prior to these steps. Early in this process, we met regularly to refine the inclusion and exclusion criteria, standardise data extraction methods, and to jointly screen several examples.

3.1.2.2 Analysis of evidence (scoring)

There are two components to scoring each conservation action in terms of ecological feasibility: a measure of the overall efficacy of the action, and a measure of our confidence in the estimation of that efficacy. Here we define efficacy as a combination of the likelihood that a compensatory measure is beneficial, and the size of effect found across studies. To do this it is necessary to first evaluate the individual studies across a range of scoring factors and then to combine these scores across studies. As some factors apply at a study level (e.g. sample size) and others are a property of the combined studies (e.g. concordance), some factors are calculated by taking means or medians, while others are evaluated by comparing across the studies. The scoring approach used here was developed for this study, however it considered best practice guidance on analysing evidence in systematic reviews (Higgins et al., 2022) and the approach used for a similar study of compensatory measures (McGregor et al., 2022) as well as similar work on understanding threats and pressures to seabird populations (Rogerson et al., 2021). The approach taken broadly follows that developed and advocated by Sutherland et al. (2021) for the objective evaluation of conservation actions.

3.1.2.2.1 Weighting of papers by relevancy

For the evaluation, we aimed to account for the relevance of each included study when forming an overall conclusion. This involved assigning scores to each study, which were than used to determine their relative importance to produce a combined score (i.e. a weighted mean). Each paper was scored against six factors (Table 7) measuring aspects of study relevancy; each factor was scored on a qualitative scale of 1–5. The overall score for a study was then the sum of these six factors (range of possible scores being 6–30). A study's weight was calculated by dividing the study's total score by the sum of the total score for all studies included for that conservation action.

The six scoring factors were chosen to cover key aspects of evaluating each piece of evidence:

- 'Type of reference' was scored highest for studies that were peer-reviewed and that included new data (i.e. primary literature); lowest for evidence lacking any clear peer-review and where evidence was preliminary (typically studies presented as talks/posters at conferences); and intermediate for secondary literature that synthesised primary evidence such as paper reviews, commissioned reports, book chapters, and master's theses. Note that while master's theses usually include new data, they represent a lower evidence standard than a PhD thesis or peer-reviewed research article.
- 'Direct/Indirect' was scored as true (direct) or false (indirect) depending on whether the evidence directly tested a conservation action. An example of direct testing would be a Before-After-Controlled-Impact (BACI) approach, were the conservation action was implemented and its effect on seabirds was measured at the site. An indirect measurement would be a study which modelled and predicted the effect of a conservation action theoretically, without practically testing it.
- 'Species' scored highest where at least one of the focal seabird species were included then progressively lower for higher taxonomic levels.
- 'Similar geographic location' scored highest when the study was conducted in the focal region (i.e. Scotland) and then progressively lower for those more distant studies where the local ecological context is most likely to differ.
- 'Publication date'. Studies conducted in recent years were given the highest weight to account for the ecological context likely to change over-time but also that more recent studies will typically have access to more advanced research methods.
- 'Sample size'. This factor is multi-factorial incorporating several aspects of sample size, including the number of individuals/nests, number of sites, and number of study years. Guideline thresholds are given (Table 7) for threshold sample sizes, but the weighting of different components of sample size will vary depending on the type of study.

Table 7. Relevancy scoring components scored for each study. The scoring scale is qualitative. All factors are scored on the same scale (1–5) but some factors exclude some levels (indicated with a dash '—').

Factor	Score level and description				
	1	**2**	**3**	**4**	**5**
Type of reference	Conference proceeding/ talk/poster	Opinion article/blog/ note article	Commissioned report/ Book/book chapter/ Review paper/ MSc Thesis	PhD Thesis	Research Article
Direct	Indirect	—	—	—	Direct
Species	Above family	Family	—	Genus	Species
Similar geographic location	Global	NE Atlantic	—	Britain & Ireland (excluding overseas territories)	Scotland
Publication date	<1990	1990–2004	2005–2014	—	2015–2023
Sample size	Few individuals/pairs (e.g. <200 demographic study, <20 tracking study), single site, or over a period of <5 years	Intermediate between levels 1–2	Intermediate individuals/pairs (e.g. >500 demographic study, <30 tracking study), several sites (>2 & <5 sites), or over a period of >10 years	Intermediate between levels 3–5	Many individuals/pairs (e.g. >1000 demographic study, >50 tracking study), multiple sites (>5 sites), or over a period of >20 years

3.1.2.2.2 Overall ecological efficacy

As introduced above, ecological efficacy is a combination of the likelihood that a conservation action is beneficial to a seabird population, and the size of effect found across studies. Each study was scored against two factors:

1. Statistical inference: A qualitative scale from 1 (low) to 5 (high), considering the statistical confidence of a real effect, this considered the study sample sizes, any stated statistical confidence (*inter alia* any p-values or confidence intervals), and that there was adequate consideration of potential confounding variables or alternative explanations. For reviews this was scored as 1 for non-systematic reviews, 3 for systematic reviews, and 5 for meta-analysis studies.
2. Degree of effect: A qualitative scale from 0 (no effect) to 5 (a high beneficial effect). This is a relative scale with a high effect considered to be a large effect on a demographic rate (e.g. >10% change in annual mortality); a weak effect being where a small effect is found (e.g. <1% change in annual mortality). Note that, theoretically, the degree of effect could also have negative values, which would indicate a detrimental effect. However, given that we were looking into conservation actions that are expected to have some degree of benefit, we did not expect to find any negative values and, therefore, were not considered within our scale.

The ecological efficacy for each study was the product of **statistical inference** and **degree of effect** which could take any value from 0 to 25 (Table 8). Higher scores reflect studies that found a strong beneficial effect of the conservation action on seabirds with high statistical inference while lower scores reflect studies that did not find a significant effect of the conservation action, or those with low statistical inference. The overall ecological efficacy for an action was calculated as a weighted mean of these scores using the relevancy weighting.

Table 8. Scoring matrix for ecological efficacy combining statistical inference and degree of effect. Shading (low - grey, high - purple) indicate the overall level of ecological efficacy. In both cases, 0 = low values and 5 = high values.

Degree of effect	Statistical inference: 1	2	3	4	5
0	0	0	0	0	0
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

3.1.2.2.3 Confidence

Confidence is an overall measure of the level of certainty we have that the assessed estimation of ecological efficacy is an accurate reflection of the true ecological efficacy of a conservation action. Confidence is not dependent on the level of ecological efficacy, i.e. we could find a strong effect but have low confidence that this is true, or we could find a low or no effect but have high confidence in this.

Table 9. Overall confidence for a conservation action was calculated as the sum of three factors, each scored on a qualitative scale of 1–5.

Evidence confidence assessment	Median relevancy scoring (index)	Independence and quantity of evidence	Concordance	Total score
Very high - 5	>0.80	Studies are from wide range of authors, study systems, and sites. 25+ studies	Evidence agrees on the direction and magnitude of impact. Degree of effect SD <0.5	14–15
High - 4	0.60–0.80	20–25 studies	Degree of effect SD = 0.5–1.0	11–13.9
Medium - 3	0.40–0.60	Studies are from a range of authors, few study systems, or few sites. 15–20 studies	Evidence agrees on direction but not magnitude of impact. Degree of effect SD = 1.0–1.5	8–10.9
Low - 2	0.20–0.40	10–15 studies	Degree of effect SD = 1.5–2.0	5–7.9
Very low - 1	<0.20	Studies are from few authors, and a very limited number of sites. <10 studies	Evidence does not agree on direction or magnitude. Degree of effect SD >2	3–4.9

We calculated three components of confidence (Table 9):

1. Median of relevance score (see 3.1.2.2.1) as an index (i.e. range 0–1) across studies.
2. Independence and quantity of evidence – a qualitative measure of the amount of evidence available incorporating both the number of studies but also how

independent those studies are (e.g. independence will be higher where there are more diverse authors/study systems/sites).

3. Concordance – Calculated by taking the standard deviation of the degree of effect measure (see 3.1.2.2.2); highest when a mix of positive and negative effects were found, indicating a low concordance across studies; lowest when all studies showed similar results/degrees of effect.

The overall confidence score was the sum of the three confidence components, leading to a range of possible values from 3–15.

3.1.2.2.4 Worked example

We show a simplified worked example with four theoretical studies (A–D).

First, all studies are scored against the six factors shown on Table 7 to determine their degree of relevancy (Table 10). Here, paper A represents a highly relevant study, while paper D represents the least relevant study, with papers B and C intermediate. Were all four papers weighted equally, then each would have a weight of ¼ (0.25), but as can be seen in Table 10, paper A has a weighting over four times greater than that of paper D.

Table 10. Worked example showing how the study weighting was calculated using the relevancy factors shown in Table 7. Weight = Sum of each study / total sum (70).

	Criteria							**Relevancy score**	
Study	Type	Direct	Species	Location	Publish date	Sample size	Sum	Sum (0 – 1)	Weight
A	5	5	5	5	5	5	30	1	0.43
B	3	5	2	2	2	4	18	0.5	0.26
C	3	1	3	4	3	2	16	0.42	0.23
D	1	1	1	1	1	1	6	0	0.09
						Total	**70**		

After scoring each study by their relevance, we proceed to score their statistical inference and degree of effect (Table 11). In this example, paper A had an excellent study design with a large sample size, over a long period, using data from several study systems, and provided relevant statistical analyses, good interpretation of the results, and accounted for confounding variables. Its results also found that the conservation action had a highly significant beneficial impact on the species and, therefore obtained the highest possible score of 25. On the contrary, paper D had a poor study design, with small sample sizes and absence of statistics, and did not find that the conservation action had an effect on seabirds, scoring a 1, the lowest possible value. Papers B and C had the same intermediate score, but for different reasons. On the one hand, paper B had a low statistical inference, with small samples sizes and poor statistics but its results indicated that the conservation action had a strong effect on seabirds. Paper C, on the other hand, had a good quality study design with appropriate statistics but its results indicated a weak effect on seabirds.

Once the ecological efficacy is obtained for each study (statistical inference * degree of effect), we proceed to obtain each studies' final score (weight * ecological efficacy). Paper A, having both the highest ecological efficacy and relevancy scores, obtained a 10.75. Paper D, the least relevant and with the lowest ecological efficacy obtained 0.09. Papers B and C had intermediate scores. We then proceeded to sum all four scores to obtain an overall ecological efficacy for the conservation action, obtaining 14.8 (Table 11). In an ideal scenario, where all studies exhibit a perfect ecological efficacy and the highest degree of relevancy, we would expect an overall final score of 25 (i.e. the maximum possible score). Such a score would indicate that the conservation action has a highly significant effect on seabirds. In this theoretical example, the score of 14.8 indicates that the evidence suggests a **medium effect** of the conservation action on seabirds, though leaning towards a medium-high effect (Figure 5).

Table 11. Worked example showing ecological efficacy (statistical inference x degree of effect) and final scores (ecological efficacy x weight). Ecological scores could have a potential score between 0 and 25. The weight values used to calculate the final score (weight * ecological efficacy) come from Table 10.

Study	**Criteria**		**Scores**		
	Statistical inference	Degree of effect	Ecological efficacy	Weight	Final score
A	5	5	25	0.43	10.75
B	2	4	8	0.26	2.08
C	4	2	8	0.23	1.84
D	1	1	1	0.09	0.09
				Total	**14.8**

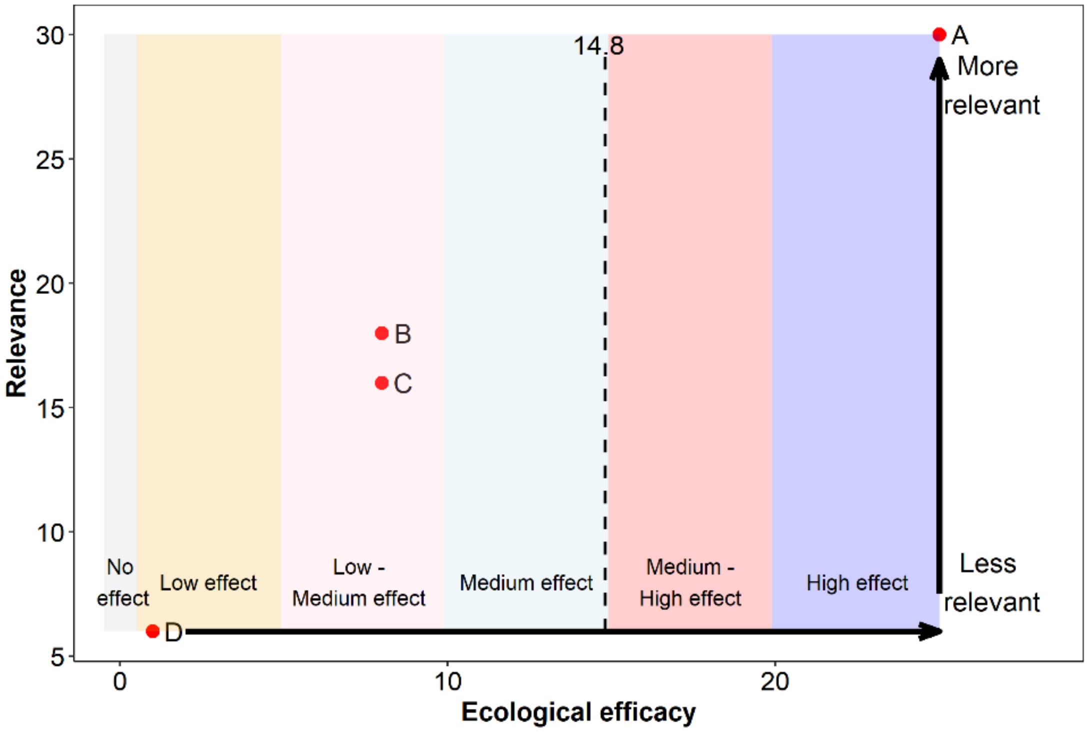

Figure 5. Ecological efficacy and relevance scores for each theoretical study (red dots). The letters correspond to the study identifier. Colours are used to differentiate the magnitude of the effect that the conservation action has on seabirds and correspond to those of Table 8. Vertical dashed line indicates the sum, and overall, ecological efficacy, which in the example is 14.8.

Finally, we estimate a score to assess the level of certainty and quality of the overall evidence, using the factors stated on Table 9. Possible values range between 3 and 15. In this example, the median score of the studies' relevancy score (using scores re-scaled to 0 – 1) was 0.46 and, following Table 9, scores a 3. Regarding independence and quantity, we will assume that the four theoretical studies shared common authors that gathered data from a limited number of study sites, scoring a 1. The standard deviation (SD) of the degree of effect across the four studies was 1.6, resulting in a cumulative score of 2. When considering the sum of these three scores, which totals 6, we conclude that the evidence indicates a **low** level of confidence on the evidence (Table 12).

Table 12. Assessment of the confidence in the evidence for the theoretical example. Refer to Table 9.

Factor	Results	Score
Median relevancy	Median = 0.46	3
Independence and quantity of evidence	Studies are from a few authors, limited study sites, <10 studies	1
Concordance	SD = 1.6	2
		Total **6/15**

Therefore, the conclusion in this worked example is that, with a low degree of confidence (6/15), the presumed conservation action has a medium effect (14.8/25) on seabirds. Applying a consistent scoring system to each conservation action allows for a more objective and quantitative way of comparing across actions. This facilitates a better understanding of which action is more likely to provide stronger significant benefits for seabirds, while also considering the confidence level in the evidence that supported that conclusion.

3.1.3 Scoping and targeted reviews – general methods

For the proposed compensatory measures (Table 4) that could not readily be allocated to conservation actions, we undertook scoping reviews (see Ecological feasibility (WP1)). For longline bycatch mitigation, however, where recent comprehensive work exists, including a recent detailed review commissioned by the Scottish Government (Kingston et al., 2023), it did not make sense to duplicate efforts by undertaking a full systematic review. Instead, we summarised the findings of these studies through a targeted review.

The purpose of scoping reviews is to scope out the potential conservation actions that correspond to each of the proposed compensatory measures and, where possible, identify which of these have most potential, so warrant further consideration. For measures assessed through the scoping reviews, we did not proceed with the practical feasibility assessments. To do so comprehensively would have required to first select the most promising conservation actions identified following the review, and then to conduct systematic reviews to assess their ecological feasibility, which was not feasible within the project's timeline. However, for bycatch mitigation a practical feasibility review was undertaken as significant evidence already exists indicating its ecological feasibility.

For both the scoping reviews and the targeted review we provide a high-level state-of-the-art review that considers key relevant recent papers and reports. Papers and reports are identified by a combination of existing knowledge, recommended reports (e.g. from the steering group), and targeted literature searches.

There is a dedicated section for each review, then at the end of this section a combined table summarising details of identified conservation actions. Each section starts with the focal species identified (see Table 4 and Table 6), followed by a general description of the key types of actions falling under each topic, identification of key sources, and discussion on potential conservation actions, followed by a brief conclusion.

3.2 Practical feasibility (WP2)

WP2 follows a similar structure to WP1, comprising of six chapters, each relating to a selected conservation action (except for the prey fisheries related actions that are grouped into a common chapter). Given the focus of this component we could not follow the systematic approach used in WP1, instead we used a combination of expert opinion, targeted literature, and web searches. References largely consisted of peer-reviewed scientific papers, commissioned reports, and government websites.

Each chapter includes the following sections, with additional sections where relevant for a conservation action:

- **A summary table**: Each chapter starts with a high-level summary table highlighting the most important and relevant information concerning the practical feasibility of the conservation action and includes the following:
    - A description of the conservation action.
    - A summary of key uncertainties on the effectiveness and practicalities.
    - An overview of the potential ecological benefits, focusing on species-specific population benefits, both for relevant focal species and other seabird species, occasionally extending to wider conservation benefits.
    - A summary of the spatial scale and the degree of population benefit that may result from the action. Spatial scale will vary from local (involving benefits at a colony level) to regional (involving several colonies within a geographical region), national (pertaining to a Scottish level), and wider (involving impacts on colonies outside of Scotland). The degree of the benefit is evaluated on a qualitative scale ranging from: none (indicating no expected benefit); low (representing negligible or small population-level response that would not be detectable though monitoring); medium (indicating measurable population-level responses, although this may require detailed monitoring to distinguish from environmental variations); and high (reflecting measurable population-level responses detectable through standard monitoring techniques, typically observable by ten years post-implementation).
    - The sequence of steps required to implement an action (i.e. a timeline).
    - Monitoring summary.
    - General key considerations, which outlines key issues that would need to be considered if seeking to progress an action as a compensatory measure.
    - Recommendation, providing a summary conclusion for each conservation action.

  The degree of detail will depend on the available evidence and knowledge, with some sections excluded or additional sections included when relevant. Some chapters include multiple conservation actions, in these cases columns are used to summarise information specific to each conservation action.
- **Background**: This section includes a high-level overview of the key points obtained in WP1 and highlights the importance of the action for seabirds.
- **Steps for implementation**: This section outlines the steps required for the practical implementation of a conservation action, covering the information needed to decide whether to proceed with the action up until post-implementation considerations. This information will be obtained from previous studies, especially those conducted within Scotland and on focal species, as well as by consulting experts and relevant government guidance.
- **Ecological effects of implementing action**: For each focal species, we provide an overview of the anticipated ecological effects that will be expected from the implementation of the action. In certain cases, species will be grouped together (e.g. ground-nesting colonial species). Additionally, we highlight potential benefits to non-focal seabird species and other species that may benefit, as well as any significant broader ecological effects. The time lag for population-level responses is also

discussed. This draws on key references identified within WP1 and additional relevant sources.

- **Research and monitoring recommendations**: This section offers recommendations for monitoring the effectiveness of the implementation, mostly identifying data to collect and associated analysis. Information was mainly gathered from analogous studies but also through discussions with individuals experienced in implementing similar actions.
- **Key considerations, potential barriers, and potential solutions**: This section provides an overview of key considerations for implementing an action. Potential barriers to implementing are identified and potential solutions are considered. The core issues considered encompass policy, legal, financial, ecological, non-financial resources, and practical and logistical aspects. We also consider other action-specific issues, such as cultural, health and safety, compliance, and additionality aspects. We gathered information from relevant studies and consulted with RSPB staff involved in practical conservation, policy, and casework (e.g. site managers, scientists, policy officers, engagement officers) to sense check the issues included and identified any additional barriers overlooked.
- **Species-specific aspects of implementation**: When relevant, we identified seabird species-specific aspects to consider during action implementation.
- **Overall conclusion**: This section includes an overall conclusion, overall uncertainty in delivery as compensation, and recommendations, including recommendations for further work.

4 Species accounts

For focal species, i.e. those assessed most likely to require compensatory measures (Table 4), we provide some background on their current conservation status and ecology. Species of large gulls and auks were grouped into combined accounts.

4.1 Black-legged Kittiwake *Rissa tridactyla*

The Black-legged Kittiwake (*Rissa tridactyla*, hereafter 'Kittiwake') is a medium sized gull species with a circumpolar distribution (breeding in northerly latitudes of both the Pacific and Atlantic). They nest on coastal cliffs often in large colonies and are the most oceanic of gull species, foraging primarily on small pelagic shoaling fish species ('forage fish'). Kittiwake are migratory with those breeding in northwest Europe dispersing widely across the North Atlantic during winter though with some birds breeding in the Britain and Ireland remaining relatively locally in winter (Frederiksen et al., 2012).

Over recent decades Kittiwake have been declining locally and within the UK, leading to corresponding negative conservation status (Table 13). The causes of declines are not fully understood but are thought to be largely driven by reduction in prey availability mediated primarily by climate impacts but also fisheries, this has led to reductions in both adult survival and productivity (Mitchell et al., 2020). Kittiwake are particularly sensitive to prey availability, being surface feeders and thus unable to dive for prey. Kittiwake were impacted by the Highly Pathogenic Avian Influenza (HPAI) outbreak in 2022 and 2023 though, on average, populations had increased between the Seabirds Count and HPAI censuses (Tremlett et al., 2024), but this masks some sites that suffered significant declines (e.g. -29% for Forth Islands).

Scotland holds a high proportion (56%) of Kittiwake breeding in the UK and are widely distributed around Scotland recognised as breeding features for 29 colony SPAs (Table 13), with the majority breeding on the east coast and in the Orkney and Shetland islands (Figure A 1). They are also a listed feature for one marine SPA, the Outer Firth of Forth and St Andrews Bay Complex SPA, both during the breeding and non-breeding seasons.

Kittiwake are thought to be vulnerable to offshore wind developments both through collision mortality and displacement. They were scored as having a vulnerability of 0.53 to collision and 0.6 to displacement placing them as the 4th and 5th most vulnerable, respectively, of the 11 species assessed by Searle et al. (2020) based on the methodology of Certain et al. (2015) using earlier assessments by Furness et al. (2013) and Wade et al. (2016). Based on in combination impacts from existing and planned offshore wind developments, the HRAs undertaken for the Sectoral Marine Plan for Offshore Wind Energy concluded that further offshore wind developments off eastern and northeastern Scotland in certain plan option (PO) sites (E3, NE2-NE4, and NE6) could lead to AEOSI. Kittiwake is therefore one of the species most likely to require compensatory measures were further offshore wind developments consented in these POs following HRA derogation (this has already occurred for developments in English Waters).

Table 13. Fact box for Black-legged Kittiwake (sources included as table footnotes), values are means (± one standard deviation) unless otherwise stated.

Species	**Black-legged Kittiwake**
IUCN Red List (global) status and trend[1]	Vulnerable (decreasing)
Birds of Conservation Concern 5 (UK) status[2]	Red list
Seabirds Count trend for Scotland (All Britain, Ireland, Isle of Man, and Channel Islands)for Seabird 2000 (ca. 2000) to Seabirds Count (ca. 2019)[3]	-57% (-42%)
Change between Seabirds Count and HPAI census (all sites)[4]	+10%
UK population (at last census in 2015-2021)[3]	215,913 (AON = apparently occupied nests)
Scotland population (at last census in 2015-2021)[3]	121,082 (AON)
Proportion of UK population in Scotland (breeding)[3]	56.1%
Age at first breeding[5]	4
Annual survival – Adult (juvenile)[5]	0.854 ± 0.051 (0.790)
Clutch size (median) [6]	2
Productivity (mean) [5]	0.690 ± 0.296
SPAs (breeding)[7] *marine SPAs	Ailsa Craig; Buchan Ness to Collieston Coast; Calf of Eday; Canna and Sanday; Cape Wrath; Copinsay; East Caithness Cliffs; Fair Isle; Flannan Isles; Forth Islands; Foula; Fowlsheugh; Handa; Hermaness, Saxa Vord and Valla Field; Hoy; Marwick Head; Mingulay and Berneray; North Caithness Cliffs; North Colonsay and Western Cliffs; North Rona and Sula Sgeir; Rousay; Rum; Shiant Isles; St Abb's Head to Fast Castle; St Kilda; Sumburgh Head; Troup, Pennan and Lion's Heads; West Westray; Noss; *Outer Firth of Forth and St Andrews Bay Complex
SPAs (non-breeding)[7] *Marine SPAs	*Outer Firth of Forth and St Andrews Bay Complex

1. The IUCN Red List of Threatened Species in 2018
2. The status of our bird populations (Stanbury et al., 2021)
3. Seabirds Count (Burnell et al., 2023)
4. HPAI census (Tremlett et al., 2024)
5. Horswill and Robinson (2015). Age at first breeding = Age of recruitment (mean); Productivity is National-average productivity (whole UK)
6. BTO (2023). BirdFacts: profiles of birds occurring in the United Kingdom. Accessed on 22/05/2023.
7. JNCC (2022). UK National Site Network. Downloaded: 2023-03-27; Last updated: 2022-09-30. Only SPAs where species are qualifying features are listed (i.e. those SPAs where a species is part of a seabird assemblage are not listed).

4.2 Large gulls: Lesser Black-backed Gull *Larus fuscus*, Herring Gull *Larus argentatus*, and Great Black-backed Gull *Larus marinus*

There are three large gull (all within *Larus* genus) species that breed in Scotland; Lesser Black-backed Gull, Herring Gull, and Great Black-backed Gull. All three species are dietary generalists feeding on a wide variety of terrestrial and marine prey. The Great Black-backed Gull is an apex predator that while a dietary generalist will also predate other birds and small mammals. All three gulls are ground nesting with natural nesting sites associated with coastal cliffs and islands but also nesting on artificial or urban sites especially on rooftops of buildings. Great Black-backed Gull are the largest of all gulls globally and are distributed throughout northern and low Arctic parts of the North Atlantic mostly being coastal but also associated with inland water bodies and larger rivers. Herring Gull (full common name European Herring Gull, *L. argentatus*, to distinguish from Arctic Herring Gull/American Herring Gull, *L. smithsonianus*, which were previously grouped as one species, see Sangster et al. (2007)) are distributed around north and northwest Europe, they are most associated with coasts but increasingly also occur inland. Lesser black-backed gull breed in northwestern Europe and northern Russia. All three species are somewhat migratory, though with many British breeding birds being largely resident or performing only shorter-range migrations within Britain and Ireland or to southwestern Europe.

For all three species the global conservation status is Least Concern, however the species have different population trends (Table 14). Within the UK the population status assessments have, to date, been based on the component of the gull populations breeding on natural sites (e.g. coastal colonies), at these sites the species have been decreasing so all three species are listed as of medium (Amber) or high (Red) concern. The number of Herring Gull and Lesser Black-backed Gull breeding on artificial sites (largely on building rooftops) has been increasing over the past few decades, and for England it is was estimated that the majority of both species nest primarily on artificial sites (Burnell, 2021). This was subsequently confirmed with the latest seabird census, Seabirds Count, including 'Urban' and 'Natural' populations (Burnell et al., 2023). Estimates of the proportion of Great Black-backed Gull using artificial nesting sites is not available for England nor Scotland, however they are recorded to use artificial sites too; e.g. small numbers were recently recorded nesting in Cardiff though at much lower levels than either Herring Gull or Lesser Black-backed Gull (Rock, 2022).

A number of potential causes of population change for gulls have been described. However, the relative contribution of these is unclear, particularly in terms of understanding to what extent reductions in natural (usually coastal) colonies has resulted from redistribution to artificial breeding sites. Causes of declines (particularly for natural colonies) include: reduction in availability of fishery discards following changes in discards practice and regulations (Sherley et al., 2020); botulism from foraging and landfill sites and culling (Coulson, 2015). Gulls were impacted by the HPAI outbreak in 2022 and 2023; Herring Gull decreased slightly between the Seabirds Count and HPAI censuses while Great Black-backed Gull declined significantly (for sites counted), and Lesser Black-backed Gull declined by an intermediate amount (Tremlett et al., 2024), however, overall trends masks some sites that suffered more significant declines (e.g. -29% for Lesser Black-backed Gull and -34% for Herring Gull from Forth Islands,).

Scotland hosts most of the UK's breeding Great Black-backed Gull, over half of natural nesting Herring Gull though less than half of all nesting Herring Gull, and a smaller proportion of Lesser Black-backed Gull (Table 14). Within Scotland there are 8 colony SPAs including Herring Gull as a designated (breeding) feature with most of these in the east or northeast of Scotland (two colonies on the west coast) and one marine SPA which is designated for both breeding and non-breeding birds (Figure A 1). There are only two Scottish SPAs (both breeding colonies) for Lesser Black-backed Gull corresponding to the relatively low proportion of the British population breeding in Scotland. For Great Black-backed Gull there are five colony SPAs designated, all in the north with the majority in the Orkney Isles (Figure A 1), and it is not a non-breeding feature for any SPAs.

The three large gulls are considered to be vulnerable to offshore wind developments primarily through collision mortality but potentially also via displacement. Herring Gull and Lesser Black-backed Gull were both scored as having a vulnerability of 0.60 to collision and 0.52 to displacement placing them as the joint 2nd and 6th most vulnerable, respectively, of the 11 species assessed by Searle et al. (2020) based on the methodology of Certain et al. (2015) using earlier assessments by Furness et al. (2013) and Wade et al. (2016). Great Black-backed Gull were not included in that assessment but would be expected to have similar vulnerability.

Table 14. Fact box for large gulls (sources included as table footnotes), values are means (± one standard deviation) unless otherwise stated.

Species	Herring Gull	Lesser Black-backed Gull	Great Black-backed Gull
IUCN Red List (global) status and trend[1]	Least concern (Decreasing)	Least concern (Increasing)	Least concern (unknown)
Birds of Conservation Concern 5 (UK) status[2]	Red List	Amber List	Amber List
Seabirds Count trend for Scotland (All Britain, Ireland, Isle of Man, and Channel Islands)for Seabird 2000 (ca. 2000) to Seabirds Count (ca. 2019)[3] natural nesters only	-44% (-44%)	-48% (-49%)	-63% (-52%)
Change between Seabirds Count and HPAI census (all sites)[4]	-6%	-12%	-32%
UK population (at last census in 2015-2021)[3]	237,573 (61,077)	324,465 (55,304)	8,021

Species	Herring Gull	Lesser Black-backed Gull	Great Black-backed Gull
(in brackets natural nesters only)			
Scotland population (at last census in 2015-2021)[3]	100,161 (37,349)	49,662 (11,001)	5,404
Proportion of UK population in Scotland (breeding)[3] (in brackets natural nesters only)	42% (61%)	15% (20%)	67%
Age at first breeding[5]	5	5	5
Annual survival – Adult (juvenile)[5]	0.834 ± 0.034 (0.798 ± 0.092)	0.885 ± 0.022 (0.820)	0.930
Clutch size (median) [6]	3	3	2-3
Productivity (mean) [5]	0.920 ± 0.477	0.530 ± 0.325	1.139 ± 0.533
SPAs (breeding)[7] *marine SPAs	Ailsa Craig; Buchan Ness to Collieston Coast; Canna and Sanday; East Caithness Cliffs; Forth Islands; Fowlsheugh; St Abb's Head to Fast Castle; Troup, Pennan and Lion's Heads; *Outer Firth of Forth and St Andrews Bay Complex	Ailsa Craig; Forth Islands	Calf of Eday; Copinsay; East Caithness Cliffs; Hoy; North Rona and Sula Sgeir
SPAs (non-breeding)[7] *marine SPAs	*Outer Firth of Forth and St Andrews Bay Complex	None	None

1. The IUCN Red List of Threatened Species in 2018
2. The status of our bird populations (Stanbury et al., 2021)
3. Seabirds Count (Burnell et al., 2023)
4. HPAI census (Tremlett et al., 2024)
5. Horswill and Robinson (2015). Age at first breeding = Age of recruitment (mean); Productivity is National-average productivity (whole UK)
6. BTO (2023). BirdFacts: profiles of birds occurring in the United Kingdom. Accessed on 22/05/2023.
7. JNCC (2022). UK National Site Network. Downloaded: 2023-03-27; Last updated: 2022-09-30. Only SPAs where species are qualifying features are listed (i.e. those SPAs where a species is part of a seabird assemblage are not listed).

4.3 Northern Gannet *Morus bassanus*

The Northern Gannet (*Morus bassanus*, here after referred to as 'Gannet', note other Gannet species exist in the Southern Hemisphere) is the largest species within the Sulidae family and is the largest breeding seabird in the Northern Atlantic (Nelson, 2002). Its distribution spans throughout both sides of the North Atlantic (BirdLife International, 2018). Currently, the UK holds 56% of the world's breeding Gannet populations (JNCC, 2021). These birds primarily establish breeding colonies on offshore islands, although a few colonies can also be found on mainland coastal cliffs. They are monogamous birds, often forming lifelong partnerships, and both parents take turns incubating the single offspring. At the end of the breeding season, both adults and juveniles from UK colonies migrate south as far as West Africa (Fort et al., 2012; Lane et al., 2021). The IUCN classifies Gannet as a species of Least Concern (Table 15), considering their wide distribution and increasing population trends worldwide (BirdLife International, 2018). The latter, however, does not account for the devastating effects caused by the ongoing outbreak of Highly Pathogenic Avian Influenza (HPAI) on Gannet populations. Consequently, current population trends are unknown.

Gannets primarily feed on pelagic fish such as mackerel and herring but can also feed on Sandeels when these are abundant. Their foraging behaviour consists mostly of plunge-diving from significant heights. This strategy entails spotting prey from elevated positions and then swiftly diving towards it to surprise and capture it. Additionally, Gannet can use their wings underwater to pursue and catch prey (Ropert-Coudert et al., 2009). Gannet have also been recorded feeding on discards from fishing vessels, where their large size provides them with a competitive advantage over other scavenging species.

Gannet populations have been increasing worldwide, including in the UK. Despite this positive trend, Gannet are categorised as Amber in the Birds of Conservation Concern 5 status (Table 15). This classification is based on two Amber list qualifying criteria, their breeding localisation (i.e. relatively few important breeding locations) and of their breeding international importance (i.e. that a high proportion of Gannet globally breed in the UK). Gannet are vulnerable to fisheries bycatch and have been recorded as one of the more frequently bycaught seabird species in UK waters (Northridge et al., 2020). Similarly in an assessment of fisheries bycatch in Portuguese Atlantic waters, Gannet were the most frequently bycaught seabird species, particularly in demersal longline operations (Oliveira et al., 2015). An emerging threat is from the rising presence of marine litter and pollution, particularly plastic debris, which poses risks through entanglement and ingestion (Rodriguez et al., 2013; Merlino, 2019). In the past, Gannet populations and colony distributions were significantly depleted due to the practice of harvesting eggs and chicks. Nonetheless, there has been a significant decrease in such practices over time. In the UK, there is presently only one licensed harvest site for Gannet chicks (see Ecological feasibility: End of the Gannet harvest at Sula Sgeir). Gannet also potentially face threats in the non-breeding season, with potential for both bycatch and competition with fisheries for prey off West Africa (Gremillet et al., 2015). Recently, HPAI has been shown to have significant detrimental effects on this species (Lane et al., 2023; Jeglinski et al., preprint). Across the UK, Gannet decreased 25% from the pre-HPAI baseline to 2023, with significant declines for key Scottish colonies (-27% for Forth Islands, including Bass Rock, and -37% for Hermaness, Saxa Vord and Valla Field) (Tremlett et al., 2024).

Scotland holds a significant proportion (>80%) of breeding Gannet within the UK, with the world's largest colony located on the Bass Rock in the Firth of Forth. Gannet are distributed around Scotland, mostly in the northern isles (Figure A 1), with breeding as a designated feature in 8 colony SPAs (Table 15). They are also a listed feature for two marine SPAs, the Outer Firth of Forth and St Andrews Bay Complex SPA and the Seas Off St Kilda SPA. No SPAs were designated for non-breeding.

Gannet are considered vulnerable to offshore wind developments both through collision mortality and displacement. They were scored as having a vulnerability of 0.67 to collision and 0.85 to displacement placing them as the most vulnerable and the 3rd most vulnerable of the 11 species assessed by Searle et al. (2020) based on the methodology of Certain et al. (2015) using earlier assessments by Furness et al. (2013) and Wade et al. (2016).

Table 15. Fact box for Northern Gannet (sources included as table footnotes), values are means (± one standard deviation) unless otherwise stated.

Species	**Northern Gannet**
IUCN Red List (global) status and trend[1]	Least Concern (increasing)
Birds of Conservation Concern 5 (UK) status[2]	Amber list
Seabirds Count trend for Scotland (All Britain, Ireland, Isle of Man, and Channel Islands) between 2003-2004 Gannet census and 2013-2014 Gannet Census & Seabirds Count (2015-2021)[3]	40% (39%)
Change between Seabirds Count and HPAI census (all sites)[4]	-25%
UK population (at last census in 2013-2021)[3]	304,176
Scotland population (at last census in 2013-2021)[3]	254,773
Proportion of UK population in Scotland (breeding)[3]	84%
Age at first breeding[5]	5
Annual survival – Adult (juvenile)[5]	0.919 ± 0.042 (0.424 ± 0.007 SE)
Clutch size (median) [6]	1
Productivity (mean) [5]	0.700 ± 0.082
SPAs (breeding)[7] *Marine SPAs	Ailsa Craig; Fair Isle; Forth Islands; Hermaness, Saxa Vord and Valla Field; North Rona and Sula Sgeir; St Kilda; Sule Skerry and Sule Stack; Noss; Outer Firth of Forth and St Andrews Bay Complex*; Seas off St Kilda*
SPAs (non-breeding)[7] *Marine SPAs	none

1. The IUCN Red List of Threatened Species in 2018
2. The status of our bird populations (Stanbury et al., 2021)
3. Seabirds Count (Burnell et al., 2023)
4. HPAI census (Tremlett et al., 2024)

5. Horswill and Robinson (2015). Age at first breeding = Age of recruitment (mean); Productivity is National-average productivity (whole UK)
6. BTO (2023). BirdFacts: profiles of birds occurring in the United Kingdom. Accessed on 22/05/2023.
7. JNCC (2022). UK National Site Network. Downloaded: 2023-03-27; Last updated: 2022-09-30. Only SPAs where species are qualifying features are listed (i.e. those SPAs where a species is part of a seabird assemblage are not listed).

4.4 Auks: Common Guillemot *Uria aalge*, Razorbill *Alca torda*, Atlantic Puffin *Fratercula arctica*

Auks, belonging to the Alcidae family, are small to medium-sized seabirds that are characterised by barrel-shaped bodies, short tails, small wings, and short legs set far back on their bodies. These morphological features are primarily adaptations for their (wing-propelled) diving (Pennycuick, 1987; Thaxter et al., 2010). Their walking ability is limited but they possess a distinctive ability to stand upright. Their flight is characterised by low and fast movements with whirring wings and limited manoeuvrability, but they are excellent swimmers and divers, using their wings to propel themselves underwater. Although there are five species of auks that breed or occur regularly in Scotland, this project will focus on three: Common Guillemot *Uria aalge*, Razorbill *Alca torda*, and Atlantic Puffin *Fratercula arctica* (Black Guillemot *Cepphus grylle* and Little Auk *Alle alle* are excluded). Guillemot exhibit a vast circumpolar distribution, inhabiting low-Arctic and boreal waters of the North Atlantic and North Pacific, it is one of the most abundant seabirds in the temperate and colder parts of the northern hemisphere. Similarly, Razorbills have a similar distribution but confined to the Atlantic Ocean and into the western Mediterranean. Puffins can be found across the North Atlantic, primarily in arctic and low-Arctic waters (IUCN, 2023; RSPB, 2023). When not breeding, auks are mostly found offshore within the North Atlantic.

The three auks here considered are pelagic species, spending most of their adult lives at sea and only going ashore to breed. During this time, they gather in large colonies on cliffs or rocky islands. Guillemots form dense nesting colonies along cliff edges, with colonies containing up to tens of thousands of individuals. Razorbills breed in colonies on cliff edges, in cracks in rocky cliffs or among boulders on rocky shores but tend to have smaller colonies and individuals are more widely spread compared to Guillemots. Both species do not build nests but lay a single egg on the bare rock, guano, or soil. Puffins, on the other hand, typically nest underground in burrows and more rarely in rocky crevices. Auks exhibit monogamous behaviour, and high fidelity to the nest site. Each pair lays one egg per breeding season, with the possibility of relaying if the first egg is lost early in the season. Both parents actively participate in parental care. However, unlike Guillemots and Razorbills, Puffins can leave their chicks unattended as their burrows provide protection. These species are piscivorous, mainly foraging on Sandeels, herring, sprat, juvenile gadoids, and capelin, but can also feed on crustaceans and worms (Harris and Wanless, 1986). All three auks swim and chase after fish underwater ('pursuit diving') but the duration spent underwater and the depth they reach depends on the species (Thaxter et al., 2010). Guillemots catch a single large fish during each feeding trip, while Razorbills and Puffins can collect several smaller fish during a single trip (Harris and Wanless, 1986).

The global conservation status for Guillemots and Razorbills is of Least Concern, with populations increasing worldwide. Atlantic Puffins, however, are categorised as Vulnerable and its populations are declining (Table 16). Despite these trends, auks face multiple threats and populations have varied accordingly. The major threat that auks are facing is starvation. The effects of overfishing and climate change have changed the proportion, distribution, nutrition quality, and size of fish they prey on which have collectively had a significant effect on the body condition, breeding success and survival of these birds (Sandvik et al., 2005; Wanless et al., 2005a; Häkkinen et al., 2022). Other threats involve high bycatch rates in some fisheries, due to their pursuit diving strategy (Costa et al., 2018; Northridge et al., 2020), oil spills (Votier et al., 2005), outwith the UK unregulated hunting at possibly unsustainable levels (Naves and Rothe, 2023), invasive mammalian predators, extreme weather conditions primarily winter storms (Häkkinen et al., 2022) and future sea level rises that may cause flooding in some parts of its geographical range (Sandvik et al., 2005). Across the UK, Common Guillemot decreased by 7% from the current baseline to 2023, following the HPAI outbreak in 2022, with significant declines for some key Scottish colonies (-42% for Forth Islands, and -34% for St Abb's Head to Fast Castle) (Tremlett et al., 2024). Razorbill and Puffin were not included in the HPAI census, though mortality is thought to have been lower than for Guillemot.

Scotland hosts most of Britain's breeding auks (>60% for all three species) (Table 16) with SPA colonies distributed around the whole of Scotland (Figure A 1). Within Scotland, Guillemots have 30 terrestrial colony SPAs as a designated (breeding) feature, and three marine SPAs, two of which are designated for both breeding and non-breeding birds (Table 16). Razorbills have smaller populations and have a more restricted distribution. Within Scotland, they have 16 colony SPAs as a designated (breeding) feature and one marine SPA designated for non-breeding birds. The Atlantic Puffin has 18 Scottish colony SPAs designated as a breeding feature, of which three are marine SPAs, and it is not a non-breeding feature for any SPAs.

The three auk species are considered to be vulnerable to offshore wind developments primarily through displacement. Razorbill, Guillemot, and Puffin were scored as having vulnerabilities to displacement of 0.9, 0.9, and 0.79 respectively, placing them joint 1st and 4th most vulnerable to displacement of the 11 species assessed by Searle et al. (2020). For collision vulnerabilities the three species were assessed as having much lower vulnerability, at 0.2, 0.23, and 0.17 (same order as before), placing them as the three least vulnerable species at 10th, 9th, and 11th of the 11 species assessed by Searle et al. (2020) based on the methodology of Certain et al. (2015) using earlier assessments by Furness et al. (2013) and Wade et al. (2016).

Table 16. Fact box for auks (sources included as table footnotes), values are means (± one standard deviation) unless otherwise stated.

Species	Common Guillemot	Razorbill	Atlantic Puffin
IUCN Red List (global) status and trend[1]	Least Concern (increasing)	Least Concern (increasing)	Vulnerable (decreasing)
Birds of Conservation Concern 5 (UK) status[2]	Amber list	Amber list	Red list
Seabirds Count trend for Scotland (All Britain, Ireland, Isle of Man, and Channel Islands)for Seabird 2000 (ca. 2000) to Seabirds Count (ca. 2019)[3]	-31% (-11%)	-2% (18%)	-21% (-14%)
Change between Seabirds Count and HPAI census (all sites)[4]	-7%	Not available	Not available
UK population (at last census in 2015-2021)[3]	1,265,888	225,015	474,679
Scotland population (at last census in 2015-2021)[3]	810,645	138,828	369,279
Proportion of UK population in Scotland (breeding)[3]	64%	62%	78%
Age at first breeding[5]	6	5	5
Annual survival – Adult (juvenile)[5] **Immature survival	0.939 ± 0.015 (0.560 ± 0.013 SE)	0.895 ± 0.067 (0.630 ± 0.209**)	0.906 ± 0.083 (0.709 ± 0.022)
Clutch size (median) [6]	1	1	1
Productivity (mean) [5]	0.672 ± 0.147	0.570 ± 0.247	0.617 ± 0.151
SPAs (breeding)[7] *Marine SPAs	Ailsa Craig; Buchan Ness to Collieston Coast; Calf of Eday; Canna and Sanday; Cape Wrath; Copinsay; East Caithness Cliffs; Fair Isle; Flannan Isles; Forth Islands; Foula; Fowlsheugh; Handa; Hermaness, Saxa Vord and Valla Field; Hoy; Marwick Head; Mingulay and Berneray; North Caithness Cliffs; North Colonsay and	Cape Wrath; East Caithness Cliffs; Fair Isle; Flannan Isles; Forth Islands; Foula; Fowlsheugh; Handa; Mingulay and Berneray; North Caithness Cliffs; North Rona and Sula Sgeir; Shiant Isles; St Abb's Head to Fast	Canna and Sanday; Cape Wrath; Fair Isle; Flannan Isles; Forth Islands; Foula; Hermaness, Saxa Vord and Valla Field; Hoy; Mingulay and Berneray; North Caithness Cliffs; North Rona and Sula Sgeir; Shiant Isles; St Kilda;

Species	**Common Guillemot**	**Razorbill**	**Atlantic Puffin**
	Western Cliffs; North Rona and Sula Sgeir; Rousay; Rum; Shiant Isles; St Abb's Head to Fast Castle; St Kilda; Sule Skerry and Sule Stack; Sumburgh Head; Troup, Pennan and Lion's Heads; West Westray; Noss; *Outer Firth of Forth and St Andrews Bay Complex; *Seas off Foula; *Seas off St Kilda	Castle; St Kilda; Troup, Pennan and Lion's Heads; West Westray	Sule Skerry and Sule Stack; Noss; *Outer Firth of Forth and St Andrews Bay Complex; *Seas off Foula; *Seas off St Kilda
SPAs (non-breeding)[7] *Marine SPAs	*Outer Firth of Forth and St Andrews Bay Complex; *Seas off Foula	*Outer Firth of Forth and St Andrews Bay Complex	none

1. The IUCN Red List of Threatened Species in 2018
2. The status of our bird populations (Stanbury et al., 2021)
3. Seabirds Count (Burnell et al., 2023)
4. HPAI census (Tremlett et al., 2024)
5. Horswill and Robinson (2015). Age at first breeding = Age of recruitment (mean); Productivity is National-average productivity (whole UK)
6. BTO (2023) BirdFacts: profiles of birds occurring in the United Kingdom. Accessed on 22/05/2023.
7. JNCC (2022). UK National Site Network. Downloaded: 2023-03-27; Last updated: 2022-09-30. Only SPAs where species are qualifying features are listed (i.e. those SPAs where a species is part of a seabird assemblage are not listed).

5 Ecological feasibility reviews

5.1 Ecological feasibility: Sandeel fishery closure

5.1.1 Summary

The systematic literature review and respective analyses provide evidence that, with a medium degree of confidence, the Sandeel fishery closure has a low to medium effect on at least one demographic parameter of Kittiwake. We conclude that Sandeel fishery closures would have benefits to Kittiwake populations. However, the size of this benefit will most likely be small and will not be possible to quantify with high confidence. This conservation action would be best considered as a resilience-building measure that may assist Kittiwake in coping with additional pressures, such as climate change.

***Note**: This review was prepared prior to the announcement of a closure of the Sandeel fishery in Scottish Waters made in early 2024 (see note at the start of the corresponding practical feasibility review: Practical feasibility: Closure and management of forage fisheries (Sandeel, Herring, and Sprat)).*

5.1.2 Introduction and background

Many piscivorous seabird species are dependent on one or a few key prey fish species, often termed 'forage fish', due to their importance within marine ecosystems (Cury et al., 2011; Tasker and Sydeman, 2023). These same forage fish are also the target of industrial fisheries. As such there is potential for seabirds and fisheries to be competing for the same resource, with fisheries reducing prey availability to seabirds. However, these ecosystems are complex with both top-down and bottom-up ecological processes acting, often at the same time (Cury et al., 2000; Hunt Jr and McKinnell, 2006; Dickey-Collas et al., 2014).

Cury et al. (2011) reviewed the global impact of prey abundance on seabirds, establishing a general principle stating that seabird populations will suffer lower productivity where forage fish stocks are below one-third of maximum observed long-term biomass. Saraux et al. (2021) subsequently identified a lower threshold (15–18% of historical maximum biomass) below which seabirds start to exert top-down regulation on forage fish populations.

In the North Sea, Sandeels (fish belonging to the family Ammodytidae) are a key forage fish for multiple seabird species including the focal species for this review, the Black-legged Kittiwake (Harris and Wanless, 1997a; Dickey-Collas et al., 2014; Wanless et al., 2018). Due to their foraging ecology (surface feeding), Kittiwake are considered to be one of the most vulnerable seabird species to reduced Sandeel abundance (Furness and Tasker, 2000). However, the North Sea is a complex system with various not fully understood feedbacks operating between different parts of the ecosystem, which means that it is not straightforward to predict the consequences of alternative management options, particularly in the face of climate change (Engelhard et al., 2013; Dickey-Collas et al., 2014).

Sandeels, especially Lesser Sandeels (*Ammodytes marinus*), are the primary food source of Black-legged Kittiwake in the UK during the breeding season and are also the main target for the largest single species fishery in the North Sea. Sandeels are also considered to be particularly at risk from rising sea temperatures due to their specialised habitat requirements and limited ability to shift their distribution amid adverse conditions (Wright, 2020; Henriksen et al., 2021), and their abundance and quality have deteriorated over the past 30 years (Furness, 2007; Wanless et al., 2018). In the North Sea, Kittiwake breeding success and survival have been strongly linked to Sandeel availability (Harris and Wanless, 1997a; Furness and Tasker, 2000; Daunt et al., 2008; Searle et al., 2023a), such that years with higher Sandeel biomass were positively associated with Kittiwake productivity (Carroll et al., 2017). Furthermore, Kittiwake breeding success has had a consistent negative relationship with fishery pressure (Searle et al., 2023a), represented by the interaction between Sandeel population size and the proportion of the fish population harvested (Cook et al., 2014). In Shetland, for example, the breeding success of several seabirds, including Kittiwake, decreased substantially after the collapse of the Shetland Sandeel stock (Furness and Tasker, 2000). This highlights the crucial role that Sandeel populations play on the survival and population dynamics of Kittiwake, a declining and already vulnerable species.

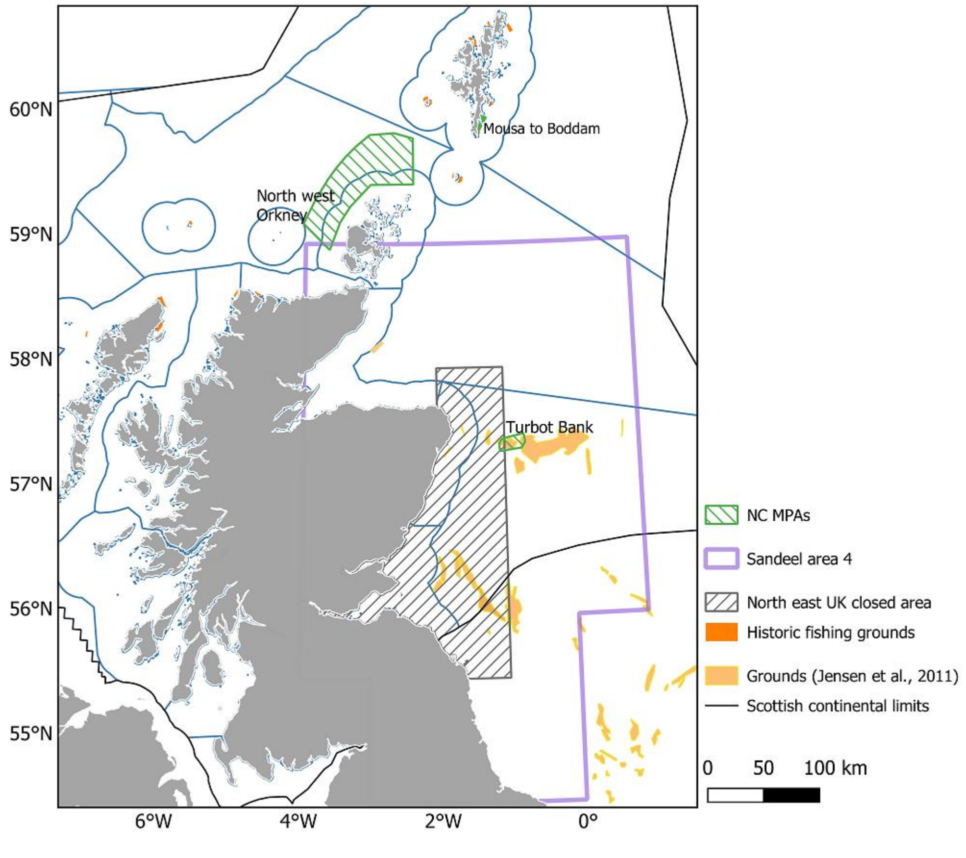

Figure 6. Chart reproduced from Wright (2020) showing the location of key Sandeel habitat (grounds) and spatial management areas in place in Scottish Waters, including the existing fishery closure area and the three Nature Conservation MPAs designated for Sandeel. Blue lines show Scottish Marine and Offshore Regions for context. Contains public sector information licensed under the Open Government Licence v3.0.

In 1990, an industrial Sandeel fishery began on the sandbanks of the Wee Bankie, Marr Bank, and Scalp Bank, 40 km off the southeast of Scotland. The fishery operated at the same time as the Kittiwake' breeding season and had a considerable spatial overlap with Kittiwake foraging areas for colonies along the east coast of Scotland. Due to considerable concern that the fishery was adversely affecting seabird populations through direct competition, an area of approximately 21,000 km^2 was closed to large scale fishing in 2000 (Figure 6) (Camphuysen, 2005; Wright, 2020). The closure was reviewed in 2007 leading to a recommendation to maintain the closure (STECF/SGMOS, 2007). Over 20 years have passed since the closure, and this is in a region where Kittiwake populations have been studied in detail before and since the closure (Daunt et al., 2008; Searle et al., 2023a). Therefore, there has been considerable research done to investigate the effect that the closure has had on Kittiwake populations.

5.1.3 Methods

The corresponding research question to this conservation action is: 'Would Kittiwake populations benefit from widening the spatial extent of the Sandeel fishery closure?'

A detailed description of the research question, keywords, search strings, and study selection (Figure 7) is provided in section 2 of Annex 1. Selection criteria can be found in Table A 2.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

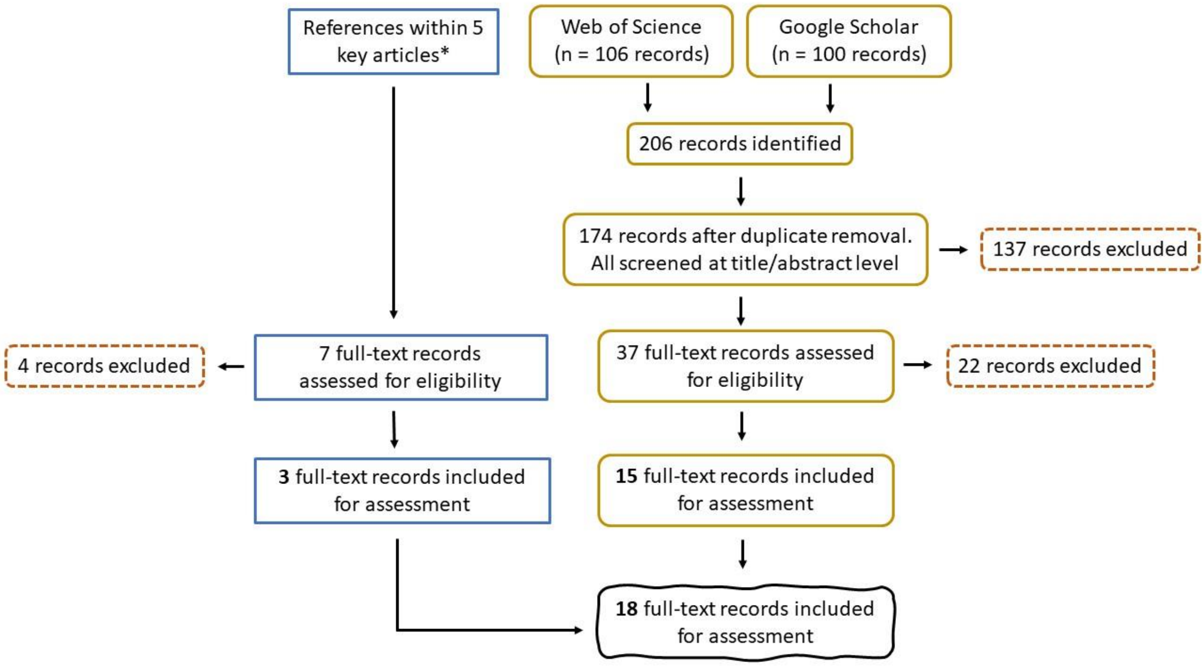

Figure 7. Flow diagram depicting the study selection process for the Sandeel fishery closure. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Furness et al. (2013), Furness (2021), Pearce-Higgins et al. (2021), McGregor et al. (2022), and Searle et al. (2023a).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

Overall, 18 references were included for the final review.

5.1.4 Results

5.1.4.1 General observations

We identified 18 references, all published in the English language, that met our criteria of testing whether the Sandeel fishery closure had an effect on Kittiwake populations. The earliest publication resulting from this literature review was in 2001, and the latest in 2023 (Figure 8A). The median publication date is 2008, and although each year consistently generated at least one article, there is a gap between 2009 and 2013, for which we found only one study that passed our inclusion criteria. From the 18 references, 61% were research articles, 28% were reports, and 11% were review papers (Figure 8B). Most studies collected, used, or analysed data from the East Coast; 14 from Southeast Scotland (SES; mostly from the Isle of May), seven from Northeast England (NEE), six from Northeast Scotland (NES), four from East England (EE), four from Orkney and Shetland (OSS), two from Northwest Scotland (NWS), and two from Southwest England (SWE) (Figure 8C). Note that some studies used data from multiple regions. Out of the 18 studies, 15 (83%) tested the Sandeel fishery closure directly, while three (17%) tested it indirectly (Figure 8D). Most studies (89%) tested or analysed the impact the closure had on Kittiwake productivity or breeding success, 39% on diet, 22% on survival rates, and 28% on other parameters such as foraging movements, abundance, population size, and population trends (Figure 8E).

The most commonly used data collection and analyses methods were observational field data and diet sample collection of Kittiwake (most studies utilised information collected from the UK-wide Seabird Monitoring Programme; SMP), Sandeel stock assessments, modelling, and use of environmental variables. Data sets analysed ranged from one year of data collection to 42 years (median = 16 years). Among the authors, the one with the highest frequency authored eight references, whereas two other authors authored six records each.

5.1.4.2 Evidence scoring

The relevance, as well as the ecological efficacy scores for all 18 references are shown in Table 17 and Figure 9 (refer to Annex 4 for a detailed breakdown of the extracted data for each study). Results from 72% of the assessed studies suggest that the Sandeel fishery closure had some sort of beneficial effect on at least one demographic aspect of Kittiwake, while the remaining 28% did not find it had any significant effect.

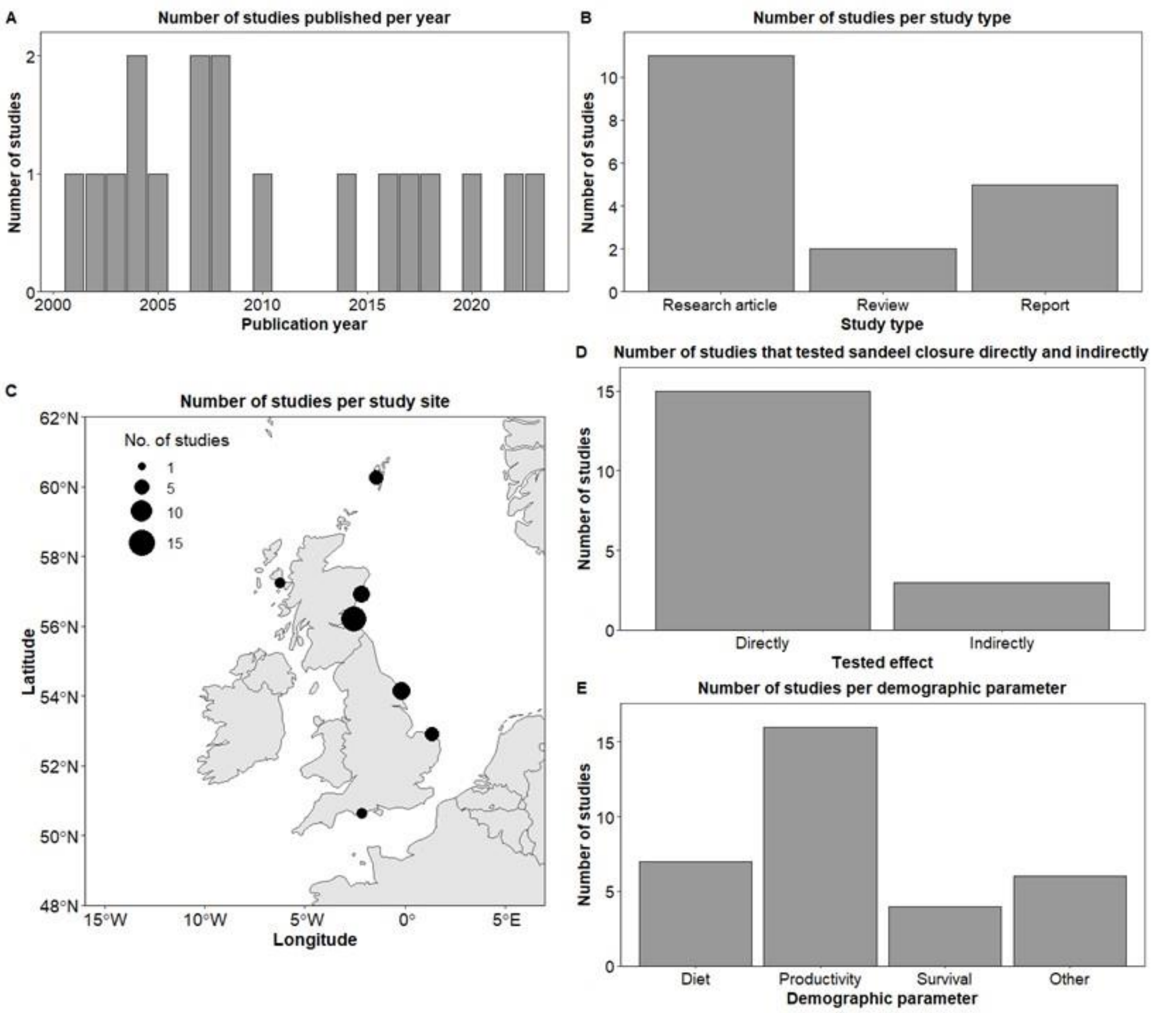

Figure 8. General observations of assessed records for Sandeel fishery closure review. A) number of studies published per year. B) number of studies per study type. C) number of studies that collected or analysed data per region, from north to south: OSS, NWS, NES, SES, NEE, EE, SEE. D) number of studies that tested Sandeel fishery closure directly and indirectly. E) number of studies per studied demographic parameters. Other = foraging movements, abundance, population size, population trends.

Table 17. Relevance and ecological efficacy scores, as well as the effect of the Sandeel fishery closure on Kittiwake for each assessed study. Relevance scores (in bold) could have a potential score between 6 and 30 (6=studies of low relevancy, 30=studies of high relevance). Ecological efficacy scores (in bold) could have a potential score between 0 and 25 (lower scores reflect studies that did not find a significant effect of Sandeel fishery closure on Kittiwake, or those with low statistical inference; higher scores reflect studies that found a strong effect of closure on Kittiwake with high statistical inference). SI = Statistical inference and DE = Degree of effect. References are ordered from lowest to highest final ecological efficacy scores (total ecological efficacy score x weight).

	Relevance									**Ecological Efficacy**			
Reference	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[1] Wanless et al. (2018)	5	5	5	5	5	4	**29**	0.96	0.065	3	0	**0**	0
[2] Wanless et al. (2007)	5	5	5	5	3	3	**26**	0.83	0.058	2	0	**0**	0
[3] Furness (2002)	5	1	5	5	2	5	**23**	0.71	0.051	2	0	**0**	0
[4] Poloczanska et al. (2004)	5	1	5	5	2	2	**20**	0.58	0.045	2	0	**0**	0
[5] Greenstreet et al. (2010)	3	5	5	5	3	2	**23**	0.71	0.051	2	0	**0**	0
[6] Furness (2003)	3	5	5	5	2	3	**23**	0.71	0.051	1	1	**1**	0.051
[7] Camphuysen (2005)	3	5	5	5	3	3	**24**	0.75	0.053	1	2	**2**	0.107
[8] Ruffino et al. (2020)	3	5	5	5	5	3	**26**	0.83	0.058	1	2	**2**	0.116
[9] Carroll et al. (2017)	5	1	5	4	5	3	**23**	0.71	0.051	4	1	**4**	0.205
[10] Lewis et al. (2001b)	5	5	5	5	2	2	**24**	0.75	0.053	1	4	**4**	0.214
[11] Daunt et al. (2008)	5	5	5	5	3	2	**25**	0.79	0.056	2	2	**4**	0.223
[12] McGregor et al. (2022)	3	5	5	5	5	3	**26**	0.83	0.058	1	5	**5**	0.290
[13] Frederiksen et al. (2004)	5	5	5	5	2	3	**25**	0.79	0.056	3	2	**6**	0.334
[14] Newell et al. (2016)	3	5	5	5	3	1	**22**	0.67	0.049	4	2	**8**	0.392
[15] Furness (2007)	3	5	5	5	3	3	**24**	0.75	0.053	2	4	**8**	0.428
[16] Frederiksen et al. (2008)	5	5	5	5	3	5	**28**	0.92	0.062	3	4	**12**	0.748
[17] Cook et al. (2014)	5	5	5	5	3	5	**28**	0.92	0.062	4	3	**12**	0.748
[18] Searle et al. (2023a)	5	5	5	5	5	5	**30**	1	0.067	4	3	**12**	0.802
Total							**449**					**80**	**5**

Overall, references were highly relevant for our assessment. Scores ranged between 20 and 30 out of a maximum possible score of 30, with a median and mean score of 24.5 and a mean average score of 25. For this reason, studies had a similar associated weight, ranging from 0.045 to 0.067 (Table 17).

The ecological efficacy, i.e. the likelihood that a Sandeel fishery closure is beneficial on at least one demographic parameter of Kittiwake, varied between studies. Out of a maximum possible score of 25, scores ranged between 0 (closure did not have an effect on at least one Kittiwake demographic parameter) and 12 (closure had a medium effect on Kittiwake). The median score is four, which indicates that half of the studies did not find a significant effect, or found a low effect, of the Sandeel closure on Kittiwake. The other half suggest that the Sandeel fishery closure had a low-medium or medium effect on Kittiwake.

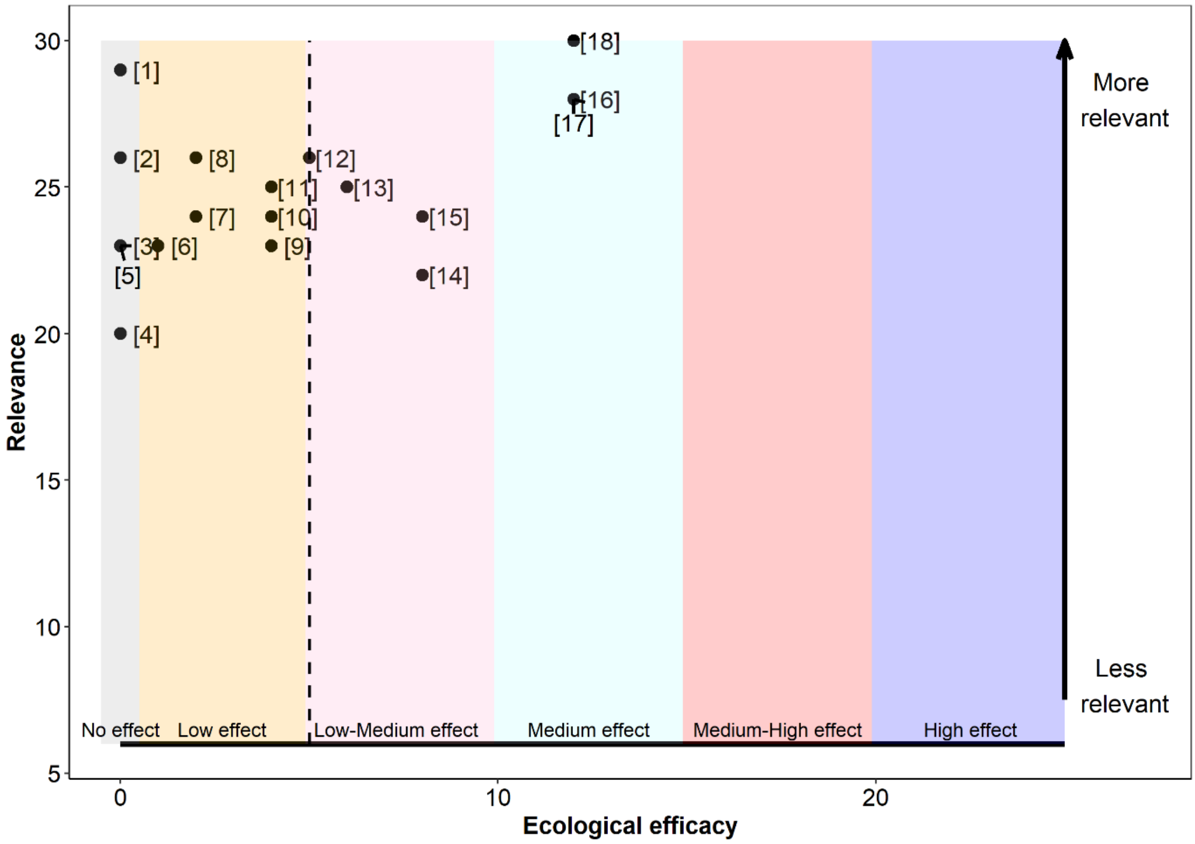

Figure 9. Ecological efficacy and relevance scores for each assessed study on the effect of Sandeel fishery closures on Kittiwake. The numbers correspond to the study identifier, as indicated in Table 17. Colours are used to differentiate the magnitude of the effect that

Sandeel fishery closure has on at least one Kittiwake demographic parameter. Vertical dashed line indicates the overall ecological efficacy of a Sandeel closure on Kittiwake.

The sum of all final weighted scores is five (i.e. the mean of ecological efficacy weighted by relevance), therefore, it can be concluded that the evidence overall support that a Sandeel fishery closure will benefit Kittiwake to a low-medium degree (Figure 9).

5.1.4.3 Overall confidence scoring

We estimated the median of the relevance index score, the independence and quantity of the evidence and the concordance between studies to obtain an overall score to assess the confidence in our findings (see Confidence). The total score for this conservation action was eight out of the possible 15 (Table 18), suggesting there is a medium degree of confidence that the assessed estimation of the ecological efficiency is an accurate reflection of the true ecological efficacy of the Sandeel closure.

Table 18. Assessment of the confidence in the evidence for the Sandeel fishery closure.

Factor	Results	Score
Median relevancy	Median = 0.77	4
Independence and quantity of evidence	Limited number of sites, 5–20 studies	2
Concordance	SD = 1.58	2
	Total	8/15

5.1.4.4 Main findings: the effect of Sandeel fishery closure on Kittiwake

In summary, our literature review and respective analyses provide evidence that, with a medium degree of confidence, the Sandeel fishery closure has a low-medium effect on at least one demographic parameter of Kittiwake.

The key findings from the highest scored studies are summarised in Table 19. Overall, results from most, but not all, studies provide evidence that Kittiwake breeding success significantly increased after the Wee Bankie closure (Lewis et al., 2001b; Frederiksen et al., 2008; Ruffino et al., 2020; Searle et al., 2023a). Breeding success for Kittiwake on the Isle of May, for example, was substantially higher in the first three years of the closure (2000–2003) but had poor breeding success during subsequent years (such as 2004, 2007, and 2008). From 2009 onwards, there was a slight recovery, but it is unclear whether this improvement resulted from the Sandeel closure itself (Newell et al., 2016; Searle et al., 2023a) or from external factors. Changes in diet have also been recorded across time; there has been a decrease in 1+group (individuals at least one year old) Sandeel consumption, and an increase in sprat and 0-group (i.e. young of the year) Sandeel consumption (Lewis et al., 2001b; Wanless et al., 2018). Breeding success has strongly correlated with Sandeel total stock biomass; with breeding success lowest in years of low Sandeel abundance, and higher in years with moderate to high Sandeel stock biomass (Furness, 2007; Daunt et al., 2008). Years where Kittiwake had a higher proportion of Sandeel in their diet were associated with higher breeding success (Searle et al., 2023a). Lower breeding success, however, has also been significantly correlated with higher sea surface temperatures (Cook et al., 2014).

To support the recent consultation on options for spatial closures of English Waters to Sandeel fisheries (Defra, 2023a), Defra commissioned a review on benefits to seabirds that included new ecosystem modelling (Natural England et al., 2023). This report was not considered in our systematic review as it did not come up in our literature search likely due to its recent publication (March 2023). The report's conclusions are in general agreement with our findings. The study concluded that there could be increased population resilience to seabird populations following a Sandeel fishery closure. There were some caveats around these findings with the seabirds modelled as a single group rather than individual species, so benefits to Kittiwake could not be specifically examined. Additionally, the authors noted that they had assumed constant conditions so do not consider future anticipated ecosystem changes driven by climate change.

The most recent and complete study to have analysed long-term Kittiwake productivity data and relate this to the Wee Bankie Sandeel fishery closure is Searle et al. (2023a). This study analysed data collected on the Isle of May (i.e. the same seabird colony used by most of the studies considered in this review) as well as data collected for other colonies of the East coast of the UK from 1986 to 2018. Breeding success after the fishery closure varied between colonies within the closure zone, ranging from -4% to 25%. Colonies such as Dunbar Coast and Farne Islands showed a continued decline since the closure, while the colony on the Isle of May had a 17% breeding success increase. Colonies within a control zone (i.e. outwith the Sandeel closure area), on the other hand, had a slight but non-significant decline in breeding success during that same time period. On the Isle of May evidence suggests a long-term decline in the overall importance of Sandeels in the diet of chicks, an increase in sprat and herring, and a shift from 1-group Sandeels to 0-group. The closure, however, did not restore the importance of Sandeels in the diet.

Numerous studies concur that Kittiwake populations are regulated by a variety of factors, including environmental conditions, fisheries, top-down processes, and Sandeel body condition. Consequently, disentangling and comprehending the individual effects of these factors can be difficult and challenging to tease apart (Lewis et al., 2001b; Wanless et al., 2007; Ruffino et al., 2020; Searle et al., 2023a).

5.1.4.5 Biases or Conflict of interest

For most of the studies considered the authors did not disclose any potential for biases or conflicts of interest. However, two of the studies were fully or partly funded by either a fisheries industry body (Furness, 2002) or by an offshore wind developer (Searle et al., 2023a). Note that we do not make judgement on whether these lead to an actual conflict of interest or influence study findings but provide the information for the readers' awareness.

Table 19. Summary findings of the seven most relevant studies on the effect of Sandeel fishery closure on Kittiwake, in order of decreasing relevance.

Reference	Results summary
[18] Searle et al. (2023a)	Overall, breeding success increased after the 2000 closure until 2018, but this was colony specific. Increase in 0-group Sandeel consumption through time. Closure reduced the rate of Kittiwake population declines but has not recovered to pre-fishery levels, despite 20 years having now passed. Noted that it is difficult to tease apart the effect of the closure and other environmental changes occurring over the same period.
[1] Wanless et al. (2018)	Kittiwake have reduced Sandeel consumption over time, especially of 1+group Sandeel, and have increased sprat consumption. Fishery closure did not have an effect on diet composition of chicks.
[17] Cook et al. (2014)	In the North Sea, Kittiwake are declining, and breeding failure rates are increasing, this correlates with fisheries. Higher sea-surface temperature (SST) also significantly negatively correlated with breeding success.
[16] Frederiksen et al. (2008)	Strong effect of fishery activity on breeding productivity within the closure zone but not in control zones; breeding productivity increased after closure.
[12] McGregor et al. (2022)	Increases in breeding success after closure and several positive relationships between Sandeels, fisheries, and Kittiwake breeding success. Did not account for potential effects of climate change.
[8] Ruffino et al. (2020)	Increase and non-significant effects in breeding success after closure, but environmental and fishery effects can interact in a complex manner, so that individual effects can be difficult to tease apart.
[2] Wanless et al. (2007)	Breeding success four years after closure was similar to that predicted if fishery was operating. But poor breeding success could be due to top-down processes, low lipid content in Sandeels, or changes in lower trophic levels.

5.1.5 Discussion

It is clear that seeking to manage the North Sea ecosystem for increased Sandeel availability would help maintain Kittiwake populations (Harris and Wanless, 1997a; Furness and Tasker, 2000; Daunt et al., 2008; Searle et al., 2023a). However, the evidence that further Sandeel fishery closures (i.e. beyond the existing closure of the Wee Bankie fishery off southeast Scotland) will deliver significant population level benefits to Kittiwake, required for this conservation action to be considered an ecologically feasible compensatory measure, is relatively weak.

The North Sea is a very well-studied ecosystem yet due to its complexity we do not have a sufficiently full understanding to confidently predict how changes in one component of the ecosystem affect others (Engelhard et al., 2013; Dickey-Collas et al., 2014; Régnier et al., 2019). More research might help improve our predictive power. However, this is likely ultimately limited with this being a complex system (Glaser et al., 2014) and one that is undergoing continuous longer term changes due to climate change, which is already leading to changes in the structure and functioning of the ecosystem (MacDonald et al., 2015; Mitchell et al., 2020; Olin et al., 2022).

A further fishery closure, in addition to the existing NE UK Sandeel closure area, may bring some ecosystem benefit through increasing ecosystem resilience, reducing the risk of a Sandeel stock collapse (e.g. Essington et al. (2015)), and by reducing prey competition with seabirds, particularly in areas near to breeding colonies where fisheries could have the most significant impact on breeding birds (Pichegru et al., 2010; Sherley et al., 2015; Hentati-Sundberg et al., 2021b). The spatial component of prey availability and how this could be impacted by fisheries may be particularly relevant for Sandeel which have low dispersal distances (Wright et al., 2019), presumably increasing potential for local depletion.

The most comprehensive study to date on the effect of the existing Sandeel fishery closure, Searle et al. (2023a), generally found increases in breeding success for Kittiwake colonies within the closure region but slight declines (though non-significant) outwith this zone. However, despite the increases in breeding success, the Kittiwake populations have not recovered to pre-fishery levels even 20 years post-closure. The authors considered the implications of their findings for use of fisheries management as a strategic conservation tool. They noted that their models generally explained relatively low proportions of variance (4–50%) and that the system is impacted by environmental changes, thus caution should be applied if trying to produce quantitative predictions on the benefits from fishery closures into the future. They also noted that studies to monitor the effects of such management interventions will generally take many years, potentially decades, to provide clear conclusions which would limit the potential for adaptive management.

The impacts of Sandeel fisheries on Kittiwake (and other seabird populations) in recent years are likely relatively less than would have been detected in earlier decades due to overall reduced levels of fishing effort and the size of climate change effects. Overall fishing mortality on Sandeel in the North Sea is now <20% of overall annual mortality, which is historically low, and considered to be at a low exploitation rate (the ratio of fisheries mortality to natural mortality) (Engelhard et al., 2013). Over the past few decades, the zooplankton community has changed substantially, particularly along the east coast of Scotland, leading to substantial long-term declines in total energy available to Sandeel, particularly to 0-group Sandeel (Olin et al., 2022). Together these changes are affecting both Sandeel abundance and likely availability (a function of the spatio-temporal abundance) to Kittiwake with potential for a trophic mismatch (Scott et al., 2006; Burthe et al., 2012; Régnier et al., 2019; Mitchell et al., 2020).

5.1.5.1 Knowledge gaps and future directions

If Sandeel fisheries are to continue operating, then it will be crucial that there is better understanding of the spatial and temporal scale of fishery effects at scales relevant to Kittiwake. This could be achieved through a mixture of model-based studies (e.g. Searle et al. (2018); Hentati-Sundberg et al. (2021b)) and new data collection. Fish surveys that more directly measure prey availability and quality for seabirds are crucial, as most existing studies make inferences using fisheries monitoring data that are rarely optimal. For example, surveys are often conducted in a different season or at a different spatial scale than that at which seabird-prey interactions occur; Sandeel assessments are primarily based on dredge sampling during winter which is not directly representative of availability in the water column during the Kittiwake breeding period. Therefore, there is a need for whole-ecosystem models that are developed and parameterised to match the scales at which seabird-prey interactions occur (see e.g. Smith et al. (2011)).

Most studies of Kittiwake and prey in the UK have focussed on North Sea populations, especially from the long-running study on the Isle of May. These have delivered valuable insights into the complex system but there is increased uncertainty when extrapolating out to other parts of Scotland and the wider UK. With the recent completion of the national seabird census ('Seabirds Count') (Burnell et al., 2023) new up-to-date population data is now available for Kittiwake populations within Scotland, which could allow studies of regional differences including re-running earlier analyses with longer time-series and/or at wider spatial scales (e.g. Cook et al. (2014); Carroll et al. (2017)).

Most studies to date looked at Kittiwake productivity with relatively few relating variation or changes in survival to fisheries and prey (Figure 8). Given that a small increase in adult survival will, all else being equal, lead to a greater population level effect than a similarly small increase in productivity, then this should be investigated. Through the Seabird Monitoring Programme, adult survival (or more accurately resighting) data are available for a number of colonies, however this is still relatively few so ideally such long-term field studies would be increased and expanded (see O'Hanlon et al. (2021)).

The wider Sandeel fishery closures announced by the UK and Scottish Governments in early 2024[2] will potentially provide an opportunity to undertake similar Before-After-Control-Impact Sandeel closure analyses to those that have been undertaken for the southeast of Scotland. While these would be of less direct relevance to Scotland, these would provide a form of study replication while also improving our understanding by increasing the range of ecological conditions represented which should enhance predictive power.

5.1.6 Conclusion

Overall, we conclude that Sandeel fisheries closures would have benefits to Kittiwake populations, however the size of this benefit is generally small and is not possible to quantify with higher confidence. This conservation action is thus best considered as a resilience-building measure that may assist Kittiwake in coping with additional pressures, such as climate change. This conclusion aligns with the findings of Natural England et al. (2023). The evidence reviewed suggests that Sandeel abundance and availability is largely driven by processes other than fisheries including climate and piscivorous fish species (Engelhard et al., 2013; Dickey-Collas et al., 2014). Therefore, we have limited confidence

[2] See note at start of: Practical feasibility: Closure and management of forage fisheries (Sandeel, Herring, and Sprat)

that further closures could deliver an ecologically meaningful gain in Sandeel populations with ensuing benefits in Kittiwake and consequently, it cannot be concluded that such closures would represent an effective conservation action in terms of a compensatory measure. However, as Montevecchi (2023) noted it is also true that the only factor potentially determining prey availability to seabirds that we can generally control directly is fisheries.

5.2 Ecological feasibility: Fishery closure or enhanced management of prey fisheries (Sprat, Herring, and Mackerel)

5.2.1 Summary

The systematic literature review and respective analyses provide evidence that, with a medium degree of confidence, the enhanced management of fisheries targeting seabird prey fish species has a low to medium effect on at least one demographic parameter of seabirds, but this is highly dependent on the seabird species and the current fisheries management practice. Whether a population level benefit can be anticipated following changes in fisheries management for a seabird species will require careful consideration of the specific ecological context, and it will rarely be possible to confidently form quantitative predictions on the level of benefit.

5.2.2 Introduction and background

Several piscivorous seabird species rely on one or a few key prey fish species (Cury et al., 2011; Pikitch et al., 2014; Tasker and Sydeman, 2023). Coincidentally, these same forage fish are targeted by industrial fisheries. This present the potential for competition between seabirds and fisheries for the same resource, with fisheries reducing prey availability to seabirds. However, these ecosystems are complex with both top-down and bottom-up ecological processes acting, often at the same time (Cury et al., 2000; Hunt Jr and McKinnell, 2006; Fauchald et al., 2011; Dickey-Collas et al., 2014).

Cury et al. (2011) estimated that seabird populations will suffer lower productivity where forage fish stocks are below one-third of the maximum observed long-term biomass. Saraux et al. (2021) subsequently identified a lower threshold (15–18% of historical maximum biomass) below which seabirds start to exert top-down regulation on forage fish populations (above this threshold predation by seabirds represents only a small proportion of overall fish mortality). However, in another global meta-analysis, marine predator productivity, including piscivorous fish, birds, and mammals, was found to be only rarely impacted by prey abundance (Free et al., 2021).

A global analysis of seabird distributions, considering seabird prey consumption and fisheries activity suggests that NW Europe, particularly around the UK, is an area of relatively high overlap in resource demands between seabirds and fisheries, and as such there is a higher expectation of potential resource competition (Karpouzi et al., 2007). There are multiple examples of seabird-prey systems in NW Europe where fisheries are considered to have had a role in reducing the availability of prey fish to seabirds leading ultimately to population level impacts. For example, a collapse in the Norwegian Herring stock was partly implicated in a decrease from 1.4 million to <600 thousands pairs of Atlantic Puffin at Røst, an island in Northern Norway, between the late 1970s and late 1990s. Around the UK the best studied system is of the dependence of seabirds in the North Sea on Sandeel and consequent impacts from reduce prey abundance (see also Ecological feasibility: Sandeel fishery closure). The breeding success of several seabirds, including Kittiwake, decreased substantially after the collapse of the Shetland Sandeel stock (Furness and Tasker, 2000). Kittiwake breeding success has had a consistent negative relationship with fishery pressure

(Searle et al., 2023a), represented by the interaction between Sandeel population size and the proportion of the fish population harvested (Cook et al., 2014).

To understand which fisheries have potential to impact seabird populations in Scotland, we must first understand the diet of seabirds, then relate that to which prey items are also the target of fisheries. However, it should be noted that there is also the potential for indirect impacts from fisheries targeting other components of the food chain; as most of the prey species targeted by seabirds are forage fish (low trophic level), fisheries targeting predatory fish can alter the levels of natural predation on forage fish. Where natural predation (the majority of which is from predatory fish) is a large component of fish mortality, then management of fisheries targeting predatory fish has potential to have greater influence on the availability of prey to seabird population than changes in management of fisheries targeting the prey fish themselves (Österblom et al., 2006; Bakun et al., 2009; Reilly et al., 2014).

Our understanding of seabird diet in the UK is better for the breeding period than for the non-breeding season. The existing evidence on seabird diets in the UK was collated by the Marine Ecosystem Research Programme which is available as a publicly available database (via the *seabirddietDB* package in the R statistical environment, Krystalli et al. (2019)). Sandeel have been the key prey for many North Sea breeding seabirds, though their relative dietary importance has reduced over the past decades (Wanless et al., 2018). A study of Common Guillemot diets around the UK (Anderson et al., 2014) found great variation in chick diets depending on location, while Lesser Sandeel were the most frequent prey, clupeids (e.g. Sprat) and juvenile gadids were also important dietary components. Gannet take similar species but typically target larger fish, both of the same species (i.e. older age classes), and of others, particularly Mackerel in the North Sea (Lewis et al., 2003).

This chapter takes a broader approach than that focussing on Sandeel (see Ecological feasibility: Sandeel fishery closure) given the wider scope of multiple fisheries and multiple focal species. We therefore started by identifying key prey fisheries to focus the review on, largely following a previous study focussed around ecosystem based management of Scottish fisheries (Heath et al., 2017).

5.2.3 Methods

5.2.3.1 Prey fish species to include

The starting point for this review was to identify what seabird prey fish species would be relevant to consider in the review. To be included, the fish species need to be those that are prey fish of at least one focal seabird species but that are also targeted by fisheries in Scotland. Heath et al. (2017) reviewed evidence around interactions between commercial fisheries and natural predators (including seabirds) in Scotland. The review included consideration of potential for bycatch mortality, impacts on prey availability and potential for predator species to benefit from discards. However, only the sections pertinent to prey availability were considered for this review. They compiled a table classifying the likelihood for significant interactions between fisheries and predators (Table 2 in Heath et al. (2017)) which summarises the findings from a workshop (held in 2016 with a number of invited experts – see page 8 of Heath et al. (2017) for participant list). Below (Table 20) is an edited and re-arranged subset from this table including our focal seabird species and the conclusion of Heath et al. (2017) on the potential for fishery related prey depletion to impact a seabird species ('predator likely to be affected by fishery').

Table 20. Prey fish species identified by Heath et al. (2017) where there was potential for seabird species to be impacted by fisheries targeting these species. An 'x' denotes where a potential negative interaction is identified, a dot '.' where no negative interaction was identified, and in one case a question mark '?' where this was not clearly stated. After table 2 in Heath et al. (2017).

Species	Kittiwake	Guillemot	Razorbill	Gannet	Fulmar	Puffin	Large gulls	Relevant to at least one seabird species
Sandeel	x	x	x	?	.	x	.	x
Sprat	.	.	.	.	.	x	.	x
Herring	.	.	.	.	.	x	.	x
Rockling	.	.	.	.	.	x	.	x
Gadoid + cod/haddock	.	.	.	.	.	.	.	.
Whiting	.	.	.	.	.	.	.	.
Mackerel	.	.	.	x	.	.	.	x

For the review we included all the prey fish species identified by Heath et al. (2017) where there was potential for at least one seabird species to be impacted by fisheries targeting those species. However, we excluded Sandeel, as these are the target of another review (see Ecological feasibility: Sandeel fishery closure), and rockling as on investigation these do not appear to be a commercially targeted fish species in Scottish Waters. The final list of prey fish species was also discussed with the project steering group (20th March 2023) where there was general agreement on the species to include, though suggestion to also consider gadoid species as the younger age classes of these are preyed on by seabirds. However, we decided to exclude these as they were not identified by our key source review (Heath et al., 2017) likely due to the abundance of the early age classes of these species being determined by complex ecosystem interactions and not primarily by fisheries targeting the adult age classes (see e.g. (Engelhard et al., 2013; Dickey-Collas et al., 2014)).

The final list of prey fish species included were Sprat, Herring, and Mackerel.

5.2.3.2 Research questions, keywords, search strings, and study selection

The corresponding research question to this conservation action is: 'Would the focal seabird species benefit from enhanced management of fisheries that target seabird prey fish species in Scotland?' In addition to the key question, we also sought to identify which prey species may be most impacted by fisheries and which seabird species could most benefit from any changes in management.

A detailed description of the research question, keywords, search strings, and study selection (Figure 10) is provided in section 3 of Annex 1. Selection criteria can be found in Table A 2.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

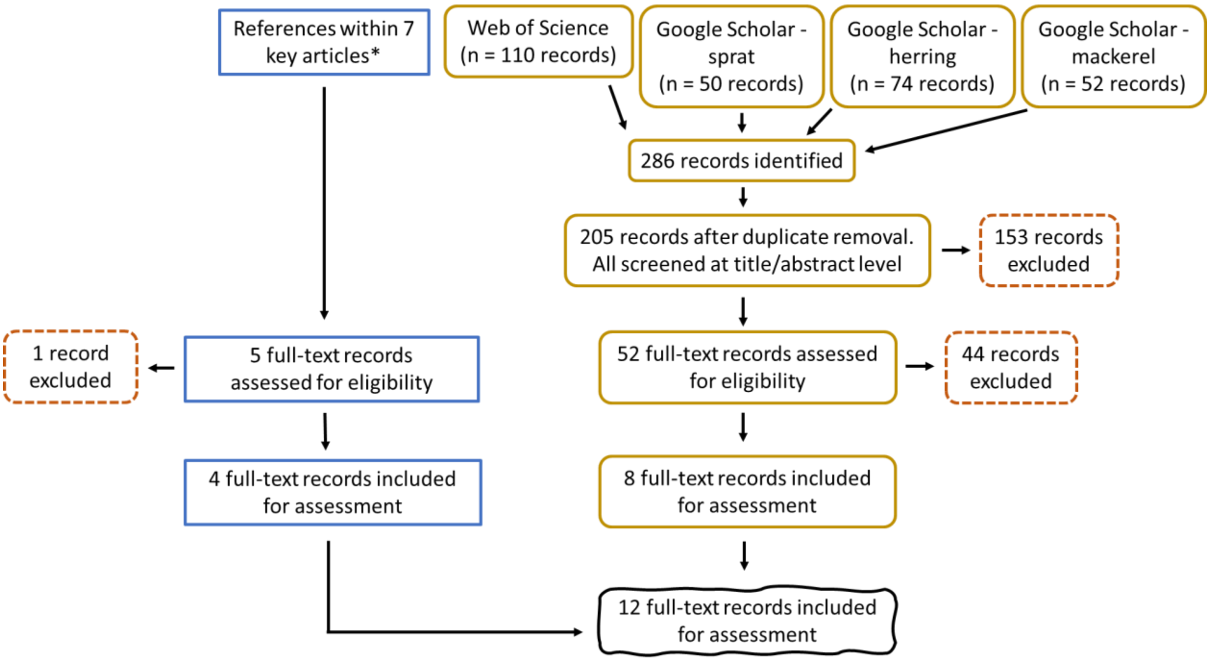

Figure 10. Flow diagram depicting the study selection process for the systematic review on fishery closure or enhanced management of prey fisheries. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: (Furness et al., 2013); Heath et al. (2017); (Furness, 2021; Pearce-Higgins et al., 2021; Cunningham et al., 2022; McGregor et al., 2022; Montevecchi, 2023).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

Overall, 12 references were included for the final review.

5.2.4 Results

5.2.4.1 General observations

We identified 12 references that met our criteria of measuring the effect of management of fisheries targeting seabird prey fish populations to affect seabird populations, all published in English. The literature review yielded publications ranging from 2006 to 2023 (Figure 11A). The median publication date is 2014. The years 2011, 2014, and 2021 had multiple publications. Most references were research articles (58%), but we also identified three review articles, one book chapter, and one commissioned report (Figure 11B).

Most studies, 58%, considered the impacts on seabird populations from fisheries management indirectly (Figure 11C). That is most studies did not include an experimental design approach (either using an experimental manipulation or opportunistically following changes in fishery management) where responses could be assessed before/during/after changes in fisheries management. Two studies did assess impacts directly, either via simulation or in an opportunistic study following seabird populations before/during/after changes in fisheries management. Finally, three studies were classified as opinion based which were in all cases narrative-based reviews thus did not include any quantitative or qualitative analysis of data. A variety of demographic related parameters were considered by the studies (Figure 11D), with productivity and population size the most common. Four studies did not clearly assess any specific demographic parameter (indicated by NA in Figure 11D); these were all review/report-based studies that had more general discussions on impacts on seabird populations that didn't consider specific parameters (e.g. by instead assessing on a vulnerability scale). Many of the studies included multiple prey species (Figure 11E), of the three focal prey species in this review, sprat was most common (83%), followed by herring (67%), and mackerel (33%). Several studies included additional prey species (58%), these were mostly international studies or those including Sandeel which were excluded from this review given the focal review considering this fishery management (see Ecological feasibility: Sandeel fishery closure). One of the review inclusion criteria (Table A 2) was that studies included the North Atlantic or Europe, which is reflected in the geographical distribution of studies (Figure 11F), however as several studies included multiple locations/regions (particularly reviews) a number of sites beyond this were included.

Most studies combined multiple types of data collection, usually using fisheries-based statistics for prey fish, and colony observations for the seabirds studied. Analyses included more basic correlational studies and those using more sophisticated multivariate models. A few studies used ecosystem models either directly (i.e. bespoke for a given study) or indirectly (in review based studies where previous ecosystem modelling was considered). Three studies (Cury et al., 2011; Smith et al., 2011; Free et al., 2021) undertook analysis of multiple prey-predator systems (all including datasets from Scotland) seeking to come to more general results on the relationship between prey fish biomass and their predators (all including seabirds, though two also including other marine predators).

Though several of the studies included at least some of the same study systems (e.g. North Sea or California Current) only a few authors contributed to more than one of the 12 studies, with six authors appearing twice, all others only appeared once.

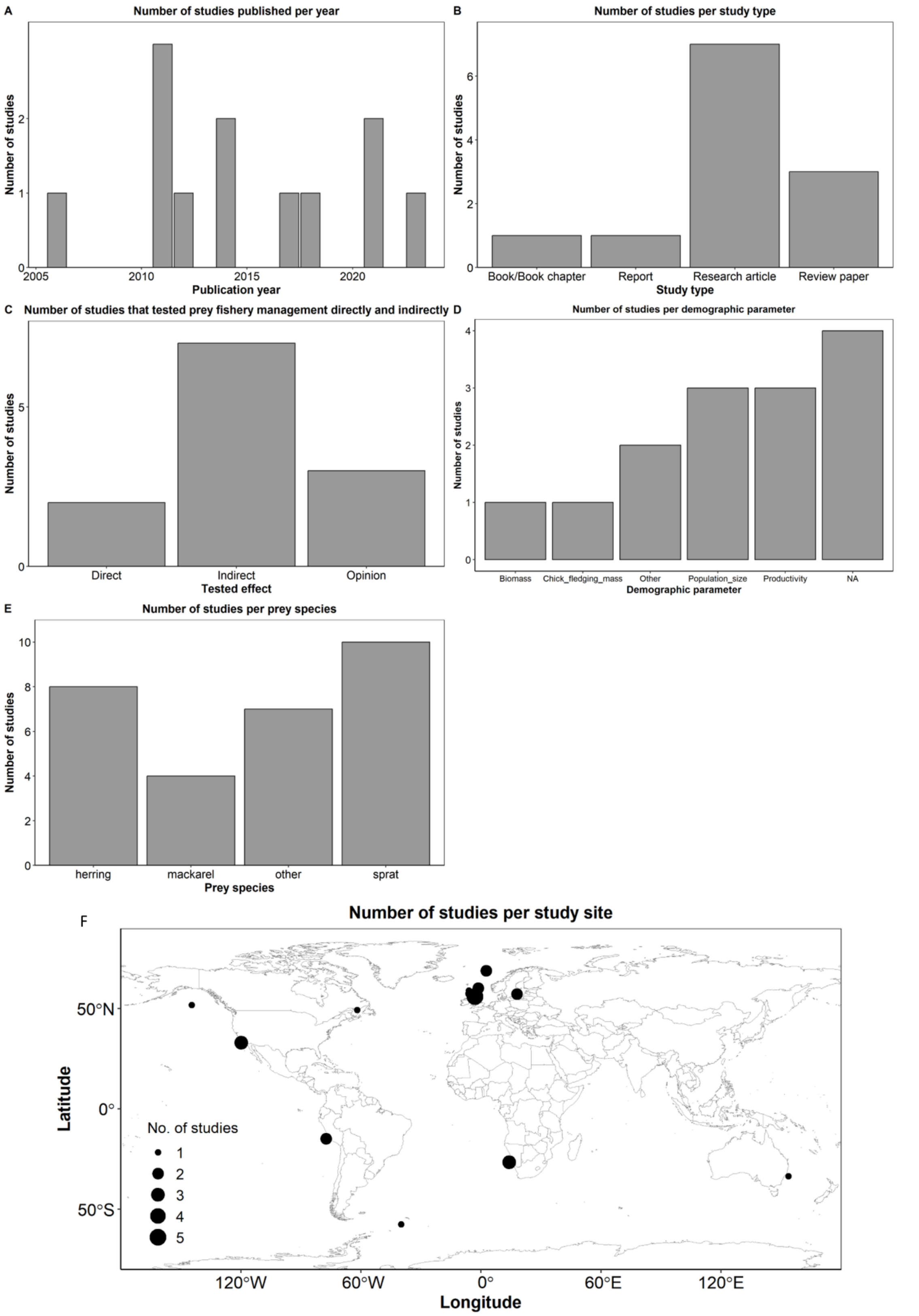

Figure 11. General observations of assessed records for the review on fishery closure or enhanced management of prey fisheries. A) number of studies published per year. B) number of studies per study type. C) number of studies that measured, directly or indirectly, the impact of management of fisheries on seabirds. D) number of studies per studied

demographic parameter; other = foraging distribution (GPS tracking or at sea abundance). E) number of studies per prey species. F) number of studies per study region. Some studies considered multiple demographic parameters and/or prey fish species and/or locations, so are included multiple times in Figures E-F.

5.2.4.2 Evidence scoring

The relevance, as well as the ecological efficacy scores for all 12 references are shown in Table 21 and Figure 12 (refer to Annex 4 for a detailed breakdown of the extracted data for each study). All studies suggested potential for some beneficial effect on at least one seabird species from management of fisheries targeting seabird prey fish species. However, the strength of an effect varied and, in several cases, while it was concluded that fisheries could impact prey availability to seabirds, this would only be significant if fishery activity were to increase.

The ecological efficacy, i.e. the likelihood that changes in the management of fisheries targeting seabird prey fish species is beneficial on at least one seabird demographic parameter, varied between studies. Out of a maximum possible score of 25, scores ranged between 1 and 12. The median score is 8.

For most of the studies included authors did not specifically compare between specific changes in management (reflected in all except one being assessed as providing non-direct evidence –Table 21). Rather most studies were focussed on either: identifying thresholds (e.g. ultimately equating to stock biomass but often expressed in relation to fisheries catch targets which for many species are currently based on maximum sustainable yield – MSY); on determining the relative balance of top-down (including predation, mostly from piscivorous fish, and fisheries removals) and bottom-up processes (for most prey species this equates proximally to zooplankton abundance and energy content which ultimately is primarily driven by primary productivity); or in reviewing previous studies. As such the ecological efficacy score here more reflects evidence that changes in fisheries management could affect seabird populations rather than more directly demonstrating a benefit.

The sum of all final weighted scores (i.e. the mean of ecological efficacy weighted by relevance) is 6.9. Therefore, it can be concluded that the evidence supports management of fisheries targeting seabird prey fish species being of benefit to seabirds, to a low-medium degree (Figure 12). However, as previously discussed, the potential for seabird populations to benefit will depend on the current fisheries management (i.e. to what extent fisheries pressure can be reduced with enhanced management).

Ecological feasibility: Management of prey fisheries

Table 21. Relevance and ecological efficacy scores of each assessed study of enhanced management of fisheries targeting seabird prey fish species. Relevance scores (in bold) could have a potential score between 6 and 30 (6=studies of low relevancy, 30=studies of high relevance). Ecological efficacy scores (in bold) could have a potential score between 0 and 25 (lower scores reflect studies that did not find a strong effect of fisheries management on seabirds, or those with low statistical inference; higher scores reflect studies that found a strong effect of enhanced fisheries management with high statistical inference). SI = Statistical inference and DE = Degree of effect. References are ordered from lowest to highest final ecological efficacy scores (total ecological efficacy score x weight).

	Relevance									Ecological Efficacy			
Reference	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[1] Dickey-Collas et al. (2014)	3	1	5	4	3	3	**19**	0.54	0.080	1	1	**1**	0.080
[2] Heath et al. (2017)	3	1	5	5	5	3	**22**	0.67	0.092	1	1	**1**	0.092
[3] Montevecchi (2023)	3	1	3	1	5	3	**16**	0.42	0.067	1	2	**2**	0.134
[4] Engelhard et al. (2013)	3	1	5	2	3	3	**17**	0.46	0.071	1	2	**2**	0.143
[5] Free et al. (2021)	5	1	4	1	5	5	**21**	0.63	0.088	2	1	**2**	0.176
[6] Hentati-Sundberg et al. (2021b)	5	1	5	2	5	3	**21**	0.63	0.088	4	2	**8**	0.706
[7] Österblom et al. (2006)	5	1	5	2	3	3	**19**	0.54	0.080	3	3	**9**	0.718
[8] Fauchald et al. (2011)	5	1	5	4	3	4	**22**	0.67	0.092	4	2	**8**	0.739
[9] Cury et al. (2011)	3	1	4	1	3	5	**17**	0.46	0.071	4	3	**12**	0.857
[10] Smith et al. (2011)	5	1	3	1	5	5	**20**	0.58	0.084	4	3	**12**	1.008
[11] Guillemette et al. (2018)	5	1	5	1	5	4	**21**	0.63	0.088	4	3	**12**	1.059
[12] Jennings et al. (2012)	5	5	2	5	3	3	**23**	0.71	0.097	3	4	**12**	1.160
Total							**238**					**81**	**6.9**

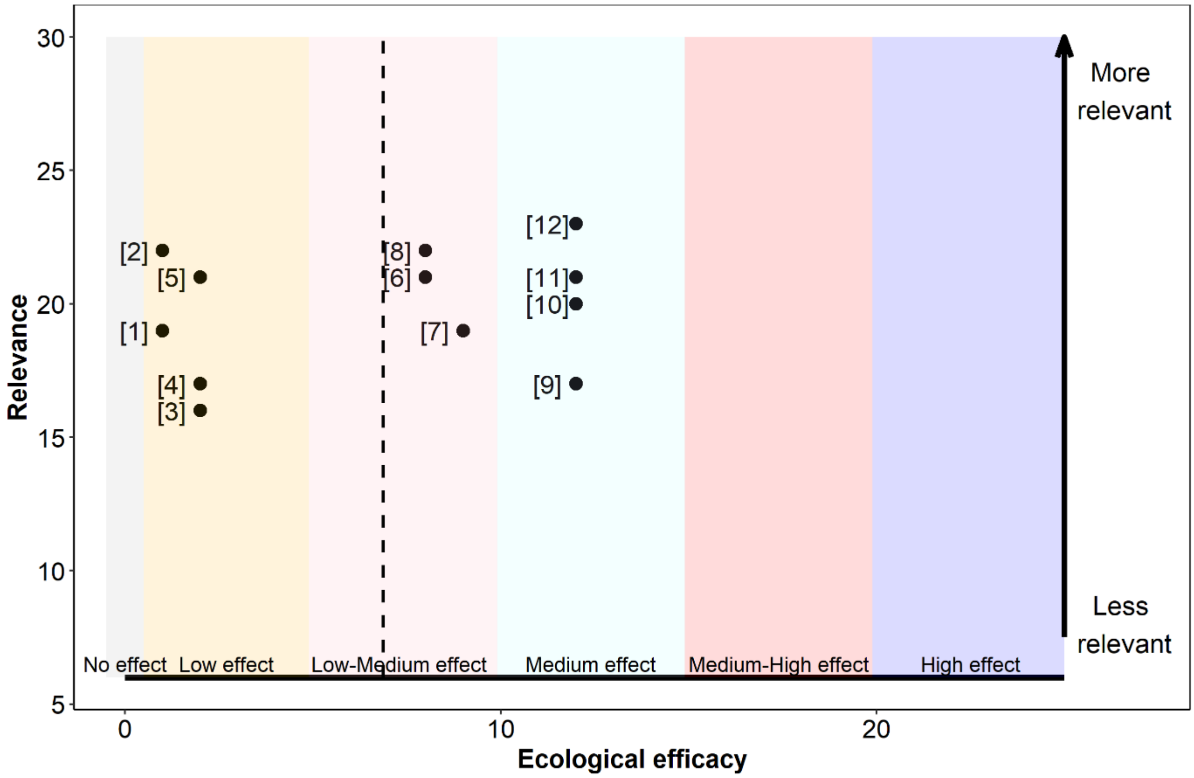

Figure 12. Ecological efficacy and relevance scores for each assessed study of enhanced management of fisheries targeting seabird prey fish species. The numbers correspond to the study identifier, as indicated in Table 21. Colours are used to differentiate the magnitude of the effect that enhanced fishery management (for seabird prey fish species) could have on seabird populations. Vertical dashed line indicates the overall ecological efficacy of enhanced management of fisheries.

5.2.4.3 Overall confidence scoring

We estimated the median of the relevance index score, the independence and quantity of the evidence and the concordance between studies to obtain an overall score to assess the confidence in our findings (see Confidence). The total score for this conservation action was 10 out of the possible 15 (Table 22), suggesting that we have a medium degree of confidence that the assessed estimation of the ecological efficiency is an accurate reflection of the true ecological efficacy of enhanced management of fisheries targeting seabird prey fish species.

Table 22. Assessment of the confidence in the evidence of enhanced management of fisheries targeting seabird prey fish species.

Factor	Results	Score
Median relevancy	Median = 0.60	3
Independence and quantity of evidence	Studies are from a wide range of authors, and study systems, but relatively few studies	3
Concordance	SD = 0.92	4
		Total 10/15

5.2.4.4 Main findings: the effect of management of prey fisheries

In summary, our literature review and respective analyses provide evidence that, with a medium degree of confidence, the enhanced management of fisheries targeting seabird prey fish species has a low-medium effect on at least one demographic parameter of seabirds, but this is highly dependent on the seabird species and the current fisheries management practice (i.e. whether changes in current management would bring benefits to seabirds).

The key findings from the most relevant studies are summarised in Table 23. Overall, the studies all provided at least some support for fisheries management having potential to benefit seabird populations via driving changes in prey availability. Most studies considered fishery impacts (positive or negative depending on the cases studied) on seabirds indirectly via relating prey fish biomass to seabird demographic parameters. In these cases the effects of different fishery management targets (e.g. maximum sustainable yield) were considered indirectly by equating these to the associated fish biomass levels expected for a given fishery stock management targets. Most studies suggested that there was not a simple linear relationship between fish biomass and seabird demography, but rather that at a lower critical threshold of prey biomass, seabird population size would start to be significantly (in some cases dramatically) reduced.

Cury et al. (2011) studied 19 time-series (comprising 14 seabird species) where seabird productivity could be matched to prey fish biomass data. From this they identified a near universal threshold of prey fish biomass where, below one third of historical maximum biomass, productivity began to decline rapidly as biomass decreased further. This level of one third of historical maximum biomass generally occurs at a level of fisheries exploitation below the common fishery target of maximum sustainable yield (MSY). Guillemette et al. (2018) performed a similar analysis though focussed on a single prey-predator system of Gannet and Mackerel in the Gulf of St. Lawrence in Canada. They found a lower threshold of 8% of historical maximum biomass below which productivity declined rapidly. Gannet breeding success was on average 73% (i.e. 73% would successfully raise a chick to fledging each breeding season) when Mackerel biomass levels were greater than 8% of historical biomass but breeding success was only around 31% below this 8% threshold. Smith et al. (2011) undertook a similar analysis to Cury et al. (2011), though instead of time-series analysis they used ecosystem models. They identified that for many top marine predators, including seabirds, negative impacts on the marine predators (as measured in terms of their biomass) generally occurred at fishery exploitation rates below MSY. Free et al. (2021) undertook a similar analysis to (Cury et al., 2011) using time-series data of marine predators and prey, but rather than using productivity rates they used population count data to derive population growth rates (i.e. change in population size over time). For most seabird populations they did not find a relationship between prey fish biomass and seabird population growth rates. Overall, these studies suggested that seabirds will benefit from having fishery targets set slightly below MSY (with the exception of Free et al. (2021)).

The studies above were all focussed on wide spatial scales (whole ecosystems, e.g. North Sea) so did not account for local/regional spatial effects (e.g. potential for local prey depletion). Similar to the studies above, Hentati-Sundberg et al. (2021b) investigated the potential impacts of different fishery targets (on Herring and Sprat) on Guillemot and Razorbill. However, they took a different approach using a spatially explicit simulation model which could account for local prey depletion and travel costs for the seabirds as well as specific traits (e.g. diving depths). Their results were broadly in line with the studies above, finding that successful breeding could generally occur at relatively low biomass levels (equating to less than MSY), though they noted that these findings may be site-specific with potential for different results if modelling other locations (they focussed on a site in the Baltic Sea).

The only study included that directly related changes in fishery management to seabird population responses was Jennings et al. (2012). Their study focussed on Common Tern and Herring in the Firth of Forth, finding that the colony counts for the terns decreased significantly during the period when a fishery was active with a subsequent recovery when the fishery was closed. While this response was quite strong the contrast in prey levels were likely quite large; although Herring levels were not measured in the study it was noted that during the period the fishery was active Herring numbers collapsed.

Several studies took a more holistic approach, reviewing the relative contributions of top-down (both natural predation and fisheries) and bottom-up processes (mediated via zooplankton) in driving prey fish abundance and relating this to seabird populations. Fauchald et al. (2011) studied the North Sea ecosystem, relating seabird abundance during the non-breeding season (at sea abundance) to Herring and Sprat abundance and to zooplankton abundance. They found evidence for both top-down and bottom-up processes operating, which has been termed a wasp-waist system (Cury et al., 2000), as relatively few mid-trophic level species drive the abundance of both lower and higher trophic levels. Fauchald et al. (2011) related their results to fisheries management suggesting that their findings lend support to the potential for the harvest of prey fish by fisheries to affect both lower (zooplankton) and higher (seabirds and other predators) trophic levels. Two studies reviewed the current scientific knowledge of the North Sea ecosystem (Engelhard et al., 2013; Dickey-Collas et al., 2014). Together these found that prey abundance is highly variable and that this is largely driven by climate and natural predation (mostly from predatory fish). They also note potential for fisheries to impact on prey abundance and for this to impact on predators (including seabirds).

Table 23. Summary findings of the six most relevant studies on the effect of enhanced management of fisheries targeting seabird prey fish species, in order of decreasing relevance.

Reference	Results summary
[12] Jennings et al. (2012)	Breeding numbers of Common Terns in the Firth of Forth were compared between four periods during and after the inshore Herring fishing fleet operated. Breeding numbers of the terns dropped significantly when the fishery was active as the Herring stock collapsed, the tern population then began to increase in the eight years following a no-take policy being implemented with the Herring stock recovering.
[8] Fauchald et al. (2011)	The abundance of seabirds at sea observed in the North Sea during winter was related to Herring and Sprat abundance. Seabird numbers (species-specific results were not provided) were higher in winters when Herring abundance was higher but there was no significant relationship with sprat abundance.
[2] Heath et al. (2017)	A workshop was held with invited experts and a literature review undertaken to assess the potential for fisheries in Scottish Waters to affect the availability of prey to seabirds. They also assessed the vulnerability of the seabird populations to prey depletion. They concluded that Kittiwake, Guillemot, Razorbill, and Puffin are potentially vulnerable to fisheries reducing Sandeel abundance. Gannet were assessed to be vulnerable to fishery impacts on Mackerel. Only Puffin were assessed to be vulnerable to fishery impacts on Sprat and Herring.
[5] Free et al. (2021)	They analysed historical time-series for prey and predator abundance (including seabirds) assessing predator population growth rates over time (45 marine predators in 5 regions). Prey abundance levels were related to fisheries management targets (e.g. MSY). Population growth rates were positively correlated with prey abundance for 6 out of the 45 marine predators, 3 of which were seabirds. In most cases there were non-significant correlations and in two cases negative correlations (increasing prey correlated with reduced population growth rates). They concluded that currently prey fish stocks are generally managed at levels that do not adversely affect marine predators.
[11] Guillemette et al. (2018)	The study related Mackerel abundance to Gannet productivity in Atlantic Canada. A threshold of Mackerel biomass (equating to approximately 8% of historical maximum biomass) was identified below which Gannet productivity declined significantly. At these levels Gannets increased time spent at sea and expanded their foraging area (evidence from GPS

Reference	Results summary
	tracking data). Above the 8% stock biomass threshold, productivity was only weakly related to stock biomass. This 8% threshold was somewhat lower than the 30% threshold previously identified across seabird populations Cury et al. (2011)).
[6] Hentati-Sundberg et al. (2021b)	This study took a simulation modelling approach of a Baltic Sea population of Guillemot and Razorbill. It simulated breeding success/failure over the course of the breeding season under varying levels of Herring and Sprat abundance, these set at different fisheries management target stock levels. Razorbill bred successfully at lower prey density than Guillemot (presumed to be due to lower travel costs with lower wing-loading). While Guillemot adults could maintain condition at lower prey densities than Razorbill due to deeper diving (able to access a higher proportion of the prey field). For the modelled colony both species could breed successfully at both current fisheries target (MSY) and the previously recommended 1/3 of maximum historical biomass (see Cury et al. (2011)).

While the majority of studies focussed on prey abundance or overall biomass, Österblom et al. (2006) investigated the effects of both prey quality and quantity (in this case Sprat) on Guillemot as measured by chick fledging weights. They found that Sprat quality (weight-at-age) affected chick fledging-mass, but Sprat abundance did not affect fledging-mass. This result contrasts with most of the studies above, in that this study reported the potential for intermediate levels of fishing to increase Sprat quality (by reducing intra-specific competition) with positive impacts for chick fledging mass.

One study, Heath et al. (2017), was highly relevant as it focussed on identifying fisheries in Scotland where there was potential for ecosystem impacts, including specific consideration of seabirds and their prey species (where these were also target species of fisheries). However, the findings were based principally on expert opinion (via a workshop) rather than empirical study. As such this report sought to identify where there is potential for fisheries to impact prey availability to seabirds (the report covers other aspects of fisheries/ecosystem interactions but those were not relevant to this review) rather than to form firm conclusions on where additional fishery management would be beneficial.

Montevecchi (2023) provides an up-to-date review of global understanding on the potential for fisheries to impact prey availability to seabirds and thus of whether changes in fisheries management could benefit seabird populations (it also covers aspects of seabird/fisheries interactions not pertinent to our review). In contrast to the other three studies included here that have a global focus (Cury et al., 2011; Smith et al., 2011; Free et al., 2021), Montevecchi (2023) does not include any new data analysis nor collation but provides a narrative overview. Overall Montevecchi (2023) concludes that fisheries can impact prey availability to seabirds but that such fishery effects can be swamped by natural variability in prey populations making attributing effects from fisheries on seabird populations challenging.

5.2.4.5 Biases or Conflict of interest

Of the 12 studies, five included potentials for conflicts of interest (note we do not make judgement on whether these lead to an actual conflict of interest or influence study findings but provide the information for the readers' awareness). Two studies were wholly or partly funded by a nature conservation organisation (Österblom et al., 2006; Hentati-Sundberg et al., 2021b), one part-funded by a fisheries sustainability accreditation organisation (Smith et al., 2011), one included an author funded by a (non-fishery) industry organisation (Jennings et al., 2012), and one an author supported by a fishery industry body (Free et al., 2021). The authors of the other studies did not disclose any potential biases or conflicts of interest.

5.2.5 Discussion

Overall, this review found evidence that the enhanced management of fisheries targeting seabird prey fish species can lead to population level benefits to seabird populations. However, this is highly dependent on the seabird species and the current fisheries management. Given the broad scope of this review considering multiple seabird species and prey fish, it was not possible to examine in detail individual species or fisheries (unlike for the review on Sandeel and Kittiwake, see Ecological feasibility: Sandeel fishery closure).

This review was focussed on fisheries targeting seabird prey fish, as such it does not consider all the ways in which fisheries can impact food availability to seabirds. Fisheries can provide direct food subsidies to seabirds via discards and offal provision (Garthe and Huppop, 1996; Votier et al., 2010), though changes in discarding regulations are thought to have reduced the availability of this (Bicknell et al., 2013; Sherley et al., 2020). While intuitively fisheries targeting prey fisheries are expected to have the greatest (fishery) impact on prey availability to seabirds, fisheries of predatory fish can also affect the abundance of prey fish by changing the ecosystem balance and changing levels of natural predation (Furness, 2002; Kadin et al., 2019). Changes in the overall balance between top-down processes (such as predation by predatory fish) and bottom-up processes (e.g. zooplankton abundance) can impact the abundance of low trophic level fish populations (termed forage fish), with fisheries targeting predatory fish having potential to lead to switching between different ecosystem states (termed regime shifts) (Österblom et al., 2006; Bakun et al., 2009). Additionally fisheries can alter fish habitat by the action of the fishing gear leading to physical disturbance to seafloor habitats (Rijnsdorp et al., 2020) (see also: Manage supporting habitats that relate to prey availability for seabirds). While these general principles are understood, these ecosystems have complex interactions which limit our capacity to predict ecological outcomes, including for the well-studied North Sea (Engelhard et al., 2013; Dickey-Collas et al., 2014).

The impacts of prey abundance on seabird populations have been well studied as have the impacts of fisheries on fish populations, however fewer studies have then linked fishing pressure to seabird demography. Ecologically this is fundamentally challenging to study, in part due to the time-lags in population level responses for seabird populations due their late sexual maturity, which should be accounted for in analyses studying drivers of seabird abundance (Sandvik et al., 2012). Meta-analysis type studies, particularly when modelling multiple taxa have often not accounted for this, which could lead to spurious results; this could be an explanation for one of the studies considered in our analysis that found limited evidence for fishery impacts on seabird populations (Free et al., 2021).

Most of the studies included in our analysis considered either productivity or population size, which reflects these being the most easily monitored population traits in seabird populations. However, to gain a more detailed understanding of population drivers there is a need to consider further demographic factors. While productivity and adult survival are often considered as independent traits, there is increasing evidence for carry-over effects between breeding and subsequent over-winter survival leading to these traits being correlated. For example, under low prey abundance during breeding Black-legged Kittiwake had lower over-winter survival (Kitaysky et al., 2010). Similarly in Common Guillemot, in years of high spring sea temperature (which is negatively correlated with various measures of prey quality), fledging success of chicks was reduced and subsequent overwinter survival for the adults birds (Wanless et al., 2023).

The extent to which prey availability, which is a key assumption behind reduced fishery pressure benefitting seabirds, affects seabird populations is context specific. In populations where top-down population processes dominate (e.g. predation) there may be limited, if any, impact from reduced fishing pressure. For example, Pettex et al. (2015) studied how prey availability affected colony establishment and growth in Gannet in Norway, they found that prey did not appear to be limiting factor, with disturbance and/or predation by White-tailed Eagle being the key driver of colony changes.

5.2.5.1 Knowledge gaps and future directions

The relationship between fish abundance and seabird population demography is complex and will rarely follow a linear relationship. Significant negative impacts on seabird populations generally only occur below a lower critical threshold (Cury et al., 2011; Smith et al., 2011; Guillemette et al., 2018). Additionally, seabirds are not solely impacted by prey abundance, but also the quality (e.g. lipid content) (Wanless et al., 2005a; Österblom et al., 2006; Österblom et al., 2008) and the availability of prey (Scott et al., 2006). Spatially explicit ecological models parameterized by empirical data can allow such relationships to be explored to better understand how changes in fisheries management targets could impact seabird populations (Hentati-Sundberg et al., 2021b).

The seas around Scotland are experiencing some of the most rapid rates of warming globally, with the North Sea warming by 1.3 °C between 1982-2006 (Belkin, 2009). This warming is associated with changes in the zooplankton community which is leading to reduced energy availability for forage fish (Olin et al., 2022). These ecosystem changes could mean that changes in fishery management may have less benefit to seabirds, if bottom-up processes become the predominant drivers of prey availability, however, conversely it has also been demonstrated that fisheries can interact with climate change to reduce fish population resilience increasing the chance of abrupt ecosystem change (Möllmann and

Diekmann, 2012). Better understanding how climate change affects marine ecosystems around Scotland would improve our ability to predict how changes in fishery management could affect prey fish, and thus seabird populations, over the longer-term.

5.2.6 Conclusion

Overall, we found that prey fisheries management can benefit seabird populations. However, prey availability to seabirds is determined by many different factors (including climate related factors), with fisheries one amongst these. Whether a population level benefit can be anticipated following changes in fisheries management for a seabird species will require careful consideration of the specific ecological context, and it will rarely be possible to confidently form quantitative predictions on the level of benefit (if any). Current fisheries management rarely fully considers ecosystem impacts, including on seabird populations (ICES, 2023a), therefore, there is potential for seabird populations to benefit from changes to management approaches. Depending on how such management changes are implemented these may have potential in the context of strategic compensation.

5.3 Ecological feasibility: End of the Gannet harvest at Sula Sgeir

5.3.1 Summary

The systematic literature review and respective analyses provide evidence that, with a high degree of confidence, the cessation of chick and/or egg harvest has a low to medium effect on at least one demographic parameter of seabirds. We consider this conservation action to be less suitable as strategic compensation, as it would primarily benefit individuals from specific SPAs (i.e. Sula Sgeir in this case), resulting in potentially low overall impact at the Scottish and UK level.

5.3.2 Introduction and background

Historically, seabirds have been harvested worldwide for their eggs, meat, and down as a means of subsistence, recreation, and commercial gain (Merkel and Barry, 2008; Naves and Rothe, 2023). For certain cultures, this activity continues to represent a crucial element of their cultural heritage (Baldwin, 2012; Fyfe and Davis, 2015; Jones et al., 2015; Henri et al., 2020). However, harvests have been identified as a threat to some seabird populations (Le Corre and Bemanaja, 2009; Chen et al., 2015; Mondreti et al., 2018) and have played an important role, alongside other factors (e.g. environmental conditions, food supply, predation), in the decline, extirpation, and extinction of others, such as Little Auks *Alle alle* (Jakubas et al., 2022), Great Auks *Pinguinus impennis* (Serjeantson, 2001; Thomas et al., 2019), and Chinese Crested Terns *Thalasseus bernsteini* (Chen et al., 2015). For example, population viability analyses on the now-extinct Great Auk revealed that even if it had not been under threat by environmental changes, human hunting alone could have been sufficient to cause its extinction (Thomas et al., 2019).

Seabirds are one of the most threatened group of birds and many populations are rapidly declining (Croxall et al., 2012). They are highly sensitive to human exploitation as they have slow population growth; they are mostly long-lived, have high adult survival rates but low immature survival, have delayed maturity and can, when conditions are poor, skip breeding seasons (i.e. sabbaticals), and they produce small clutch sizes (Schreiber and Burger, 2001; Young and VanderWerf, 2023). This life history strategy makes seabird populations particularly susceptible to exploitation of adults. Species like Gannets, that nest colonially, have high philopatry, breed synchronously and on the ground where eggs, and chicks can be accessed easily, are particularly vulnerable to human harvest (Rodríguez et al., 2019).

Although seabird harvesting is not as important for sustenance as it was in the past, it still has an important traditional and cultural importance (Naves, 2018). Overharvesting can lead to declines in seabird populations, which can have cascading effects on the marine ecosystem. Therefore, egg and chick harvest are strictly regulated by international and national laws and is only permitted in a few places around the world, including Scotland (Denlinger and Wohl, 2001; Merkel and Barry, 2008; Naves and Rothe, 2023). The harvest is usually done by collecting eggs or chicks from nests during the breeding season, but this varies depending on the species and location.

Harvest regulations aim to manage harvests at sustainable levels by balancing harvest quantities and population size, accounting for other factors that may be affecting the populations (e.g. density-dependent processes, predation, bycatch, food availability) (Naves and Rothe, 2023). Therefore, the degree of the harvest (the number, proportions and type of harvest target i.e. eggs, chicks or adults), and the timing of the harvest within the year and within the life cycle of the species, are main factors in determining the potential impacts that harvests have on the targeted and surrounding populations (Hunter and Caswell, 2005; Moller et al., 2009; Lyver et al., 2015; Naves and Rothe, 2023).

The practice of harvesting seabirds in Scotland, primarily for their meat, eggs, oil and fat, dates back to prehistoric times (Best and Mulville, 2016). Even in 1860, seabirds and their eggs continued to play an important role in the economy and culture in several localities throughout the country (Baldwnn, 1974; Baldwin, 2012). In the 19th century, harvesting became more regulated. Complete protection to seabirds was granted in Britain by the Protection of Birds Act, introduced in 1954 but the Wild Birds (Gannets on Sula Sgeir) Order 1955 allowed members from the community of Ness, on the Isle of Lewis, to continue the Gannet harvest (Benn et al., 1989).

Sula Sgeir is a small, uninhabited rocky islet located 18 km west of North Rona (59°5’43.44" N, - 6°9’ 22.6188"W), with a large Gannet breeding colony (Angus and Maclennan, 2015). To date, 2000 Gannet chicks or ‘gugas’, equivalent to at least 17% of annual chick production, can be harvested annually – a quota set by the Scottish Government, with advice from NatureScot (formerly known as the Scottish Natural Heritage) (Wanless et al., 2015). The annual harvest occurs in late August and early September, after most seabird species have ceased breeding reducing potential for disturbance of other species, however, Fulmars (Benn et al., 1989; Angus and Maclennan, 2015) and Storm Petrel will still be present. The harvest itself is believed to be sustainable (in terms of not leading to a population decline), as the 2013 count indicated that the number of Apparently Occupied Sites increased over the previous nine years despite the continued harvesting. This slight increase may, however, be due to immigration of individuals originating from St Kilda and/or Sule Stack (Wanless et al., 2015), and these studies were prior to recent impacts (2022 and 2023) from HPAI which heavily affected Gannet populations across the UK (Tremlett et al., 2024).

Currently, the UK holds 56% of the world’s breeding Gannet populations, the majority of which nest on cliffs or islands in Scotland (JNCC, 2021). It is important to recognise the cultural importance of the harvest, while also working to minimise the negative impacts this may have on Gannet populations. This literature review aims to gather evidence on the impact that egg and chick harvests have on seabird populations to gain a clearer understanding of the possible impacts that the 2000 chick quota may be having on the Sula Sgeir and surrounding Gannet populations.

5.3.3 Methods

The corresponding research question to this conservation action is: ‘Would the Gannet population at Sula Sgeir and/or in the wider SPA network benefit from ending the harvest of Gannet chicks at Sula Sgeir?’

A detailed description of the research question, keywords, search strings, and study selection (Figure 13) is provided in section 3 of Annex 1. Selection criteria can be found in Table A 2.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

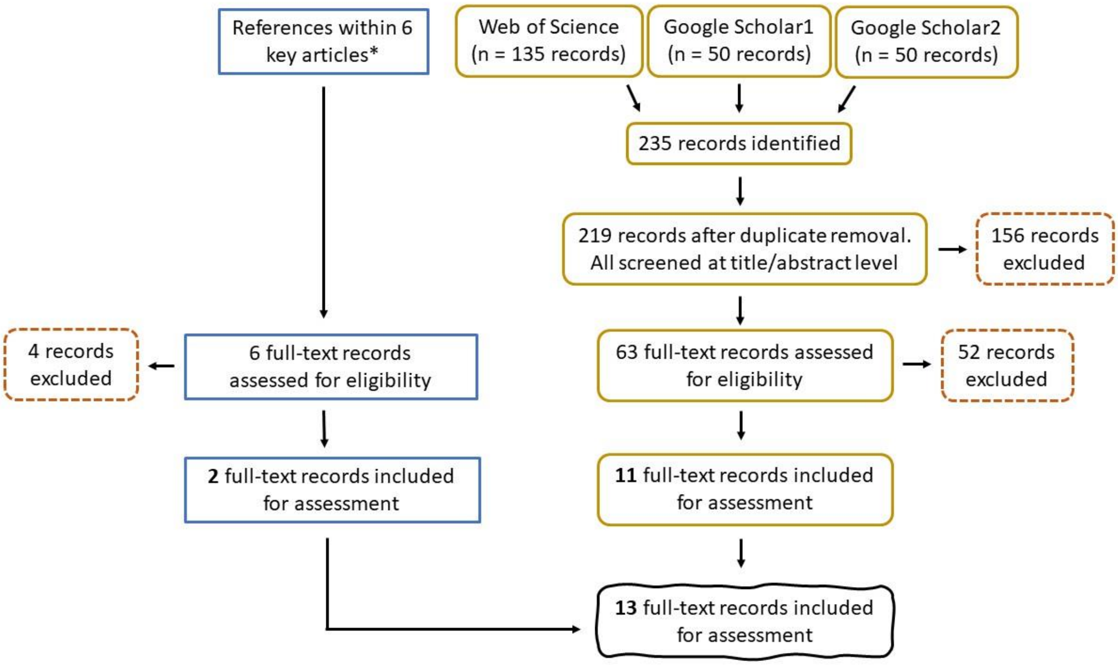

Figure 13. Flow diagram depicting the study selection process for the systematic review on ending the Gannet harvest at Sula Sgeir. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Furness et al. (2013), Trinder (2016), Lewis et al. (2017), Furness (2021), Pearce-Higgins et al. (2021), and Naves and Rothe (2023).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

Overall, 13 references were included for the final review.

5.3.4 Results

5.3.4.1 General observations

We identified 13 references that met our criteria of measuring the effect of chick and/or egg harvest on seabird populations. All of which were published in English. The literature review yielded publications ranging from 2004 to 2018 (Figure 14A). The median publication date is 2013. The year 2015 had the highest number of publications among the identified references. References were either research articles or reports, representing 85% and 15%, respectively (Figure 14B). No review papers were included for the final assessment. Most studies (77%) measured or assessed the impact of chick and/or egg harvest indirectly, either by employing population models or by simulating population trends under different levels of harvest intensity rates (Figure 14C). On the other hand, 22% of the studies used empirical data to compare demographic parameters between harvested and neighbouring unharvested colonies with seemingly comparable environmental conditions (Figure 14C).

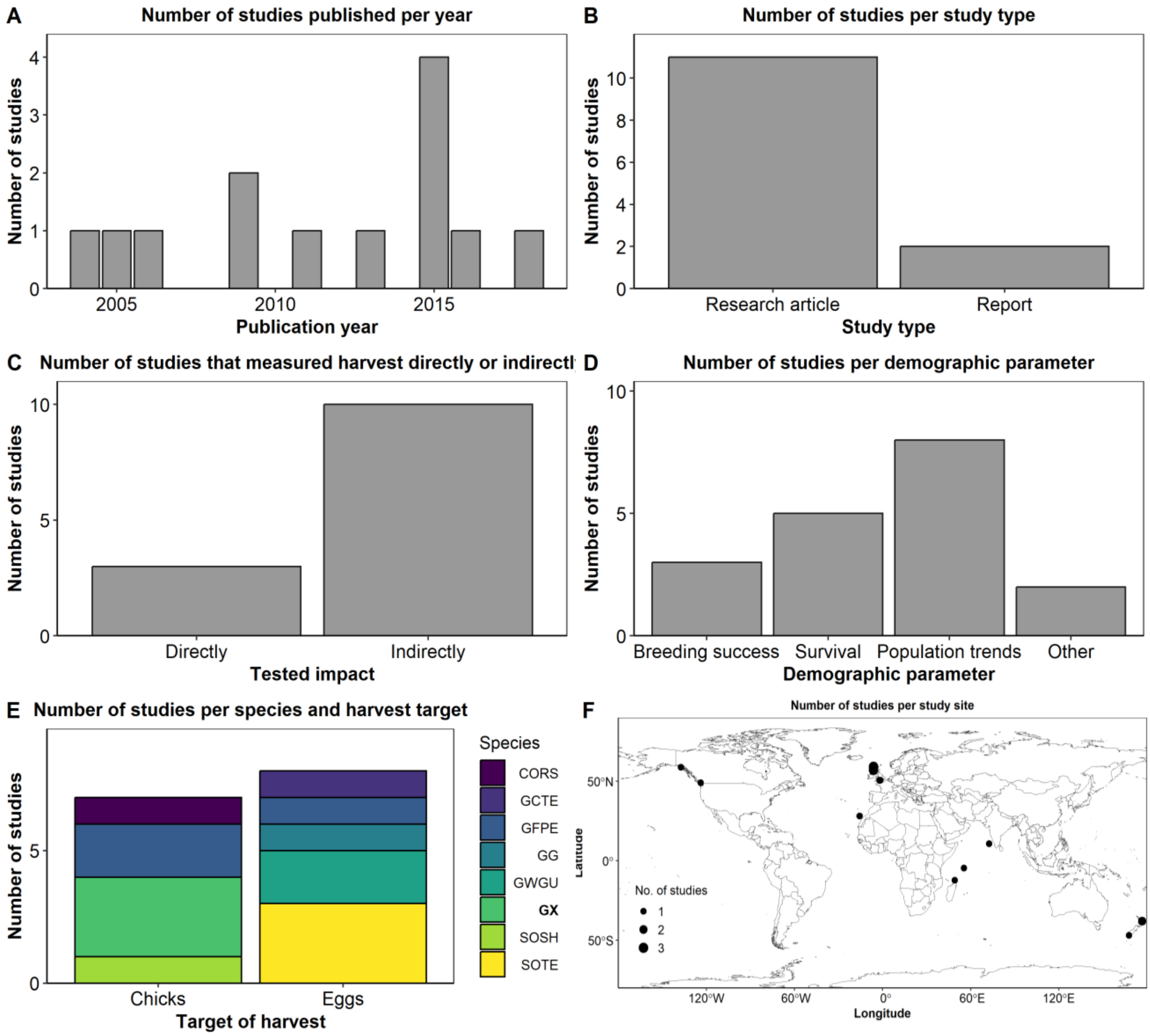

Figure 14. General observations of assessed records for the ending chick and/or egg harvests review. A) number of studies published per year. B) number of studies per study type. C) number of studies that measured, directly or indirectly, the impact of chick and/or egg harvest. D) number of studies per studied demographic parameter. Other = predation rates and egg quality. E) number of studies per species and harvest target: CORS = Cory's Shearwater, GCTE = Great Crested Tern, GFPE = Grey-faced Petrel, GG = Black-headed Gull), GWGU = Glaucous-winged Gull, GX = Gannet (in bold), SOSH = Sooty Shearwater, SOTE = Sooty Tern. F) number of studies per study site.

Most studies (62%) analysed or modelled the impact of chick and/or egg harvest on population trends, 39% on survival rates, 23% on productivity or breeding success, and 15% on other parameters such as predation rates and egg quality (Figure 14D). Half of the studies explored the effect of chick harvest and the other half the effect of egg harvest. Note that Figure 14E does not reflect the latter statement, as one reference studied the effect of egg harvest on two different seabird species. Studies focussed on several seabird species (listed from most studied to least): Sooty Tern (*Onychoprion fuscatus*; 'SOTE'), Gannet ('GX'), Grey-faced Petrel (*Pterodroma gouldi*; 'GFPE'), Glaucous-winged Gull (*Larus glaucescens*; 'GWGU'), Cory's Shearwater (*Calonectris borealis*; 'CORS'), Great Crested Tern (*Thalasseus bergii*; 'GCTE'), Sooty Shearwater (*Ardenna grisea*; 'SOSH'), and Black-headed Gull (*Chroicocephalus ridibundus*; 'GG') (Figure 14E). All Gannet-related studies explored the effect of chick harvest. Studies collected, analysed, or simulated data from the UK, Spain, Madagascar, Seychelles, India, New Zealand, USA, and Canada (Figure 14F). In the UK, three records investigated the population trend of the Sula Sgeir Gannet population (Furness et al., 2013; Murray et al., 2015; Trinder, 2016), and one study explored the impact of egg harvesting on breeding success of Black-headed Gulls in Hampshire and Dorset in southern England (Wood et al., 2009).

The most frequent data collection methods were observational field data, nest monitoring, aerial and terrestrial surveys, harvest observations, ringing, questionnaires, and interviews. Numerous studies utilised population models and simulations as analytical tools. Most of the authors contributed to only one of the included references.

5.3.4.2 Evidence scoring

The relevance, as well as the ecological efficacy scores for all 13 references are shown in Table 24 and Figure 15 (refer to Annex 4 for a detailed breakdown of the extracted data for each study). Overall, references were of medium relevancy for our assessment, with only three studies surpassing 20 points. Scores ranged between 13 and 26 out of a maximum possible score of 30, with a median and mean score of 17 and 18, respectively. For this reason, studies varied in their associated weight, ranging from 0.057 to 0.114 (Table 24).

The ecological efficacy, i.e. the likelihood that ceasing chick and/or egg harvest is beneficial on at least one seabird demographic parameter, varied between studies. Out of a maximum possible score of 25, scores ranged between 3 and 16. The median score is nine. This conservation action, however, is peculiar. Any degree of chick or egg harvest will undoubtedly have detrimental effects on seabird populations. This is because individuals are being taken out artificially and not replaced. The only exception to this is when eggs are harvested at the start of the season, provided that the birds relay. Therefore, it is important to note that the focus of most studies was not on testing the direct effect of the conservation action itself, ending the harvest, but rather on measuring or simulating the impact of the effect of the harvest on seabird populations. We, therefore, assumed that a strong negative effect of harvest would indicate a high beneficial effect if the conservation action were to be implemented. Hence, to estimate the degree of the effect we considered the proportion of chicks and/or eggs being harvested, the degree of the effect discussed by authors, and the status of the species. The low to medium scores reflect the degree of statistical inference (e.g. weak statistical power) rather than the degree of effect.

Ecological Feasibility: End of Gannet harvest

Table 24. Relevance and ecological efficacy scores of each assessed study on ending chick and/or egg harvest review. Relevance scores (in bold) could have a potential score between 6 and 30 (6=studies of low relevancy, 30=studies of high relevance). Ecological efficacy scores (in bold) could have a potential score between 0 and 25 (lower scores reflect studies that did not find a significant effect of ending the chick and egg harvest, or those with low statistical inference; higher scores reflect studies that found a strong beneficial effect of ending harvests with high statistical inference). SI = Statistical inference and DE = Degree of effect. References are ordered from lowest to highest final ecological efficacy scores (total ecological efficacy score x weight).

	Relevance									Ecological Efficacy			
Reference	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[1] Feare and Doherty (2004)	5	1	1	1	2	3	**13**	0.29	0.057	2	2	**4**	0.228
[2] Furness et al. (2013)	3	1	5	5	3	2	**19**	0.54	0.083	1	3	**3**	0.250
[3] Le Corre and Bemanaja (2009)	5	5	1	1	3	1	**16**	0.42	0.070	1	4	**4**	0.281
[4] Lyver et al. (2015)	5	1	1	1	5	4	**17**	0.46	0.075	3	2	**6**	0.447
[5] Zador et al. (2006)	5	1	1	1	3	2	**13**	0.29	0.057	3	3	**9**	0.513
[6] Jones et al. (2015)	5	1	1	1	5	1	**14**	0.33	0.061	3	3	**9**	0.553
[7] Mondreti et al. (2018)	5	1	1	1	5	2	**15**	0.38	0.066	2	5	**10**	0.658
[8] Blight et al. (2015)	5	1	1	1	5	5	**18**	0.50	0.079	3	3	**9**	0.711
[9] Hunter and Caswell (2005)	5	1	1	1	3	3	**14**	0.33	0.061	4	3	**12**	0.737
[10] Murray et al. (2015)	5	1	5	5	5	5	**26**	0.83	0.114	3	3	**9**	1.026
[11] Trinder (2016)	3	1	5	5	5	5	**24**	0.75	0.105	4	3	**12**	1.263
[12] López-Darias et al. (2011)	5	5	1	2	3	3	**19**	0.54	0.083	4	4	**16**	1.333
[13] Wood et al. (2009)	5	5	1	4	3	2	**20**	0.58	0.088	4	4	**16**	1.404
Total							**228**					**119**	**9.4**

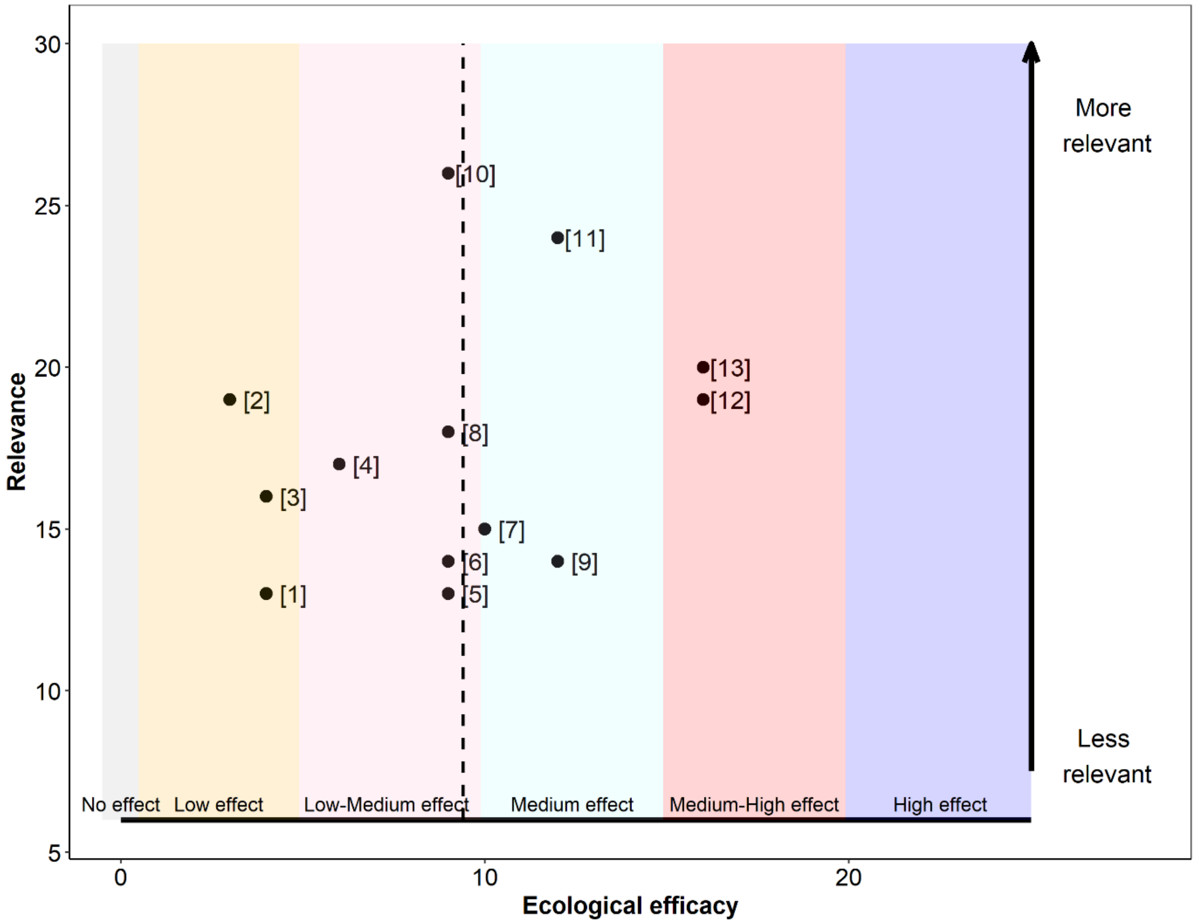

Figure 15. Ecological efficacy and relevance scores for each assessed study on the effect of ending chick and/or egg harvests. The numbers correspond to the study identifier, as indicated in Table 24. Colours are used to differentiate the magnitude of the effect that ending chick and/or egg harvest would have on at least one seabird demographic parameter. Vertical dashed line indicates the overall ecological efficacy of ending harvests.

The sum of all final weighted scores is 9.4 (i.e. the mean of ecological efficacy weighted by relevance), therefore, it can be concluded that the evidence overall support that ending chick and/or egg harvest will benefit seabirds to a low-medium degree (Figure 15), although, as discussed previously, the proportion of chicks and/or eggs being harvested and the conservation status of the affected species will play a major role in this effect.

5.3.4.3 Overall confidence scoring

We estimated the median of the relevance index score, the independence and quantity of the evidence and the concordance between studies to obtain an overall score to assess the confidence in our findings (see Confidence). The total score for this conservation action was 11 out of the possible 15 (Table 25), suggesting that we have a high degree of confidence that the assessed estimation of the ecological efficiency is an accurate reflection of the true ecological efficacy of ending harvests.

Table 25. Assessment of the confidence in the evidence for ending chick and/or egg harvests.

Factor	Results	Score
Median relevancy	Median = 0.46	3
Independence and quantity of evidence	Studies are from wide range of authors, study systems, Limited number of sites, 20–50 studies	4
Concordance	SD = 0.80	4
		Total 11/15

5.3.4.4 Main findings: the effect of ending Gannet chick and/or egg harvest

In summary, our literature review and respective analyses provide evidence that, with a high degree of confidence, the cessation of chick and/or egg harvest has a low-medium effect on at least one demographic parameter of seabirds, but this is highly dependent on the proportion of the population being harvested, the conservation status of the species, and the timing of the harvest within the year and within the life cycle of the species.

The key findings from the most relevant studies are summarised in Table 26. Overall, chick and/or egg harvest is shown to negatively impact seabird populations. For example, one study investigated the changes in Glaucous-winged Gull populations over the course of a century (Blight et al., 2015) and suggest that the strong population increases observed during the mid-1900s correspond with the passing of the 1917 Canadian Migratory Birds Convention Act that led to the cessation of seabird harvests. Similarly, in India, fishermen were estimated to be harvesting 14–45% of the eggs of an already declining species, the Sooty Tern. At this rate, this unregulated and illegal activity may drive this population to extirpation in the near future (Mondreti et al., 2018).

Studies that directly tested differences between harvested and unharvested sites also found significant differences in breeding success, population trends, and overall survival rates between colonies. In Madagascar, tern colonies were monitored to understand the impact of human harvest. For a colony of Sooty Terns that was intensively harvested for eggs; it was estimated that 66% of the eggs were harvested. Although regulated, the harvest rate is probably beyond the sustainable threshold and may lead to declines (Le Corre and Bemanaja, 2009). On the other hand, a colony of Great Crested Terns increased 10-fold, from 1000 pairs in 1997 to 10840 in 2008 when it became protected, and harvests stopped completely (Le Corre and Bemanaja, 2009). Similarly, on the Canary Islands, the breeding success of Cory's Shearwaters was higher in unharvested colonies compared to harvested colonies, and the colonies with low to medium harvest intensities had higher breeding success than those intensively harvested (up to 63% of chicks) (López-Darias et al., 2011). In southern England, those sites where Black-headed Gull eggs were harvested were characterised by reductions in egg volume, yolk-to-albumen ratio, and eggshell thickness, which translated to poorer breeding success and chick survival (Wood et al., 2009).

Table 26. Summary findings of the five most relevant studies on the effect of ending chick and/or egg harvests, in order of decreasing relevance.

Reference	Results summary
[10] Murray et al. (2015)	Between 2004 and 2013, there was a 22% increase in the number of Apparently Occupied Nests at the Gannet population at Sula Sgeir. There appears to be space for further colony expansion. 2013 counts are the highest recorded since 1985.
[11] Trinder (2016)	The Gannet chick (or 'guga') harvest at Sula Sgeir has reduced the rate of the population growth rate below the level that would be predicted in the absence of harvest. Likely that this has had an effect on other neighbouring populations linked through immigration and emigration (e.g. St Kilda and Sule Stack). Nevertheless, the population has continued to grow, and it seems probable that this would continue to be the case at the current harvest level (of 2,000 chicks per year). Levels above 3,500 chicks are very likely to lead to long-term declines.
[13] Wood et al. (2009)	Harvested sites in England were characterised by reductions in egg volume, yolk-to-albumen ratio, and eggshell thickness, which translated to poorer breeding success and chick survival in Black-headed Gulls. Harvested sites had a higher proportion of abnormal eggs. Floods caused higher losses on the harvested site. The reduced breeding success on harvested colonies is likely to be linked to depletion of the female's endogenous reserves which can also reduce future survival and breeding propensity.
[12] López-Darias et al. (2011)	At the Canary Islands, breeding success was higher during years of lower harvest of Cory's Shearwaters. Chick harvesting has potential to greatly increase the risk of extinction of the species.
[2] Furness et al. (2013)	Ending the Gannet chick harvest at Sula Sgeir would increase productivity and would likely result in more rapid growth of breeding numbers. If management action to increase survival or productivity of Gannet was desirable, the termination of the licenced harvest of young Gannets from Sula Sgeir is the most cost-effective approach in the British Isles.

Although harvests have proven to have a detrimental effect on populations, many studies highlight the cultural and social importance of seabird harvesting for certain cultures around the world. These studies argue that sustainable harvesting practices may even allow for sustained population growth rates and are not necessarily synonymous with declines. For example, Grey-faced Petrels in New Zealand, could potentially sustain a fixed-quota harvest of up to 6,000 chicks or a fixed-proportion harvest of up to 30% of chicks before the population is predicted to decline (Lyver et al., 2015). Harvesting at a fixed intensity but less frequently, earlier in the season and at a fixed quota could further reduce the degree of effect (Feare and Doherty, 2004; Zador et al., 2006; Jones et al., 2015).

Regarding the Gannet population at Sula Sgeir, Trinder (2016) suggested that the harvest has reduced the rate of population growth below the level that would be predicted in the absence of a harvest, and this has likely impacted other neighbouring populations linked through immigration and emigration, such as those from St Kilda and Sule Stack. Nevertheless, the Sula Sgeir population is increasing, and there appears to be space for the colony to expand further, suggesting that the population may not be at maximum carrying capacity with respect to nest sites. In fact, the number of Apparently Occupied Nests increased 22% from 2004 to 2013 (Murray et al., 2015; Wanless et al., 2015). This steady increase could continue despite the current harvest level (of 2,000 chicks per year), but levels above 3,500 chicks would likely lead to long-term declines (Trinder, 2016). Ending the chick harvest would increase productivity and would likely result in more rapid growth of breeding numbers. Furness et al. (2013) concluded that the termination of the harvest would be the most cost-effective approach to increasing survival or productivity for Gannet at the level of the British Isles.

5.3.4.5 Biases or Conflict of interest

The authors did not disclose any biases or conflicts of interest, and our investigation did not reveal any such concerns.

5.3.5 Discussion

All the literature reviewed on this subject agreed that harvesting chicks and eggs undoubtedly affects seabird populations. The degree of this effect, however, depends significantly on the harvest target, the proportion of the population being harvested, the conservation status of the population, the timing of the harvest within the year and within the life cycle of the species, and other population-limiting factors, such as environmental conditions, predation rates, pollution, and diseases.

Gannet survival rates increase with age. In Britain and Ireland, for example, first-year Gannets have an annual survival rate between 0.41 and 0.44, second-, third-, and fourth-year birds have an annual survival rate between 0.82 and 0.90, and adult birds have an annual survival rate of 0.92 (Wanless et al., 2006). The differential survival rates between young and adults, mean that the target of the harvest, whether it is eggs, chicks, or adults have varying effects on population dynamics. Egg harvests, if timed correctly and undertaken earlier in the season, may be less disruptive than chick and adult harvest, as birds can relay and still produce fledglings, depending on the timing of harvest and on food availability (Wood et al., 2009). In contrast, when chicks are harvested, relaying is not possible (it being too late in the season), and birds cannot compensate for the extraction.

The population growth rate of Gannet, like many other long-lived species, is much more susceptible to changes in adult survival than reproduction (Hunter and Caswell, 2005), therefore, adult harvests result in significantly worse population level consequences than both egg and chick harvests. Models using data gathered from Grey-faced Petrels estimated that the population started to decline when 2% or more of adult birds were harvested compared with the threshold harvest of 25% or more of either eggs or chicks (Lyver et al., 2015). Similarly, in Sooty Shearwater a chick exploitation rate of 5% reduces population growth by 0.3%, whereas a 5% adult exploitation reduces population growth by 3% (Hunter and Caswell, 2005). The fact that adults are not harvested in Madagascar may explain the persistence of a large Sooty Tern colony, despite a significant egg harvest of up to 66% (Le Corre and Bemanaja, 2009).

How harvests are managed – the proportion of the population being harvested and the timing and intensity of the harvest within the year – will also determine the degree of effect of the harvest on bird populations. Several studies have identified population- and species-specific sustainable harvest thresholds; 5% of chicks for Sooty Shearwaters (Hunter and Caswell, 2005), 20% of eggs for Glaucous-winged Gulls (Zador et al., 2006) and Sooty Terns (Feare and Doherty, 2004), and 6000 chicks, or 30% of chicks or eggs, for Grey-faced Petrels (Jones et al., 2015; Lyver et al., 2015). Similarly, harvesting at a fixed intensity, with less frequency, and earlier in the season may reduce the negative impacts on reproductive success by increasing the probability of relaying, reducing disturbance, other types of predation, and nest abandonment, and increasing breeding synchrony (Zador et al., 2006; Lyver et al., 2015). However, species of higher conservation concern, especially those with declining populations, should not be harvested under any circumstances, as even relatively small harvests can have detrimental effects on these populations (Chen et al., 2015; Alfaro-Shigueto et al., 2016).

5.3.5.1 Gannets at Sula Sgeir

Gannet lay a single-egg clutch and do not replace lost clutches, therefore, if management regimes were similar, egg and chick extraction may potentially have the same effect on the Sula Sgeir population (except in terms of carry-over effects, see e.g. (Fayet et al., 2016)). Although Trinder (2016) predicted that the current harvest regime has resulted in a small reduction in the population growth rate compared to what would be expected without the harvest, the population had been increasing (2.2% in the last decade) up to that assessment, and Trinder concluded that this growth was likely to continue with the harvest level at that time. As long as the harvest threshold is below 3500 chicks per year, immigration is stable, and environmental conditions remain relatively similar, then the Sula Sgeir population was expected to remain stable or to increase (Trinder, 2016). Given the above, and that Gannet population growth rates are more sensitive to changes in adult survival rates, rather that immature survival rates and breeding success (WWT Consulting, 2012), the Sula Sgeir chick Gannet harvest seems to have had a relatively small effects on Gannet population size over past years.

However, Trinder (2016) proposed that the level of growth observed at Sula Sgeir is only possible in the face of current harvest levels with immigration of Gannet from other colonies. It was calculated that the population requires over 270 breeding age recruits annually from neighbouring colonies, such as St Kilda and Sule Stack. This inevitably means that the harvest reduces the number of recruits available for other colonies, especially those located nearer to Sula Sgeir, although, as Scottish Gannet populations increase, an overall increase in potential recruits is expected. Additionally, at a meta-population level, chick and egg harvesting can lead to population fragmentation and loss of genetic diversity (Naves and Rothe, 2023). As certain colonies are targeted for harvesting, the genetic makeup of the population may become increasingly homogenous, making it more vulnerable to environmental stressors and reducing the overall resilience of the species.

It is unclear how the harvest affects other UK colonies, but the impact, if any, should diminish as the distance from the harvesting site increases (see e.g. Jeglinski et al. (2023)). Ending the chick harvest at Sula Sgeir would enhance breeding success at the colony and potentially accelerate the growth of neighbouring Gannet populations, but may not necessarily lead to significant changes in colonies farther away (e.g. North East Scotland, England).

It is important to note that the impact of harvests is influenced by other factors that limit population growth, including predation rates, pollution, disease, bycatch, and environmental conditions at breeding and non-breeding sites. Therefore, if the harvest were to continue, then the harvest regime, which involves a 2000 chicks per year quota, should be evaluated periodically, and carefully adjusted based on current population trends and environmental factors. This is particularly important given that stochastic events, such as the 2022 outbreak of Highly Pathogenic Avian Influenza (HPAI), can have significant detrimental effects on Gannet (Tremlett et al., 2024; Jeglinski et al., preprint). If other limiting factors are causing population growth to decline, ending, or reducing, the harvest should be considered.

5.3.5.2 Knowledge gaps and future directions

Assessing the relative impacts of harvest and other threats on seabird populations is a challenging task that requires a substantial amount of data and appropriate population modelling frameworks, which are often scarce. Although Before-After-Control-Impact (BACI) studies would be the preferred approach for understanding the impact of ending seabird harvests, they are not always feasible due to illegal harvesting and the difficulty of accurately estimating harvest rates. Additionally, we could not find any records that have measured the effect of ending the harvest in a single colony. It is important to note that population models and simulations are typically used to predict the impact of harvest on seabirds, but they have limitations; the accuracy of these models are highly dependent on the data available, and the parameters used, which are often incomplete, and the degree of uncertainty increases over time when testing the models with multiple years of data. Furthermore, these models rarely model meta-population processes (e.g. immigration/emigration and density dependent processes), although this could now be explored further for Sula Sgeir by building on a recently developed meta-population model by Jeglinski et al. (2023) and Peery et al. (2006). This would be particularly valuable to conduct now that we have updated population counts for key Gannet colonies (including Sula Sgeir) following the HPAI outbreak in 2022/2023 (Tremlett et al., 2024).

It is crucial to recognise that the survival of seabird populations, such as the Sula Sgeir population, is not solely impacted by harvest, but by other factors as well, including bycatch during the breeding period and migration, and HPAI. To make informed decisions about harvest quotas, it is essential to assess the impact of these factors on the population and neighbouring populations and adjust the harvest quota accordingly.

5.3.6 Conclusion

This conservation action is less suitable as strategic compensation since it would provide primarily local benefits (i.e. Sula Sgeir, Sule Stack), limited at the regional level due to metapopulation dynamics, and would likely have a low impact at Scotland and UK level. If the harvest were to continue, regular reviews of the level of harvest should take place, accounting for current stochastic events, such as the HPAI, and involving collaboration between researchers, government, and harvesters.

Any type of seabird harvest will undoubtedly affect seabird populations. The degree of this effect, however, depends significantly on the harvest target, the proportion of the population being harvested, the conservation status of the species, the timing of the harvest within the year and within the life cycle of the species, and other population-limiting factors, such as environmental conditions, predation rates, pollution, and diseases.

The Sula Sgeir Gannet population (the impact of the harvest at Sula Sgeir is considered further in the relevant section in WP2) is subject to a licensed annual harvest of 2,000 full-grown chicks. The harvest occurs over a two-week period towards the end of the breeding season and is restricted to accessible areas. At this stage, most chicks are already well-developed, so are less vulnerable to disturbance meaning that indirect mortality should be low (i.e. mortality to additional chicks beyond those harvested), though levels of additional mortality are not known. Given that the Sula Sgeir Gannet population, as well as most other Scottish Gannet populations, has been increasing[3] and adult mortality has a stronger effect on population growth than breeding success, the harvest does not appear to have had a strong impact on the population persistence but may be affecting the overall population size. While discontinuing the controlled harvest would be expected to accelerate the growth rate of the Sula Sgeir colony and to a lesser extent that of neighbouring populations, the impact at the UK scale is likely be minimal due to the distance and small levels of emigration to Sula Sgeir. In addition to ecological considerations, there are also cultural heritage considerations to ending the harvest, given that the traditional harvest has persisted for centuries.

[3] Prior to the HPAI outbreak which was ongoing at the time of writing.

5.4 Ecological feasibility: Mammalian predator eradication and/or management

5.4.1 Summary

The systematic literature review and respective analyses provide evidence that, with a medium degree of confidence, the eradication and/or control of invasive mammalian predators has a medium effect on at least one demographic parameter of seabirds. The degree of success, however, will depend on the focal seabird species, the mammalian predator that is being eradicated/controlled, the success of post-management biosecurity measures, and external factors (e.g. distance to mainland and other islands, climate change, presence of other predator species, terrain, and level of human activity).

5.4.2 Introduction and background

Invasive alien species (also called invasive non-native species), as defined by the Convention on Biological Diversity (CBD, 2023), are species introduced by humans, intentionally or unintentionally, outside their natural geographic range. These species have a significant impact on native biological diversity in the areas they invade. They share common characteristics such as rapid reproduction and growth, high dispersal ability, generalist foraging strategies, and the capability to thrive in diverse and novel environments. Unlike in their native habitats, invasive species often encounter a lack of natural predators and competitors in the introduced areas, allowing them to flourish and reproduce with minimal constraints (CBD, 2023).

Invasive species are the primary land-based threat to seabird species worldwide (Phillips, 2010; Dias et al., 2019; Spatz et al., 2023a). Seabirds are primarily impacted by invasive species through direct predation at the breeding sites (usually of eggs and young), especially on islands, but are also impacted indirectly through habitat degradation, stress, trampling of nests, disease transmission, and competition. Seabirds have life histories characterised by longevity and low fecundity which make them slow to recover from predation and chronic reproductive failures caused by invasive species. Seabirds have not evolved to respond to terrestrial predation by vertebrate predators, and many seabirds nest in colonies on the ground or in burrows and crevices rendering them more susceptible to predation. In particular, predation by invasive mammals has resulted in the probable global extinction and local extirpations of several seabird species and has contributed to the globally threatened status of many other species (Blackburn et al., 2004).

Predation by invasive mammals, such as rats and cats, is the primary driver behind the decline of seabird populations worldwide (Dias et al., 2019). These species have successfully established themselves on most major islands around the world. Cats and rats, in particular, pose a significant threat due to their ability to target all life stages of seabirds and their proficiency in accessing and preying upon seabird nests, irrespective of their remoteness or inaccessibility (Angel and Cooper, 2006; Jones et al., 2008; Le Corre, 2008). Nonetheless, other medium-sized mammals such as mink, dogs, goats, and foxes have also caused detrimental effects on seabirds (Moore et al., 2003; Davis et al., 2018). The degree of vulnerability to invasive mammals depends on the seabird species according to its size and nesting ecology (Lewison et al., 2012). For example, while nearly all seabird species can be preyed upon by rats, the impact is stronger among smaller species that nest in crevices or burrows compared to those nesting on cliff-tops (Jones et al., 2008).

The eradication and/or control of invasive mammalian species have proven to be an effective conservation strategy for seabird conservation (Genovesi, 2005; DIISE, 2018). There is increasing evidence that implementing eradication and/or control measures targeting invasive mammals can yield substantial benefits for seabird populations breeding on islands. Eradication involves the complete removal of wild populations of invasive species from a defined area, presenting an opportunity for significant long-term benefits. On the other hand, control measures aim to suppress the invasive species population through ongoing removal and control efforts. The decision to pursue eradication or control measures depends on the specific predator and the site where management is being considered. To date, more than 2000 efforts to eradicate invasive vertebrate species, mostly mammals, have taken place on over 800 islands around the globe in 60 countries, with an overall success rate of 88% (DIISE, 2018). These efforts have had significant benefits to seabirds, from increases in productivity and survival, to population growth, distribution expansion, and recolonisation. Jones et al. (2016) reported that 84 out of 87 seabird species exhibited a beneficial trend following mammal eradication on islands.

Scotland, with its abundance of islands, is not exempt from the challenges posed by invasive mammal species. The presence of such species (often multiple species) is confirmed or suspected for many of Scotland's islands (Stanbury et al., 2017). The introduction of rats, cats, mink, and other invasive mammals (invasive here means being present outside of their normal range, e.g. many islands are historically free of rodents) to these islands has had severe detrimental effects on local seabird populations. The aim of this literature review is, therefore, to identify the main mammalian predators in Scotland and gather all available evidence of the effect of mammalian predator eradication and/or control efforts on seabird species, with a focus on our focal species. By examining the effectiveness of predator eradication and/or control efforts, conservation efforts can be better targeted and prioritised to find the most cost-effective solutions, which may have potential as strategic compensatory measures of the impacts of offshore wind farms on seabirds. Additionally, this review aims to identify which seabird species would benefit most from predator eradication or control efforts to strategically target eradication efforts to help protect and conserve our focal seabird species (i.e. those species most likely to be affected by offshore windfarms).

5.4.3 Methods

This conservation action was associated with two research questions. The first, 'What is the potential for seabirds to have increased productivity or survival from mammalian predator eradication/management?' explores the effect of eradication and/or control of mammalian predators on seabird populations. Then the second question, 'Among mammalian predators, which ones offer the most potential for effective eradication and/or management?', aims to identify the mammalian species with higher probabilities of eradication and/or management success.

A detailed description of the research question, keywords, search strings, and study selection (Figure 16) is provided in section 5 of Annex 1. Selection criteria can be found in Table A 2.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

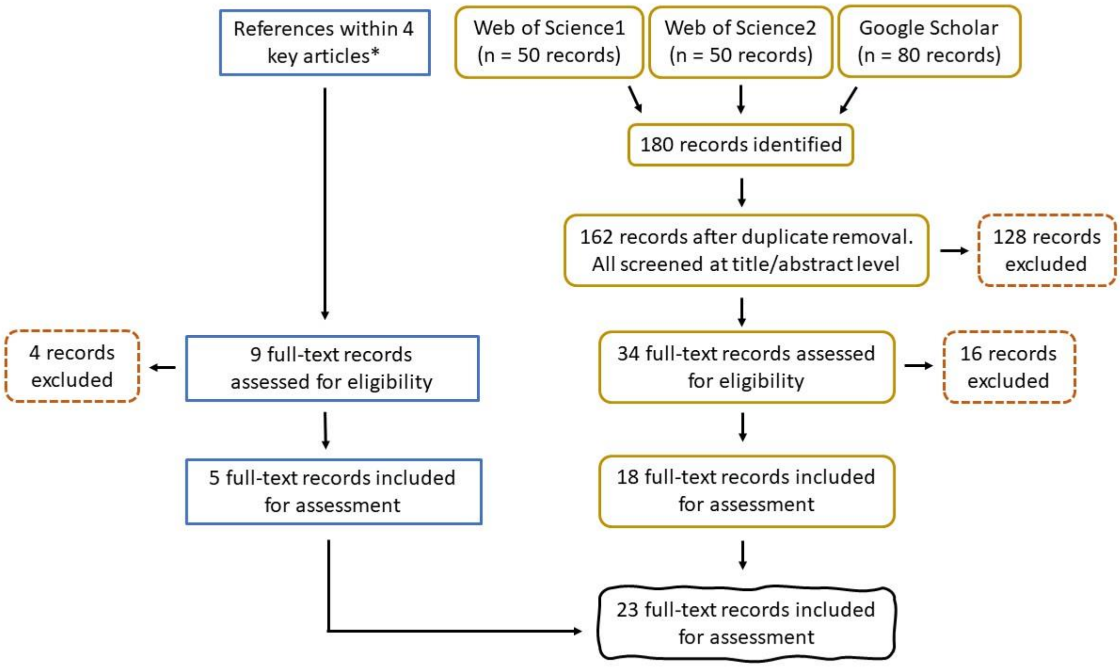

Figure 16. Flow diagram depicting the study selection process for the systematic review on mammalian predator eradication and/or management. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Furness et al. (2013), Veitch et al. (2019), Furness (2021), and Holmes et al. (2023).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

Overall, 23 references were included for the final review.

5.4.4 Results

5.4.4.1 General observations

We identified 23 references that met our criteria of measuring the effect of eradication and control of mammalian predators on seabird populations, all published in English. The literature review yielded publications ranging from 2001 to 2021 (Figure 17A). The median publication date is 2010. The years 2006, 2008, and 2019 had the highest number of publications among the identified references. Most references were research articles (78%), but we also identified two research note articles, a review, a report, and a scientific blog post (Figure 17B). Most studies (96%) measured or assessed the impact of mammal eradication and/or control directly, meaning that the impact on seabirds was measured empirically either by before-and-after studies, or by comparing managed and non-managed sites (Figure 17C).

Studies researched the effect of several mammalian predators on diverse seabird species groups (Figure 17D). Out of the studied mammalian predators, Black rats had the highest number of studies focussed on their eradication and/or control, with 12 studies. Brown rats followed with nine studies, then mink with four, and cats and foxes with two and one study, respectively. Studies focussed on several seabird species groups (listed from most studied to least): petrels and shearwaters (13 studies; i.e. Cory's Shearwater, Manx Shearwater, Audubon's Shearwater, Yelkouan Shearwater, Wedge-tailed Shearwaters, Black-vented Shearwater, European Storm Petrel, Band-rumped Storm Petrel), auks (8 studies; i.e. Atlantic Puffin, Razorbill, Black Guillemot, Ancient Murrelet, Cassin's Auklet, Scripp's Murrelet), gulls (6 studies; i.e. Black-legged Kittiwake, Great Black-backed Gull, Lesser Black-backed Gull, Herring Gull, Common Gull), terns (5 studies; Arctic Tern, Common Tern, Little Tern, Sooty Tern, White Tern), fulmars (3 studies), European shags (2 studies), and 5 studies focussed on other seabird species (i.e. Ascension Frigatebird, Magnificent Frigatebird, Brown Noddy, Black Noddy, Arctic Skua, Masked Booby, Brown Booby, Red-footed Booby, White-tailed Tropicbird, Red-billed Tropicbird). Note that some reference studied multiple predators and seabird species.

Of the studies analysed, 57% focussed on the impact of mammal eradication/control on breeding success, while 30% studied breeding pairs/population, 26% studied recolonisation, 9% studied survival/population trends, and 13% focussed on other parameters such as population size and burrow occupancy (Figure 17E). Most studies (65%) focussed on mammal eradication, with 39% studying control (one study analysed both) (Figure 17F). Studies were conducted primarily on islands (96%), with only one study on foxes conducted on the mainland. Data was collected, analysed, or simulated from multiple islands across the globe, including the UK and its overseas territories, Canada, French territories in the Indian Ocean, Finland, Malta, USA, Spain, and Mexico (Figure 17G). Within the UK, nine eradication and control projects were carried out, primarily on islands (Figure 17H). These projects included various sites on the west coast of Scotland, such as Handa Island, the Island of Rum, the Uists, Canna Island, Sanday Island, and Ailsa Craig, along with Lundy Island and South Walney in England, and Ramsey Island in Wales (Figure 17H). Of these studies, six examined the impacts of rat eradication, two focussed on mink control, and one on fox control.

The most frequent data collection methods were observational field data, nest monitoring, and surveys. The most frequently employed mammalian eradication methods were poison baiting, followed by traps and shooting. Most of the authors contributed to one reference.

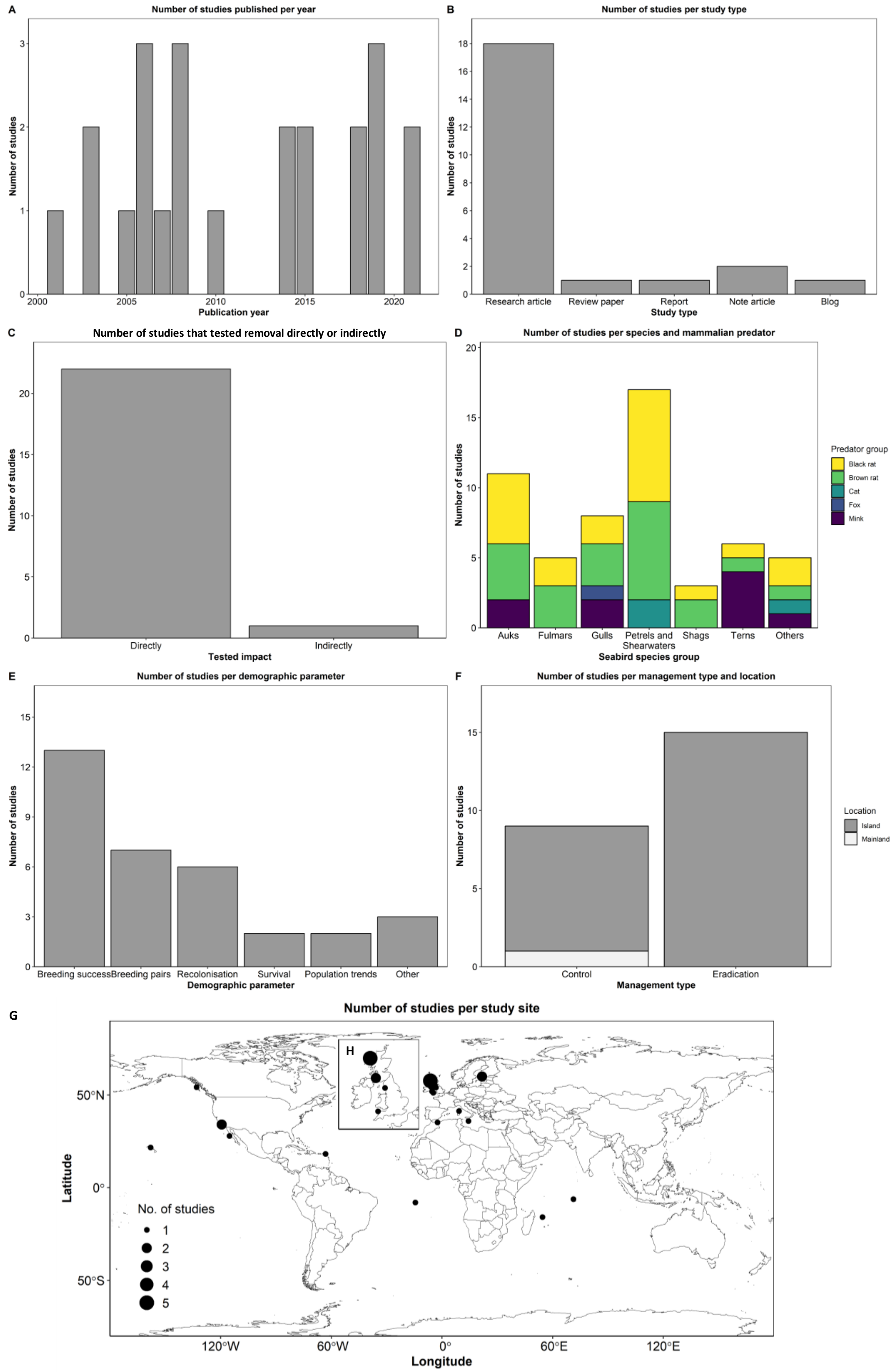
A
Number of studies published per year
Number of studies
Publication year
2000
2005
2010
2015
2020
B
Number of studies per study type
Number of studies
Research article
Review paper
Report
Note article
Blog
Study type
C
Number of studies that tested removal directly or indirectly
Number of studies
Directly
Indirectly
Tested impact
D
Number of studies per species and mammalian predator
Number of studies
Auks
Fulmars
Gulls
Petrels and Shearwaters
Shags
Terns
Others
Seabird species group
Predator group
Black rat
Brown rat
Cat
Fox
Mink
E
Number of studies per demographic parameter
Number of studies
Breeding success
Breeding pairs
Recolonisation
Survival
Population trends
Other
Demographic parameter
F
Number of studies per management type and location
Number of studies
Control
Eradication
Management type
Location
Island
Mainland
G
Number of studies per study site
H
Latitude
50°N
0°
50°S
Longitude
120°W
60°W
0°
60°E
120°E
No. of studies
1
2
3
4
5

Figure 17. General observations of assessed records for mammalian eradication and/or management review. A) number of studies published per year. B) number of studies per study type. C) number of studies that measured, directly or indirectly, the impact of mammalian eradication/control on seabirds. D) number of studies per seabird species group and mammalian predators; others = frigatebirds, noddies, boobies, tropicbirds, and skuas. E) number of studies per studied demographic parameter; other = population size and burrow occupancy. F) number of studies per management type (i.e. eradication or control), and location type (i.e. island or mainland). G) number of studies per study site. H) number of studies conducted within the UK.

5.4.4.2 Evidence scoring

The relevance, as well as the ecological efficacy scores for all 23 references are shown in Table 27 (refer to Annex 4 for a detailed breakdown of the extracted data for each study). Overall, references were of medium-high relevancy for our assessment, with ten studies surpassing 20 points. Scores ranged between 12 and 28 out of a maximum possible score of 30, with a median and mean score of 20. For this reason, studies varied in their associated weight, ranging from 0.026 to 0.061 (Table 27). Out of the assessed studies, all but one suggests that eradication/control efforts had a positive effect on at least one demographic parameter of seabirds. However, the study that did not observe any effect attributed this to the presence of other rodents on the island that began predating seabirds after the target rodent (rats) was eradicated (Lambert et al., 2021).

The ecological efficacy, i.e. the likelihood that eradication/control efforts are beneficial on at least one seabird demographic parameter, varied across studies. Scores ranged between 3 (eradication/control efforts had a low effect on seabirds) and 20 (eradication/control efforts had a strong effect on seabirds) out of a maximum possible score of 25. The median score was 12, indicating that the effect varied according to the study. Half of the studies found a low to medium effect, while the other half found a medium to high effect.

The sum of all final weighted scores is 12.8 (i.e. the mean of ecological efficacy weighted by relevance), indicating that overall, the evidence suggests that mammalian eradication and/or control will benefit seabirds to a medium degree (Figure 18), although, as we will discuss, the degree of this effect is influenced by factors such as the species, of both the predators and the seabirds, the future biosecurity measures and on external factors.

Table 27. Relevance and ecological efficacy scores, of each assessed review. Relevance scores (in bold) could have a potential score between 6 and 30 (6=studies of low relevancy, 30=studies of high relevance). Ecological efficacy scores (in bold) could have a potential score between 0 and 25 (lower scores reflect studies that did not find a significant effect of eradicating/controlling mammalian predators, or those with low statistical inference; higher scores reflect studies that found a strong beneficial effect of eradicating/controlling mammalian predators with high statistical inference). SI = Statistical inference and DE = Degree of effect. References are ordered from lowest to highest final ecological efficacy scores (total ecological efficacy score x weight).

	Relevance									Ecological Efficacy			
Reference	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[1] Keitt and Tershy (2003)	2	5	1	1	2	1	**12**	0.250	0.026	1	5	**5**	0.130
[2] Lambert et al. (2021)	5	5	1	5	5	1	**22**	0.667	0.048	3	1	**3**	0.143
[3] Bright et al. (2014)	5	5	1	1	3	1	**16**	0.417	0.035	2	3	**6**	0.208
[4] Ratcliffe et al. (2010)	5	5	1	1	3	2	**17**	0.458	0.037	3	2	**6**	0.221
[5] Zonfrillo (2001)	2	5	5	5	2	2	**21**	0.625	0.046	2	3	**6**	0.273
[6] Davis et al. (2018)	3	5	5	4	5	2	**24**	0.750	0.052	3	2	**6**	0.312
[7] Ratcliffe et al. (2006)	5	5	1	5	3	2	**21**	0.625	0.046	3	3	**9**	0.410
[8] Lago et al. (2019)	5	5	1	1	5	2	**19**	0.542	0.041	2	5	**10**	0.412
[9] Whitworth and Carter (2018)	2	5	2	1	5	3	**18**	0.500	0.039	3	4	**12**	0.469
[10] Appleton et al. (2006)	5	5	1	4	3	2	**20**	0.583	0.043	3	4	**12**	0.521
[11] Nordstrom et al. (2003)	5	5	5	1	2	2	**20**	0.583	0.043	4	3	**12**	0.521
[12] Whitworth et al. (2015)	5	5	2	1	5	3	**21**	0.625	0.046	3	4	**12**	0.547
[13] Igual et al. (2006)	5	5	1	1	3	2	**17**	0.458	0.037	4	4	**16**	0.590
[14] Marie et al. (2014)	5	5	1	1	3	3	**18**	0.500	0.039	4	4	**16**	0.625
[15] Stoneman and Zonfrillo (2005)	5	5	5	5	3	2	**25**	0.792	0.054	3	4	**12**	0.651
[16] Regehr et al. (2007)	5	5	2	1	3	3	**19**	0.542	0.041	4	4	**16**	0.660

	Relevance									Ecological Efficacy			
Reference	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[17] Luxmoore et al. (2019)	5	5	5	5	5	3	**28**	0.917	0.061	3	4	**12**	0.729
[18] Benkwitt et al. (2021)	5	1	1	1	5	4	**17**	0.458	0.037	5	4	**20**	0.738
[19] Pascal et al. (2008)	5	5	1	1	3	4	**19**	0.542	0.041	4	5	**20**	0.824
[20] Banks et al. (2008)	3	5	5	1	3	4	**21**	0.625	0.046	5	4	**20**	0.911
[21] Le Corre et al. (2015)	5	5	1	1	5	4	**21**	0.625	0.046	4	5	**20**	0.911
[22] Ratcliffe et al. (2008)	5	5	1	5	3	3	**22**	0.667	0.048	4	5	**20**	0.954
[23] Bell et al. (2019)	5	5	1	4	5	3	**23**	0.708	0.050	4	5	**20**	0.998
Total							**461**					**291**	**12.8**

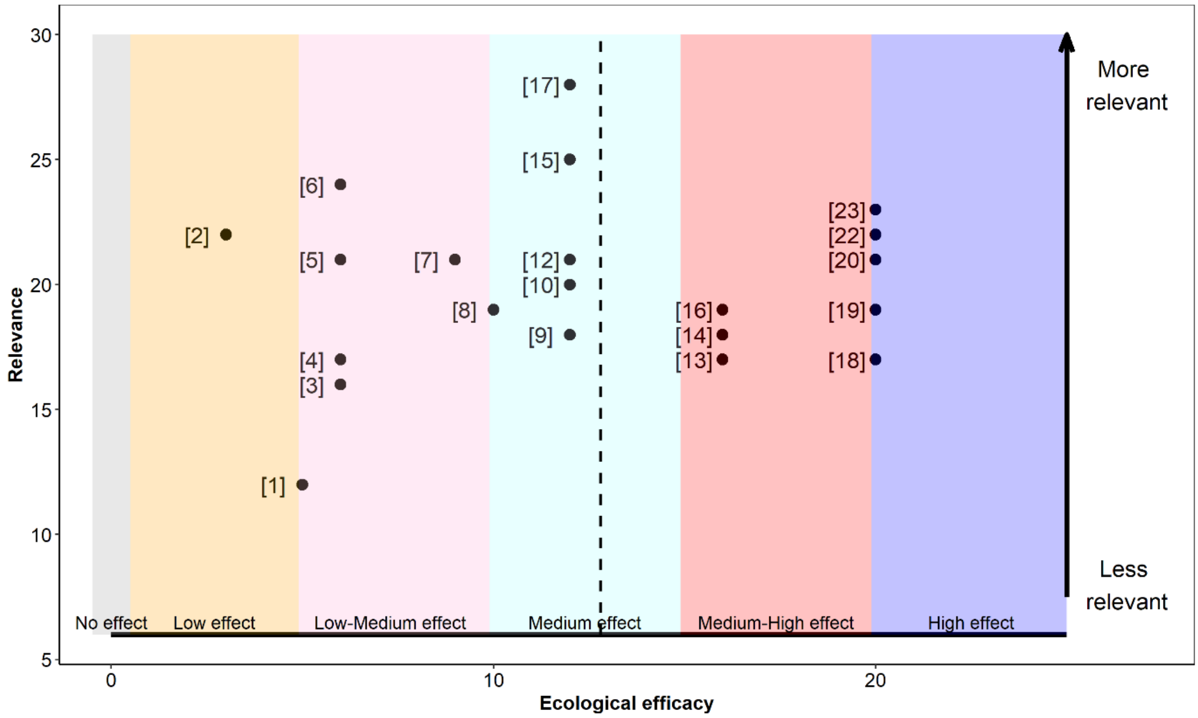

Figure 18. Ecological efficacy and relevance scores for each assessed study on the effect of mammalian predator eradication and/or control on seabirds. The numbers correspond to the study identifier, as indicated in Table 27. Colours are used to differentiate the magnitude of the effect that mammal eradication and/or control have on at least one seabird demographic parameter. Vertical dashed line indicates the overall ecological efficacy of mammal eradication/control.

5.4.4.3 Overall confidence scoring

We estimated the median of the relevance index score, the independence and quantity of the evidence and the concordance between studies to obtain an overall score to assess the confidence in our findings (see Confidence). The total score for this conservation action was 10 out of the possible 15 (Table 28), suggesting that we have a medium degree of confidence that the assessed estimation of the ecological efficiency is an accurate reflection of the true ecological efficacy of mammalian predator eradication/control efforts.

Table 28. Assessment of the confidence in the evidence for eradication and/or control of mammalian predators.

Factor	Results	Score
Median relevancy	Median = 0.58	3
Independence and quantity of evidence	Studies are from wide range of authors, study systems, 20–25 studies	4
Concordance	SD = 1.1	3
	Total	10/15

5.4.4.4 Main findings: the effect of mammalian predator eradication and/or management

In summary, our literature review and respective analyses provide evidence that, with a medium degree of confidence, the eradication and/or control of mammalian predators has a medium effect on at least one demographic parameter of seabirds, but this depends on the seabird species, the mammalian predator that is being eradicated/controlled, the success of post-management biosecurity measures, and external factors.

The key findings from the most relevant studies are summarised in Table 29. Overall, the effect of successful eradication/control efforts had a positive effect on at least one demographic parameter of seabirds. The studies that did not find a significant benefit or found a low benefit attributed this to external factors such as other predators present in the area or environmental conditions, and not to the predator eradication/control *per se* (e.g. Blight et al. (2015)).

Table 29. Summary findings of the six most relevant studies on the effect of mammalian predator eradication and/or control on seabirds, in order of decreasing relevance.

Reference	Results summary
[17] Luxmoore et al. (2019)	Some seabirds show good evidence of recovery since the rat eradication 10 years previously at Canna Island, Scotland. Others, however, have not recovered, most likely due to food shortages or storm events. Increasing populations of Lesser Black-backed Gulls, European Shags, and Common Gulls. Populations of Great Black-backed Gulls and Herring Gulls have stabilised. Guillemots, Razorbills and Kittiwake are still declining but at slower rates. Manx Shearwaters re-established at the main sub-colony and Puffins which were restricted to confined to sea stacks re-established on main island. Fulmars are still declining. Productivity has increased for some species. Overall, the removal of rats from Canna had some very beneficial impacts on some species of seabirds but this effect was masked for other species by some external factors.
[15] Stoneman and Zonfrillo (2005)	Successful eradication of rats from Handa Island, Scotland[4]. Since then, Puffin population increased and expanded, terns increased breeding success, but was variable by years, European Storm Petrels recolonised, and Fulmars did not show any change. Rat eradication has enabled the colony to thrive when conditions are good, but other external factors, such as food supply or weather, may be having an adverse impact on the colony in some years.
[6] Davis et al. (2018)	Enclosure fences were constructed to exclude foxes from gull colonies at South Walney, England. Despite breaching events, the predator-exclusion fencing appeared to have some

[4] Eradication was initially successful but subsequent to this publication, rats recolonised Handa (see Handa Island Newsletter- 2019).

Reference	Results summary
	beneficial effect, with productivity being significantly higher than expected within the fenced areas compared to the unfenced areas. This appeared to be largely due to higher survival at the chick stage, as there was little evidence to show any effect of fencing on nest survival rates, which were high both within and outside the fenced area.
[23] Bell et al. (2019)	The breeding population size of Manx Shearwaters at Ramsey Island, Wales, increased 3-fold and 5-fold, 8 and 17 years after the rat eradication, respectively. Distribution range spread. European Storm Petrels are slowly recolonising and breeding again.
[22] Ratcliffe et al. (2008)	Across west Scotland, Mink have been under a control regime. Common and Arctic Terns had higher breeding success at controlled sites (0.84), compared to uncontrolled sites (0.33). If Mink were to be absent from the entire region, productivity of both tern species would be sufficient to allow increases in numbers to the putative equilibrium number 1.5 times greater than those at present.
[2] Lambert et al. (2021)	Rodenticides were used to control Brown rats on the island of Rum, Scotland. Manx Shearwater breeding success in controlled and uncontrolled sites. The rodenticide treatments did not result in increased Manx shearwater breeding success, and productivity was similar at both sites. These results could be due to an increase of mice and shrews which likely predated the nests. It is highly important to consider all rodent species for a successful eradication programme.

The effect that eradication/control had on seabirds varied strongly on the predator and seabird species. A summary of the effect that eradication and/or control efforts had on seabirds are shown in Table 30. For further details and references see Table A 3.

Table 30. Key findings of the studies for each seabird species within the mammalian predator eradication and/or control on seabirds review . Focal species are highlighted in italics. Information regarding boobies, frigatebirds, noddies, and tropicbirds were excluded as it was deemed less relevant. The effect is colour-coded as follows: red or '=' = no effect, white or '+' = small effect but not enough to reflect a population increase (e.g. populations stabilised or recolonisation but no evidence of breeding or decreased rate of decline), and blue or '++' = effect that led to a population increase (e.g. measured increase in productivity).

Group	Species	Nesting ecology	Predator	Effect	Reference
Gulls	*Great Black-backed Gull*	ground nesting	Rats	+	Luxmoore et al. (2019)
			Mink	=	Nordstrom et al. (2003) and Banks et al. (2008)
	Lesser Black-backed Gull	ground nesting	Foxes	++	Davis et al. (2018)
			Rats	++	Luxmoore et al. (2019)
			Rats	++	Zonfrillo (2001)
	Herring Gull	ground nesting	Foxes	++	Davis et al. (2018)
			Rats	++	Zonfrillo (2001)
			Rats	+	Luxmoore et al. (2019)
	Common Gull	ground nesting	Mink	++	Nordstrom et al. (2003) and Banks et al. (2008)
			Rats	++	Luxmoore et al. (2019)
			Rats	++	Stoneman and Zonfrillo (2005)
	Kittiwake	cliff nesting	Rats	++	Luxmoore et al. (2019)
Auks	*Guillemot*	cliff nesting	Rats	+	Luxmoore et al. (2019)
	Razorbill	cliff and crevice nesting	Rats	++	Zonfrillo (2001)
			Mink	+	Nordstrom et al. (2003) and Banks et al. (2008)
			Rats	+	Luxmoore et al. (2019)

Group	Species	Nesting ecology	Predator	Effect	Reference
	Puffin	burrow nesting	Rats	++	Stoneman and Zonfrillo (2005)
			Rats	++	Luxmoore et al. (2019)
			Rats	++	Zonfrillo (2001)
	Ancient Murrelet	burrow nesting	Rats	++	Regehr et al. (2007)
	Cassins Auklet	burrow nesting	Rats	++	Regehr et al. (2007) and Whitworth et al. (2015)
	Scripp's Murrelet	crevice nesting	Rats	++	Whitworth and Carter (2018)
	Black Guillemot	crevice nesting	Rats	+	Zonfrillo (2001)
Terns (Arctic Tern, Common Tern, Little Tern)	*Terns*	ground nesting	Rats	++	Stoneman and Zonfrillo (2005)
	Terns		Mink	++	Nordstrom et al. (2003) and Banks et al. (2008)
	Terns		Mink	++	Ratcliffe et al. (2008)
	Terns		Mink	++	Ratcliffe et al. (2006)
Fulmar	Fulmar	cliff nesting	Rats	++	Zonfrillo (2001)
	Fulmar		Rats	=	Stoneman and Zonfrillo (2005)
	Fulmar		Rats	=	Luxmoore et al. (2019)
European Shag	Shag	cliff and ground nesting	Rats	++	Luxmoore et al. (2019)
	Shag		Rats	++	Zonfrillo (2001)
Arctic Skua	Skua	ground nesting	Mink	++	Nordstrom et al. (2003) and Banks et al. (2008)
Petrels and Shearwaters	European Storm Petrel	burrow and crevice nesting	Rats	++	Stoneman and Zonfrillo (2005)
	Manx Shearwater	burrow nesting	Rats	++	Appleton et al. (2006)

Group	Species	Nesting ecology	Predator	Effect	Reference
	Manx Shearwater		Rats	++	Bell et al. (2019)
	Manx Shearwater		Rats	++	Luxmoore et al. (2019)
	Manx Shearwater		Rats	+	Zonfrillo (2001)
	Manx Shearwater		Rats	=	Lambert et al. (2021)
	Yelkouan Shearwater	burrow nesting	Rats	++	Lago et al. (2019)
	White-tailed Shearwater	burrow and crevice nesting	Rats	++	Marie et al. (2014)
	Cory's Shearwater	burrow and crevice nesting	Rats	++	Igual et al. (2006)
	Cory's Shearwater		Rats	++	Pascal et al. (2008)
	Madeiran Storm Petrel	crevice nesting	Cats	=	Ratcliffe et al. (2010)
	Black-vented Shearwater	burrow and crevice nesting	Cats	++	Keitt and Tershy (2003)

A total of 16 studies researched the effects of Brown and/or Black Rats on seabird populations, all were conducted on islands across the globe (i.e. rather than mainland sites). These islands ranged in distance from <1 km to 3,200 km from the mainland. Overall, studies demonstrated that rats pose a significant threat to seabirds, and their successful eradication and/or control can have a positive impact on seabird populations (Table 30). Species such as terns (Stoneman and Zonfrillo, 2005), fulmars (Zonfrillo, 2001), Lesser Black-backed Gulls (Zonfrillo, 2001), European Shags, (Luxmoore et al., 2019), Ancient Murrelets (Regehr et al., 2007), Yelkouan Shearwaters (Lago et al., 2019), Wedge-tailed Shearwaters (Marie et al., 2014), Cory's Shearwaters (Igual et al., 2006; Pascal et al., 2008), and Scripp's Murrelet (Whitworth and Carter, 2018) increased breeding success. Puffins (Stoneman and Zonfrillo, 2005; Luxmoore et al., 2019), Ancient Murrelets (Regehr et al., 2007), frigatebirds (Bright et al., 2014), boobies (Bright et al., 2014), Manx Shearwaters (Bell et al., 2019), and Scripp's Murrelets (Whitworth and Carter, 2018) increased number of breeding pairs. Kittiwake (Luxmoore et al., 2019), Common Gulls (Luxmoore et al., 2019), Manx Shearwaters (Appleton et al., 2006), Scripp's Murrelet (Whitworth and Carter, 2018), and boobies (Le Corre et al., 2015) populations are increasing or predicted to increase. Cassin's Auklets (Regehr et al., 2007; Whitworth et al., 2015), Storm petrels (Stoneman and Zonfrillo, 2005; Bell et al., 2019), Manx Shearwaters (Zonfrillo, 2001; Luxmoore et al., 2019), and Black Guillemots (Zonfrillo, 2001) recolonised and/or presented evidence of breeding. Herring

Gulls (Luxmoore et al., 2019), Great Black-backed Gulls (Luxmoore et al., 2019), Lesser Black-backed Gulls (Luxmoore et al., 2019) populations stabilised but prior to eradication were declining. Populations of Guillemots (Luxmoore et al., 2019) and Razorbills (Luxmoore et al., 2019) are continuing to decline but at slower rates. Great Black-backed Gull (Zonfrillo, 2001), Manx Shearwaters (Lambert et al., 2021), fulmars (Stoneman and Zonfrillo, 2005; Luxmoore et al., 2019) did not show evidence of beneficial effects.

Four studies researched the effects of Mink on seabird populations, all conducted on islands within Scotland and Finland. The distance from the islands to the mainland varied but were generally close (<150 km). Due to the proximity of the islands to other islands or the mainland, and that mink can swim long distances, mink are hard to eradicate and are therefore usually controlled rather than eradicated. Results from the studies showed varying effects of mink control on seabirds. In the Scottish west coast, terns showed higher breeding success at controlled sites, compared to uncontrolled sites (Ratcliffe et al., 2006; Ratcliffe et al., 2008). In the Archipelago National Park, Finland, Mink have been controlled since the 1990s. The effect it has had on biodiversity has been substantial, with many seabirds, land birds, and water birds having benefited from it (Nordstrom et al., 2003; Banks et al., 2008). Regarding seabirds, Great Black-backed Gulls have not shown signs of change since the control, Razorbills recolonised the sites, and Arctic Skuas, Arctic Terns and Common Gulls increased their breeding success.

The two studies that focussed on feral cat eradication occurred in the tropics. In Ascension Island, a UK overseas territory, feral cats were eradicated (Ratcliffe et al., 2010). The results were highly seabird species-specific. Species that showed population increases were tropicbirds, Masked and Brown-footed Boobies, and Brown Noddies. Other species such as the Madeiran storm petrel, frigatebirds, Red-footed Boobies, and White Terns did not show evidence of population increase or recolonisation. In Natividad Island, Mexico, mortality rates of Black-vented Shearwaters decreased 90% after cat eradication (Keitt and Tershy, 2003).

The single study that focussed on Red Foxes was undertaken in South Walney, England (Davis et al., 2018). Results showed that, for both Lesser Black-backed Gulls and Herring Gulls, the predator-exclusion fence appeared to have some beneficial effect, with productivity being significantly higher than expected within the fenced areas compared to the unfenced areas. This appeared to be largely due to higher survival at the chick stage.

The impact of eradication and/or control measures varied depending on the nesting ecology of birds, as shown in Table 30. Of burrowing nesters, 88% experienced significant positive effects, one record showed a weak beneficial effect, and one record showed no effect. Regarding ground nesting birds, 83% of the records indicated a strong beneficial effect, while 11% showed a weak beneficial effect, and 6% showed no effect. Among crevice nesters, 64% experienced a strong beneficial effect, 27% a weak beneficial effect, and one record showed no effect. As for cliff nesters, 50% of the records displayed a strong beneficial effect, 30% showed a weak effect, and 20% showed no effect.

Furthermore, a review conducted by Brooke et al. (2018) examined the impact of mammal eradication efforts on seabird populations on islands. The authors collected data from the Database of Island Invasive Species Eradications (DIISE, 2018), comprising information on 181 populations of 69 seabird species across 61 islands. The results of this study demonstrate that, following successful eradication, the median population growth rate was 1.119; the number of populations exhibiting positive growth (151 populations) far exceeded those experiencing declines (23 populations), while seven populations showed no significant population change. Authors also identified that population growth was faster at: newly established colonies compared to those already established, during the first few years after eradication, among gulls and terns compared to other seabird groups, and when several invasive mammals were eradicated simultaneously.

5.4.4.5 Biases or Conflict of interest

The authors did not disclose any biases or conflicts of interest, and our investigation did not reveal any such concerns.

5.4.5 Discussion

Overall, evidence suggests that the eradication/control of invasive mammalian species has a beneficial effect on at least one demographic parameter of seabird populations at the breeding sites. These results are also supported by global assessments in recent literature reviews such as those elaborated by Croxall et al. (2012), Jones et al. (2016), Brooke et al. (2018), Sutherland et al. (2021), and Spatz et al. (2023a). These findings are also in common with previous recommendations developed around eradication and biosecurity for UK islands (Stanbury et al., 2017). The degree of this effect, however, is highly dependent on the mammalian predator, the nesting ecology of the seabird species, the success of post-management biosecurity measures, and other external factors.

5.4.5.1 Predators

Findings from this literature review indicate that the impact of eradication/control efforts varied between rats, cats, mink, and foxes, the predominant invasive mammals in Scotland, and their management approach (i.e. eradication or control).

Black and Brown rats are the invasive species with the most devastating impacts on seabird populations and are likely responsible for the greatest number of extinctions and ecosystem changes on islands caused by any predator (Towns et al., 2006; Dias et al., 2019; Spatz et al., 2023a). They pose a significant threat to seabirds as they prey on their eggs, chicks, and, rarely, on adults, and their eradication or control has been proven to have a positive impact on seabird populations (Howald et al., 2007; Jones et al., 2008). Due to their small size, agility, and ability to hide, rats can be difficult to detect when introduced to new sites. Their rapid reproductive rates and ability to exploit various food sources contribute to their successful establishment and population growth.

Globally, rodents have been eradicated from at least 284 islands, with an ~85% success rate; 387 invasive rodent eradication campaigns were recorded, of which 332 were successful, 35 failed, and 20 were of unknown outcome (Howald et al., 2007). Successful rat eradication/control, mostly through poisoning, has led to an increase in breeding success and breeding pairs, to population growth, the recolonisation of previously abandoned breeding sites and the stabilisation or reduced decline rates of several seabird species. However, not all seabirds, like fulmars, have shown immediate beneficial effects, and some studies have even observed coexistence between rats and seabirds (Jones et al., 2008; Quillfeldt et al., 2008).

Medium-sized mammals, such as cats, mink, and foxes, are more easily detectable but pose greater challenges due to their swimming abilities, long distance movements, and adaptability. Control measures, such as trapping or hunting, are often implemented to manage their populations (Nogales et al., 2004). Medium-sized mammalian predators can prey on seabirds at all stages of their life cycle (Spatz et al., 2023a) and just a small number of individuals can have devastating consequences on seabirds, as they can exterminate entire colonies in a short period.

Cats, in particular, are highly adaptable predators that feed on a variety of animals, even when they have had enough to satiate themselves. They have been associated with significant seabird declines and present additional challenges due to their close association with humans. Of the two studies that examined the effects of cat control, one reported increased survival rates on Black-vented Shearwaters (Keitt and Tershy, 2003), but another did not show a significant beneficial effect on Madeiran Storm Petrels (Ratcliffe et al., 2010). American Mink, being semi-aquatic and a generalist predator, can swim to islets at least 2 km from shore, and even further if linked by an island chain (Ratcliffe et al., 2008). They prey on the eggs and chicks of ground-nesting seabirds. Most of the studies demonstrated beneficial impacts on seabirds following mink control, particularly in terms of breeding success but one study reported no effect, potentially due to the specific focal species, the Great Black-backed Gull (Banks et al., 2008). Foxes, known for their intelligence, can also have devastating effects on seabird colonies, impacting breeding success and adult survival. The only study that focussed on them found that excluding foxes had a positive impact on gulls (Davis et al., 2018).

5.4.5.2 Seabirds' ecology

The impact of mammal eradication and control efforts is also influenced by the body size and nesting strategy of seabirds. In Table 30, we categorised seabirds based on their nesting ecology into four groups: (1) burrow-nesting birds, including puffins, petrels, and some species of auklets, which excavate burrows in the soil or utilise pre-existing ones for nesting; (2) ground-nesting birds, such as gulls and certain tern species, which lay their eggs on the ground in open areas or rocky outcrops; (3) cliff-nesting birds, including Guillemot, Razorbill, and Kittiwake, which lay their eggs on narrow ledges along steep cliffs or rocky coastal outcrops; and (4) crevice-nesting birds, such as shearwaters, petrels, and Razorbill, which lay their eggs in narrow crevices or cavities commonly found in rocky cliffs or boulder fields (some species use more than one nesting strategy so appear in multiple groups).

These distinct nesting strategies, along with body size, contribute to differing levels of vulnerability to mammalian predators and can affect the success of eradication and control efforts (Lewison et al., 2012). A meta-analysis conducted by Jones et al. (2008) suggested that smaller birds nesting in crevices and burrows, such as storm petrels, are particularly vulnerable to rat predation. Conversely, larger ground-nesting birds, like gulls, exhibit lower vulnerability. Our findings align with these observations.

Most burrow-nesting birds (auks, petrels and shearwaters) were mainly affected by rats. Most of the studies included in this literature demonstrated strong positive effects of eradication efforts on various aspects of their ecology, such as increased breeding success and survival. The only study that did not show a benefit (Lambert et al., 2021), in Manx Shearwaters, was due to the presence of a second rodent predator and not due to the reduced impact of rat removal. Ground-nesting birds, such as gulls, terns, shags, and skuas, also seem to strongly benefit from control and eradication efforts. These species, nesting in open areas, face threats from all invasive mammals, not only from direct predation, but also from trampling and egg displacement when mammals appear at the colony. However, Great Black-backed Gulls were not significantly affected.

Crevice nesters (auks, petrels and shearwaters) were predated by rats, mink and cats. These nests are sheltered and sometimes hard for predators to reach and find, but their eradication still had beneficial effects. Only one record showed no effect, and it was on Madeiran Storm Petrels. Cliff- nesting birds (Kittiwake, auks, Fulmar, and shags) were the least impacted by rat and mink eradication/control efforts. The nests of these species are usually on steep cliffs, inaccessible to predators, so it is not surprising that their eradication did not have a strong effect on them, especially on Fulmar, which have a highly effective defence mechanism of spitting and deterring predators. If a predator managed to infiltrate the colony though, chaos could ensue, leading to the dislodging of eggs and chicks from the cliffs.

Additionally, differences in susceptibility may be attributed to feeding strategies. Burrow-nesting seabirds, like the Atlantic Puffin and petrels, can temporarily leave their young chicks unattended during feeding (even for multiple days in shearwater and petrel species), making them particularly vulnerable to predation at that time. In contrast, ground- and cliff-nesting birds usually always have at least one adult present to protect the eggs and chicks.

5.4.5.2.1 Focal species

Overall, there is evidence that rat eradication in Scotland will likely benefit all the focal seabird species, though to different degrees, whether by increasing their breeding success, pausing, or decelerating decline rates, or by stimulating recolonisations and breeding range expansion. Fox control also seemed to have a strong benefit on gulls, but mink control was beneficial for terns and Razorbill but not for large gulls. Brooke et al. (2018) found faster population growth after eradication efforts among terns and gulls than among other seabird groups, mostly because of their mobility and lack of philopatry to breeding sites.

5.4.5.3 Effects on other species and/or ecosystems

Invasive mammalian predators can have detrimental effects on ecosystems, disrupting the natural balance, impacting native and endemic flora and fauna, and contributing to habitat degradation. Eradicating these predators can allow ecosystems to recover, leading to positive cascading effects on other species and ecological processes (Bried et al., 2009; Jones, 2010). For example, the initially successful eradication of Brown rats from Handa

Island not only benefitted seabirds but also resulted in successful breeding for Common Shelduck *Tadorna tadorna*, Eurasian Oystercatchers *Haematopus ostralegus*, Common Redshank *Tringa totanus* and Ringed Plovers *Charadrius hiaticula*, which was previously not recorded and Pygmy Shrews also appeared to increase on the island (Stoneman and Zonfrillo, 2005). Similarly, mink control efforts in the Finnish Archipelago benefitted seabirds, but also small mammals and amphibians, such as frogs and toads (Banks et al., 2008). While Stanbury et al. (2017) identified 66 species of bird, reptile, amphibian, and mammal that could potentially benefit from invasive mammal eradications across UK islands (and crown dependencies). Jones (2010) showed that soil, plant, and spider-derived nitrogen levels and C:N ratios take mere decades to recover even after centuries of rat invasion. The author also suggests that the recovery of seabird colonies can further speed up the recovery as they provide nutrients that are integral to maintain island biodiversity and ecosystem function.

Nevertheless, eradication/control efforts, if not undertaken in a careful and thoughtful manner, can result in unintended ecological consequences. Many eradication/control methods, such as poison, traps, or guns, can inadvertently harm non-target species, including humans (Appleton et al., 2006; Ratcliffe et al., 2010; Bell et al., 2019). Therefore, it is also important to thoroughly assess the ecological interactions and potential impacts of removing the target mammalian predator, as the absence of such predators may cause changes in prey dynamics and lead to population increases of other predator species, posing a new potential threat to seabirds (Luxmoore et al., 2019; Lambert et al., 2021).

5.4.5.4 External factors that may affect the effectiveness of eradication/control efforts

While eradication and control efforts targeting mammalian predators have shown positive impacts on seabird populations, there are several external factors that can hinder their effectiveness. The effects of climate change, for instance, can lead to habitat loss and a decline in food availability, impeding the recovery of seabird populations (Regehr et al., 2007). For example, in Lewis, terns had low productivity in certain years, despite successful mink control efforts which authors attributed to poor food supply and/or bad weather conditions during that period (Ratcliffe et al., 2006). These results also led authors to believe that in some years, mink predation may not be as harmful, as individuals could be taking eggs and chicks that would otherwise likely have subsequently starved due to poor conditions (Ratcliffe et al., 2006).

The presence of other invasive predator species on the island or region can also undermine eradication efforts. This is of particular relevance to islands in the UK (including Scotland) where the presence of multiple invasive mammalian predators is confirmed or suspected (Stanbury et al., 2017). If only one species is targeted, eliminating that predator can create an ecological vacancy which could allow other invasive species to assume the top predator role, and thus weakening the effect of the eradication (Ballari et al., 2016). This was observed on the Isle of Rum, where localised rat control did not lead to an increase in Manx Shearwater productivity. Authors attributed this to an increase of predation rates by wood mice (Lambert et al., 2021). Furthermore, human activities can disturb nesting behaviours, cause stress, and contribute to declining seabird populations, even in the absence of invasive predators. Therefore, it is crucial to account for these external factors in conjunction with eradication efforts to develop appropriate management efforts for the recovery of seabird populations.

5.4.5.5 Biosecurity measures

The latent risk of mammals reinvading from neighbouring islands or being reintroduced through human activities persists, even after islands have been predator-free for an extended period (Marie et al., 2014). To ensure the success of eradication and control efforts, it is therefore crucial to implement robust biosecurity measures, such as quarantine procedures, monitoring and surveillance systems, and stringent control measures (Holmes et al., 2023). Quarantine and monitoring programmes, such as 'Biosecurity for Life', play a crucial role in preventing the introduction (or re-introduction) of species by ensuring restrictions on the movement of people, materials, and animals to and from islands. By closely monitoring these activities, potential threats can be identified and intercepted before they have the chance to gain a foothold in the island ecosystem. These measures are essential for preventing the reintroduction of mammalian predators and the introduction of new invasive species, particularly on islands (Appleton et al., 2006; Banks et al., 2008; Ratcliffe et al., 2008; Phillips, 2010; Marie et al., 2014; Bell et al., 2019; Luxmoore et al., 2019). Neglecting biosecurity efforts can reverse the outcomes of eradication efforts, particularly considering that the positive effects resulting from them may take many years to become apparent. Additionally, measures such as post-eradication habitat restoration programmes and the use of acoustic-playback and decoys can help provide suitable habitat and help attract individuals to further accelerate recolonisations and distribution expansions (Holmes et al., 2023; Spatz et al., 2023a).

5.4.5.6 Social aspects

The eradication and control of mammalian predators, along with the implementation of biosecurity measures, is as dependent on social factors as it is on scientific knowledge and experience (Martin, 2018). As these management strategies become more widely employed, it also comes under increasing public scrutiny (Martin, 2018). It is important to recognise that predator eradication/control efforts, which involve actions such as poisoning, trapping, and shooting animals, can evoke strong emotions and varied opinions within local communities, conservation organisations, and the general public (García-Llorente et al., 2008). This is especially true when working with animals that humans have a greater emotional attachment to, like cats. They are popular as pets and eradication campaigns may face opposition from inhabitants wishing to keep and import domestic animals during and after eradication and because of concerns for their wellbeing (Nogales et al., 2004; Ratcliffe et al., 2010). A feral cat eradication programme, for example, accidentally killed a large proportion of the domestic cat population (Ratcliffe et al., 2010). Failing to account for these opinions and concerns can jeopardise the success of the entire eradication effort, particularly on large, inhabited islands close to the mainland.

Early, inclusive, public consultation and engagement, and transparent communication are therefore essential for building trust and fostering understanding about the need and benefits of such actions (García-Llorente et al., 2008; Crowley et al., 2017). Involving all participants in the decision-making processes and addressing their concerns can help ensure social acceptance and support for this conservation action, both during the eradication process and for the crucial implementation of biosecurity measures (Nogales et al., 2004; Pearson et al., 2019; Holmes et al., 2023).

5.4.5.7 Knowledge gaps and future directions

While the impacts from invasive species are clear, data on invasive mammal presence on islands is still lacking worldwide, potentially underestimating the global threat of invasive species and preventing the identification of areas in need of invasive species management (Spatz et al., 2023a). Even in the UK, where there is generally good monitoring information for certain sites and mammals, there is suspected rather than confirmed presence of predator species (Stanbury et al., 2017). Predator control and prevention in mainland seabird colonies pose unique challenges due to their accessibility to the public. The presence of human activity and coexisting wildlife increases the vulnerability of these colonies to the introduction and spread of invasive species, which further complicates the eradication process. Approaches are less well developed and studied for the control (or ideally eradication) of invasive mammalian predators on mainland or large inhabited islands. For these sites controlling predators is often significantly more challenging than for smaller offshore islands. For the ten UK and Crown Protectorate islands identified as having the greatest potential conservation benefit (this assessment not exclusively for seabirds) from eradication programmes by Stanbury et al. (2017), eradication was only considered realistic for one of these islands as the other nine islands were relatively large with significant human populations. There is, therefore, a need for exploration of control strategies and comprehensive research to enhance our knowledge and inform the development of appropriate management approaches for mainland colonies and for larger inhabited offshore islands.

Achieving successful eradication efforts requires a solid foundation of baseline knowledge, not only about the ecology of seabirds and predators but also about the entire ecosystem. This includes understanding the interactions among multiple co-existing predators and how they regulate each other (Ballari et al., 2016), data which is usually lacking. Therefore, investigating post-eradication ecosystem changes within a whole ecosystem context is vital. It is also important to recognise that the impacts of eradication efforts take time to become visible, particularly when assessing their effects on long-lived species like seabirds. A study on Manx Shearwaters, for example, predicted that during the first six years after eradication the population was going to continue to decline, but after 6–12 years there was going to be a convex growth, and after that an exponential growth, until density dependent limitations cause growth rates to slow (Appleton et al., 2006). Therefore, the success of the eradication effort should be studied over an ecologically appropriate time frame. Given this extended time frame, efforts to accelerate the recovery of seabird populations, like promoting native vegetation or actively restoring seabird populations through activities like translocating chicks or using sounds and decoys to attract prospecting adults should be considered (Benkwitt et al., 2021; Spatz et al., 2023a). Overall, it is crucial to allocate resources and effort towards preventive measures, including the development of monitoring techniques and analytical tools, to predict potential invasion hotspots and prioritise the early detection of invasive species before they pose a significant threat to seabirds and whole ecosystems (Spatz et al., 2023a).

5.4.6 Conclusion

In conclusion, our review provides compelling evidence supporting the effectiveness of mammalian predator eradication as a valuable conservation tool for the protection and enhancement of seabird colonies, particularly for island colonies. The management strategies employed varied depending on the targeted predator, with rats generally being eradicated and larger mammals requiring more focussed control measures. However, the success of these efforts is influenced by multiple factors, including the specific predator, the nesting strategy and body size of seabird species, and various external factors (e.g. distance to mainland and other islands, climate changes, presence of other predator species, terrain, and degree of human presence).

Rats have shown high success rates in eradication campaigns, whereas other medium-sized mammals require more focussed and controlled management. Rats have higher eradication success rates, and mink good control success. Feral cats present unique challenges due to difficulty in gaining community support for lethal control methods. Foxes, on the other hand, exhibit learning behaviours, emphasising the need for adaptable and dynamic efforts for controlling the species. Therefore, eradication and control efforts require adaptive management to accommodate the ecology of the mammalian predators. Most seabird species are expected to show some benefit from mammalian eradication and control efforts, but the degree of the effect will depend on body size and nesting ecology; small burrow and nesting birds are expected to benefit more than large gulls and cliff-nesting birds. Ultimately, rodents mainly affect reproduction (through reduced nest site availability and/or quality or decreased productivity), so their impact tends to be relatively low compared to that of larger invasive species which reduce adult survival (Lewison et al., 2012).

It is crucial to recognise that eradication and control programmes are long-term initiatives, requiring continuous monitoring, preventive measures, and sustained resource investment (Holmes et al., 2023). The timeline for observing positive effects can vary significantly, ranging from short-term to long-term outcomes that may span months or even decades. Additionally, logistical challenges and costs are associated with eradicating mammalian species, particularly in mainland sites and larger islands with higher human population density, making control measures a more feasible management option than eradication. It is essential to consider all predators present on an island during eradication efforts to prevent the rise of alternative predator populations. The success of eradication efforts hinges on the inclusion of local communities throughout the entire process, from the planning stages to the implementation of biosecurity measures to secure the conservation gains and their long-term effectiveness and sustainability. Ultimately, successful eradication or control of invasive species should be viewed as a long-term commitment that requires unwavering vigilance and collaboration among conservation organisations, researchers, and local communities and must sometimes be performed in combination with other conservation actions.

5.5 Ecological feasibility: Avian predator management

5.5.1 Summary

The systematic literature review and respective analyses provide evidence that, with a medium degree of confidence, the management of avian predators has a low to medium effect on at least one demographic parameter of seabirds, but this strongly depends on the species involved and management type (e.g. diversionary feeding, removal, deterrence, and habitat modification). Considering this conservation action as strategic compensation becomes challenging due to its highly site- and species-specific nature and the overall lack of evidence on their short- and long-term effectiveness. Further complications arise when both the target seabird and predator species are of conservation concern.

5.5.2 Introduction and background

Predation by avian predators, in addition to mammalian predators (as discussed in Ecological feasibility: Mammalian predator eradication and/or management), can exert substantial impacts on some seabird species, particularly those that are ground-nesting and colonial (Roos et al., 2018). Avian predators such as raptors, corvids, and large seabirds like gulls and skuas have been demonstrated to cause detrimental effects on seabird colonies (Parrish and Paine, 1996; Donehower et al., 2007; Hipfner et al., 2012; Smart and Amar, 2018; Anker-Nilssen et al., 2023; Langlois Lopez et al., 2023; Pollet et al., 2023). These predators can affect seabird populations directly, by targeting eggs and chicks, or indirectly, through disturbance or kleptoparasitism, when an individual steals food or prey from another individual (Finney et al., 2001; Sanz-Aguilar et al., 2009; Perkins et al., 2018). Such disturbances can induce stress in seabirds, leading to behavioural changes that include the reduction of foraging time due to heightened vigilance, an increase in foraging efforts when food is stolen before reaching the chicks, or changes in nesting behaviour as defensive responses. These behavioural changes and predation can consequently affect energetic reserves, breeding success, overall colony structure and distribution, and, ultimately, survival (Gilchrist, 1999; Votier et al., 2004; Oro and Martínez-Abraín, 2007; Perkins et al., 2018; Wilson et al., 2020; Anker-Nilssen et al., 2023).

Within the UK, numerous avian predators have been observed preying on seabirds. For example, large gulls have been recorded to prey on Roseate Terns in Coquet Island (Alfarwi, 2021), on Common Terns and Black-headed Gulls in Kent (Akers and Allcorn, 2006), and on Arctic Terns in the Farne Islands (Boothby et al., 2019), and are kleptoparasites of Puffins on the Isle of May (Finney et al., 2001; Langlois Lopez et al., 2023). In Great Yarmouth, Kestrels prey on Little Tern chicks (Smart and Amar, 2018) and in Shetland, Great Skuas prey on Kittiwake (Votier et al., 2008). Results from the Breeding Bird Survey (BBS) suggest that populations of half of the common and widespread avian predator species increased significantly between 1995 and 2015 (Roos et al., 2018). While these findings encompass avian predators of all bird species and are not specifically limited to seabirds, the increasing abundance of these predators undoubtedly raises the potential likelihood of intensified predation rates at seabird colonies, and so the potential benefit from predator management.

Understanding the dynamics of prey-predator interactions is particularly essential for developing effective management and conservation strategies, especially when both prey and predator are of conservation concern. There have been many exploratory management actions to reduce avian predation rates in seabird and waterbird colonies, ranging from supplementary and diversionary feeding (Martínez-Abraín and Oro, 2013; Smart and Amar, 2018; Laidlaw et al., 2021) and targeted and untargeted predator nest and/or individual removal (Finney et al., 2001; Akers and Allcorn, 2006; Oro and Martínez-Abraín, 2007; Sanz-Aguilar et al., 2009; Lavers et al., 2010; Paracuellos and Nevado, 2010), to deterrence of avian predators using bioacoustics or physical objects (Boothby et al., 2019; Alfarwi, 2021; Laidlaw et al., 2021), amongst others. The degree of effectiveness of each management action, however, can vary across species, location, and predator-prey interactions. Therefore, targeted management actions tailored to specific contexts are needed and should be carefully designed and implemented considering the ecological dynamics and potential unintended consequences to both prey and predator species.

The aim of this literature review is to identify the main avian predators in Scotland and gather all available evidence of the effect of management actions on seabird species, with a focus on our focal species (i.e. those species most likely to be affected by offshore windfarms). By examining the effectiveness of avian predator management, conservation efforts can be better targeted and prioritised to find the most cost-effective solutions, which may have potential as strategic compensatory measures for the impacts of offshore wind farms on seabirds. Additionally, this review aims to identify which seabird species would benefit most from different avian predator management actions.

5.5.3 Methods

The conservation action, the management of avian predators, involves a set of different management actions and was, therefore, associated with three research questions. The first research question, ‘What is the potential for seabirds to experience increased productivity or survival through avian predator management?’, investigates the impact of avian predator management actions on seabird populations. The second question, ‘Which management action is more effective?’ aims to identify the management action that has the strongest beneficial effect on seabird populations. The third question, ‘For which avian predator is there the most potential for effective management?’, aims to identify the avian species with higher probabilities of management success.

We focussed our search on three management actions deemed relevant for the UK: (1) diversionary feeding, (2) deterrence of avian predators with bioacoustics or physical objects, and (3) targeted nest and/or individual removal or translocation.

A detailed description of the research question, keywords, search strings, and study selection (Figure 19) is provided in section 6 of Annex 1. Selection criteria can be found in Table A 2.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

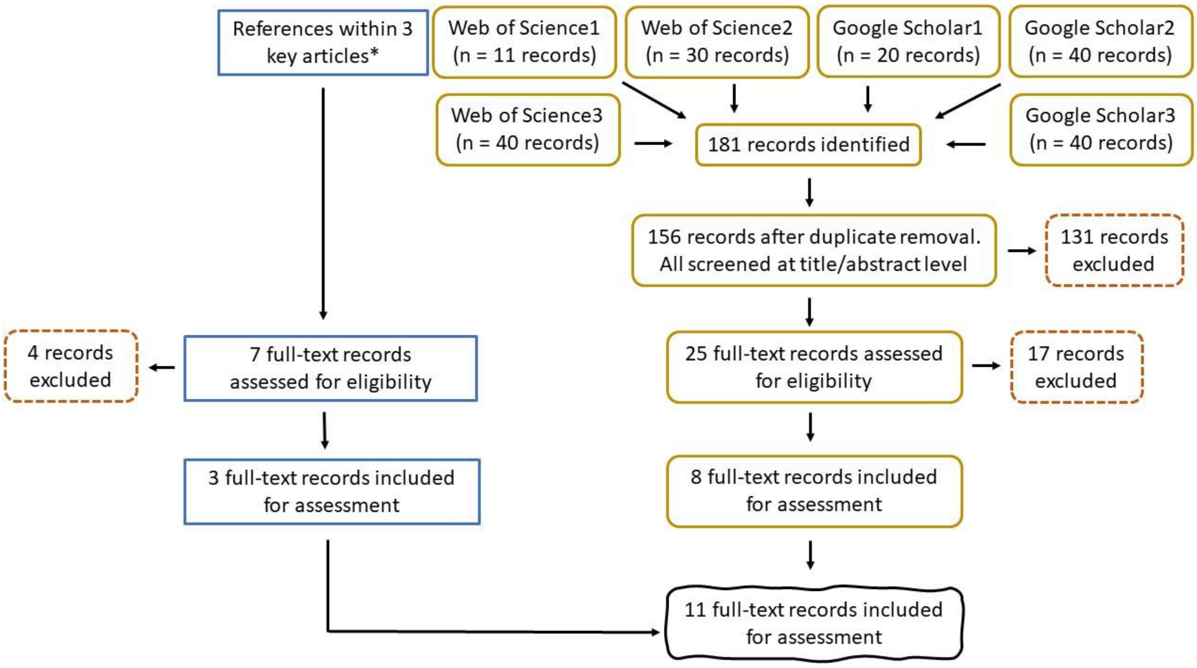

Figure 19. Flow diagram depicting the study selection process for the systematic review on avian predator management. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Lavers et al. (2010), Laidlaw et al. (2021), and Sutherland et al. (2021).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

Overall, 11 references were included for the final review.

5.5.4 Results

5.5.4.1 General observations

We identified 11 references that met our criteria of measuring the effect of the three identified avian predator management actions on seabird populations, all published in English. The literature review yielded publications ranging from 1980 to 2021 (Figure 20A). The median publication date was 2001, which also coincided with the only year where more than one study was published. Apart from one short communication, all records were full research articles (Figure 20B). Due to the nature of this conservation action, all studies assessed the impact of at least one avian predator management action. Most studies conducted field experiments to directly test the degree of impact of the management either on seabird or waterbird colonies. Of the assessed studies, 91% focussed on the impact of an avian predator management action on productivity, while 46% studied predation rates, 18% studied survival, 18% studied breeding pairs, and 27% focussed on other parameters such as population size, flush rates, and area occupied for breeding (Figure 20C).

Studies researched the effect of several avian predators on diverse seabird and waterbird species groups (Figure 20D). Out of the studied avian predators, gulls (i.e. Herring Gull, Lesser Black-backed Gull, Great Black-backed Gull, Yellow-legged Gull, Common Gull, and Ring-billed Gull) had the highest number of studies focussed on their management, with eight studies. The second most commonly studied avian predator were raptors (i.e. Kestrel *Falco tinnunculus*, Red Kite *Milvus milvus*, and Bald Eagle *Haliaeetus leucocephalus*), with three studies. One record focussed on Carrion Crows *Corvus coronea*. Studies focussed on several seabird (or waterbird/wader) species groups (listed from most studied to least): terns (4 studies; i.e. Little Tern *Sternula albifrons*, Common Tern *Sterna hirundo*, and Arctic Tern *Sterna paradisaea*), waders (3 studies; Northern Lapwing *Vanellus vanellus*, Oystercatcher *Haematopus ostralegus*, Golden Plover *Pluvialis apricaria*, Curlew *Numenius arquata*, Redshank *Tringa totanus*), auks (2 studies; Atlantic Puffin and Guillemot), and a study on European Storm Petrels *Hydrobates pelagicus* and one on the Audouin's Gulls *Ichthyaetus audouinii*. Note that some references studied multiple predators and seabird/waterbird species.

Studies used different methods to manage avian predators, the majority in a non-lethal manner (Figure 20E). Seven studies undertook a removal management action. This type of management included targeted and non-targeted culling of adults, either by shooting, poisoning, or trapping (lethal), and the removal and destruction of nests and eggs to prevent predators from breeding in the area (non-lethal) (Figure 20E). Two studies measured the impact of diversionary feeding of raptors (Kestrel and Red Kite) on Little Terns and Northern Lapwing, respectively. Here they used platforms and/or ground feeding stations to provide 100% of the daily food requirement of the predators for a limited period, mostly during the predator's chick-rearing period. Two studies undertook habitat modifications, either by providing an artificial habitat that provided protection or by controlling vegetation growth. One study undertook experiments on the effect of placing canes around nests on predation rates. Most studies (64%) were conducted on islands, while the remaining 36% were undertaken on the mainland (Figure 20F). Data was collected from multiple sites across the globe, including the UK, Spain, Canada, and the USA (Figure 20G). Within the UK, six studies were undertaken, three on the mainland and three on islands (Figure 20H). These projects included various sites on the east Coast, such as (from north to south): Kerloch, the Isle of May, Farne Islands, Great Yarmouth, and on the RSPB nature reserve at Otmoor (Figure 20H). Note that locations are grouped per UK-region (northeast Scotland, southeast Scotland, northeast England, and east England), or at a country-level and do not necessarily reflect the exact coordinates of the study sites. Of these, three studies focussed on removal experiments, two on diversionary feeding and one on predator deterrence using canes.

The most frequent data collection methods were observational field data, nest monitoring, pellet collection, chick measurements, and surveys. Most of the authors contributed to one reference.

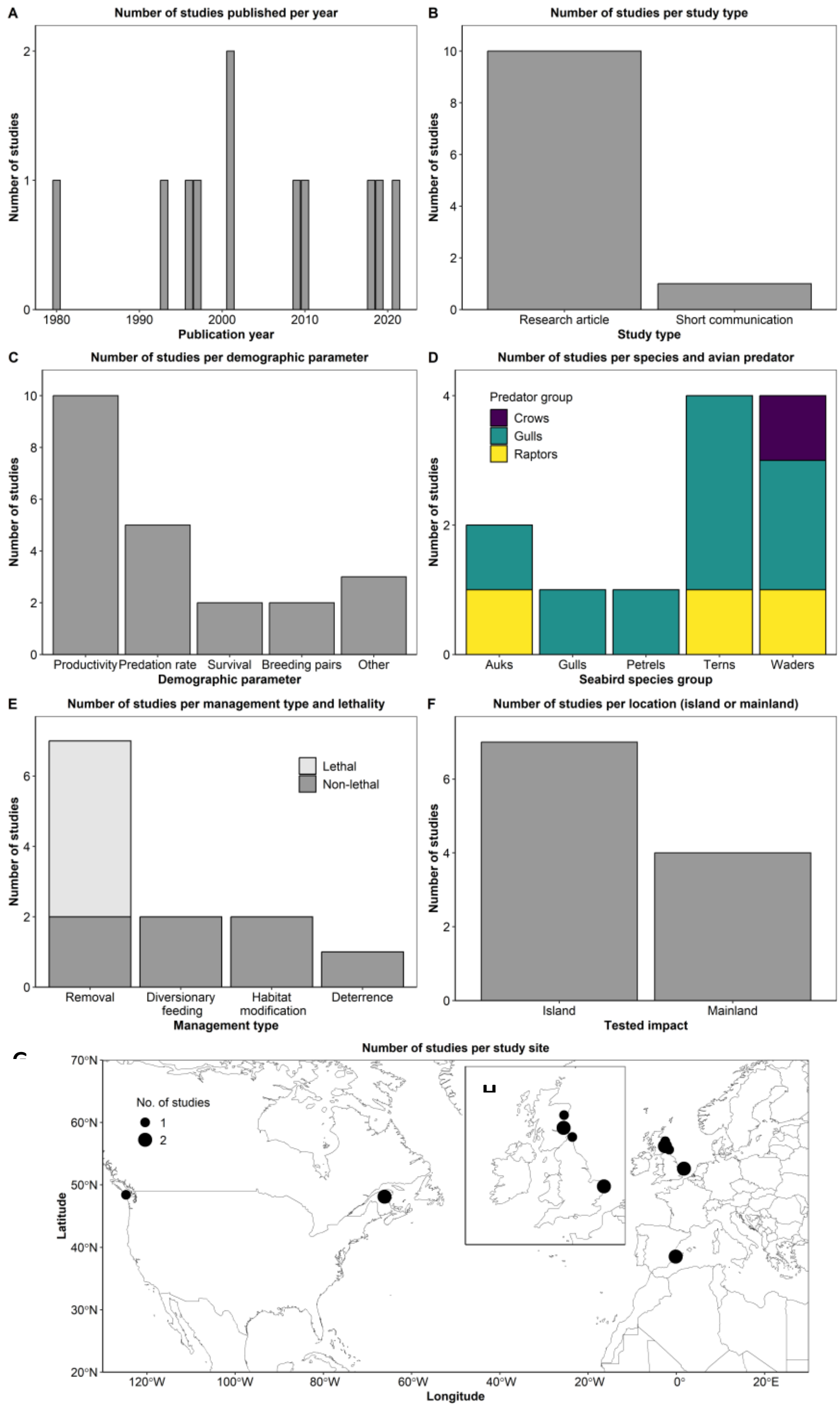

Figure 20. General observations of assessed records for avian predator management review. A) number of studies published per year. B) number of studies per study type. C) number of studies per studied demographic parameter; other = population size, flush rates, and area occupied. D) number of studies per seabird species group and avian predator group. E) number of studies per management type and whether it was lethal. F) number of studies per location (i.e. whether on an island or on mainland). G) number of studies per study site. H) number of studies conducted in the UK. Note that points are grouped per UK-region (northeast Scotland, southeast Scotland, northeast England, and east England), or at a country-level, and do not necessarily reflect the exact study coordinates.

Ecological feasibility: Avian predator management

Table 31. Relevance and ecological efficacy scores, as well as the management intervention and its effect on seabirds or waterbirds for each assessed study of the avian predator management review. Relevance scores (in bold) could have a potential score between 6 and 30 (6=studies of low relevancy, 30=studies of high relevance). Ecological efficacy scores (in bold) could have a potential score between 0 and 25 (lower scores reflect studies that did not find a significant effect of avian predator management, or those with low statistical inference; higher scores reflect studies that found a strong beneficial effect of avian predator management with high statistical inference). REM= Removal, DET = Deterrence, DF = Diversionary feeding, HM = Habitat Modification, SI = Statistical inference, and DE = Degree of effect. References are ordered from lowest to highest final ecological efficacy scores (total ecological efficacy score x weight).

		Relevance									**Ecological Efficacy**			
Reference	Management intervention	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[1] Finney et al. (2001)	REM	5	5	5	5	2	2	**24**	0.750	0.107	3	0	**0**	0
[2] Boothby et al. (2019)	DET	5	5	1	4	5	3	**23**	0.708	0.102	3	0	**0**	0
[3] Parrish and Paine (1996)	HM	5	5	5	1	2	1	**19**	0.542	0.084	1	1	**1**	0.084
[4] Morris et al. (1980)	REM and HM	5	5	1	1	1	2	**15**	0.375	0.067	2	2	**4**	0.267
[5] Parr (1993)	REM	5	5	1	5	2	2	**20**	0.583	0.089	4	1	**4**	0.356
[6] Harris and Wanless (1997b)	REM	5	5	1	5	2	5	**23**	0.708	0.102	2	2	**4**	0.409
[7] Guillemette and Brousseau (2001)	REM	5	5	1	1	2	1	**15**	0.375	0.067	3	3	**9**	0.600
[8] Sanz-Aguilar et al. (2009)	REM	5	5	1	1	3	3	**18**	0.500	0.080	3	4	**12**	0.960
[9] Smart and Amar (2018)	DF	5	5	1	4	5	4	**24**	0.750	0.107	3	3	**9**	0.960
[10] Mason et al. (2021)	DF	5	5	1	4	5	3	**23**	0.708	0.102	4	4	**16**	1.636
[11] Paracuellos and Nevado (2010)	REM	5	5	2	1	3	5	**21**	0.625	0.093	5	5	**25**	2.333
Total								**225**					**84**	**8**

5.5.4.2 Evidence scoring

The relevance, as well as the ecological efficacy scores for all 11 references are shown in Table 31 (refer to Annex 4 for a detailed breakdown of the extracted data for each study). Overall, references were of medium-high relevancy for our assessment, with six studies surpassing 20 points. Scores ranged between 15 and 24 out of a maximum possible score of 30, with a median and mean score of 21. For this reason, studies varied in their associated weight, ranging from 0.067 to 0.107 (Table 31). Out of the assessed studies, all but two suggest that managing avian predators has a positive effect on at least one demographic parameter of seabirds or waterbirds.

The ecological efficacy, i.e. the likelihood that the management of avian predators is beneficial on at least one seabird (or waterbird) demographic parameter, varied across studies. Scores ranged between 0 (the management of avian predators does not have an effect on bird colonies) and 25 (the management of avian predators has a strong effect on bird colonies) out of a maximum possible score of 25. The median score was 4, indicating that the effect varied greatly according to each study (Figure 21).

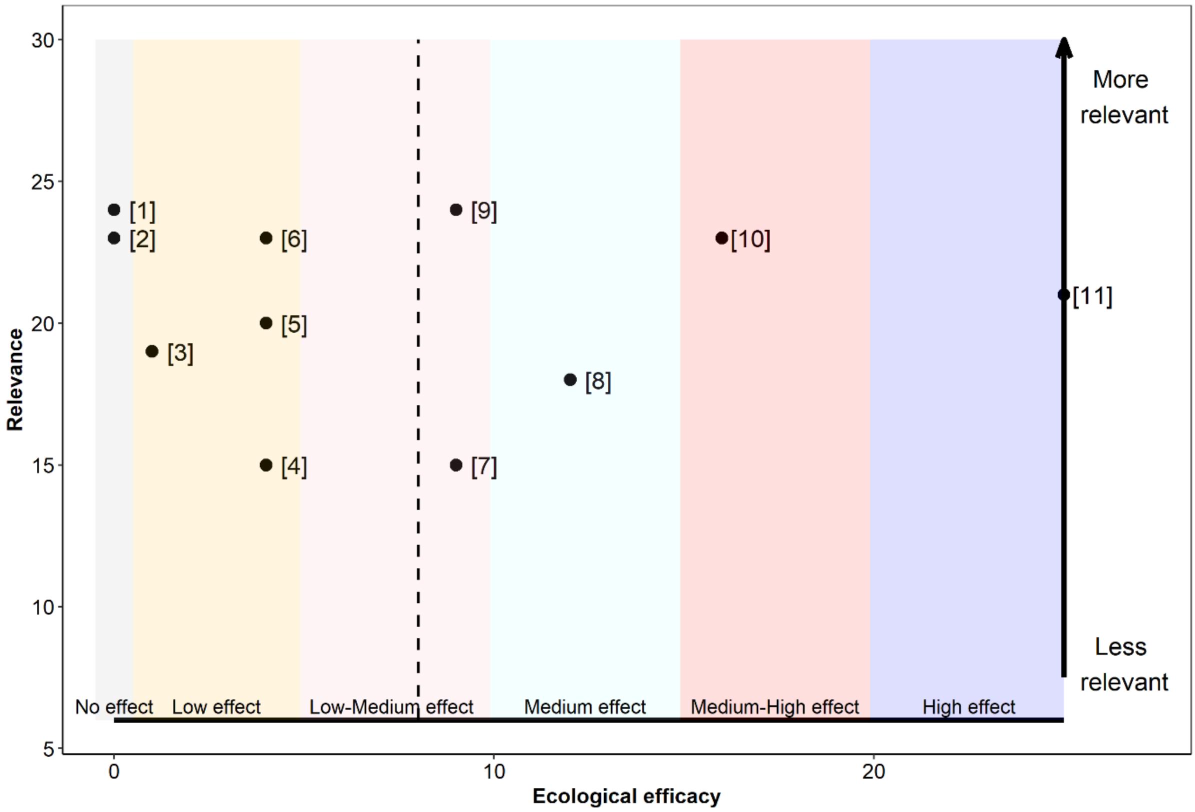

Figure 21. Ecological efficacy and relevance scores for each assessed study on the effect of avian predator management on bird colonies. The numbers correspond to the study identifier, as indicated in Table 31. Colours are used to differentiate the magnitude of the effect that avian predator management has on at least one seabird demographic parameter. Vertical dashed line indicates the overall ecological efficacy of avian predator management.

The sum of all final weighted scores is 8 (i.e. the mean of ecological efficacy weighted by relevance), indicating that overall, the evidence suggests that avian predator management will benefit seabirds to a low-medium degree (Figure 21), but this strongly depends on the management type.

5.5.4.3 Overall confidence scoring

We estimated the median of the relevance index score, the independence and quantity of the evidence and the concordance between studies to obtain an overall score to assess the confidence in our findings (see Confidence). The total score for this conservation action was 8 out of the possible 15 (Table 32), suggesting that we have a medium degree of confidence that the assessed estimation of the ecological efficiency is an accurate reflection of the true ecological efficacy of the management of avian predators.

Table 32. Assessment of the confidence in the evidence for management of avian predators.

Factor	**Results**	**Score**
Median relevancy	Median = 0.63	4
Independence and quantity of evidence	Studies are from several of authors and study systems, 10–15 studies	2
Concordance	SD = 1.6	2
		Total 8/15

5.5.4.4 Main findings: the effect of avian predator management

In summary, our literature review and respective analyses provide evidence that, with a medium degree of confidence, the management of avian predators has a low-medium effect on at least one demographic parameter of seabirds, but this strongly depends on the management type.

The key findings from the most relevant studies are summarised in Table 33. Overall, the effect of avian predator management had, to some degree, a positive effect on at least one demographic parameter of colonial birds, including seabird and waterbirds. The degree of this effect, however, varied strongly on the management type (Table 34).

Two studies researched the impact of diversionary feeding (DF) of raptors on the productivity of two ground nesting species, the Little Tern (Smart and Amar, 2018) and Northern Lapwing (Mason et al., 2021) in eastern England. Both studies compared predation rates and productivity during DF and non-DF years. Smart and Amar (2018) found that Kestrel predation rates were 47% lower (or 88% during additional intensive monitoring) and productivity of Little Terns doubled during DF years, from a mean of 0.42 fledged chicks/pair in non-DF years to 0.88 in DF years, though the difference was not statistically significant. Mason et al. (2021) found extremely similar results but when studying diversionary feeding of Red Kites. Their results also show lower predation rates during DF years and a mean increase in lapwing productivity, from a mean of 0.47 fledged chicks/pair in non-DF years to 1.02 in DF years.

Table 33. Summary findings of the five most relevant studies on the effect of avian predator management on bird colonies, in order of decreasing relevance.

Reference	Management type	Results summary
[9] Smart and Amar (2018)	Diversionary feeding	Diversionary feeding (DF) of kestrels to protect Little Tern chicks in Great Yarmouth, eastern England. Authors used a 17-year dataset of annual estimates of Little Tern productivity and counts of kestrel predation events to compare years with and without DF (DF = 6 years). Predation rates were 47% lower and productivity of Little Terns doubled in years when kestrels were fed. Intensive monitoring showed that predation rates by kestrels at the colony were 88% lower in the two years when kestrels were fed. The number of Little Tern chicks eaten by kestrels peaked in mid-season and declined during late season.
[1] Finney et al. (2001)	Removal	Natural experiment that evaluated the effectiveness of maintaining gull-free areas as a management action. Authors compared kleptoparasitism (when one animal deliberately takes/'steals' food from another) rates and reproductive performance of Puffin breeding in gull-occupied habitats with that of Puffin nesting in areas where the breeding of gulls was delayed (by removing the first clutch) at the Isle of May, Scotland. Three treatments: gull-free site, normal gull breeding site, and a gull breeding delay site. Lower kleptoparasitism at gull-free plots; gulls predominantly attacked Puffins that bred close to them. Mean feeding frequency of Puffins breeding in normal gull habitat was significantly lower than that of Puffins breeding in gull-free areas. Breeding success, hatching date, peak weight, fledging period, fledging weight was the same in all treatments, which suggests that gulls did not have an immediate negative impact on Puffin reproductive performance. Removing the gulls' first clutch of eggs resulted in two changes: peak hatching of gull chicks was delayed by ca. 3 weeks and the mean density of gull chicks decreased as not all pairs that had their first clutch removed laid a second clutch. There was no evidence that delaying gull breeding had a significant impact on the mean frequency or success of kleptoparasitic attacks. Delaying gull breeding did not affect the rate at which Puffins brought back food for their chicks.
[10] Mason et al. (2021)	Diversionary feeding	Diversionary feeding (DF) of kites to protect Northern Lapwings, a declining wader in Otmoor, England. Two

Reference	Management type	Results summary
		years of non-DF, then two years of DF, followed by a year of non-DF. DF decreased predation rates and successful strikes per hour, and on average doubled Lapwing productivity, reaching numbers that would stabilise the population. Other scavenger species that fed on the DF did not affect lapwing productivity.
[6] Harris and Wanless (1997b)	Removal	Gull control on the Isle of May over many years. Although the number of breeding pairs of Oystercatchers increased significantly, breeding success did not change. It was apparent that the two parts of the island where Oystercatcher productivity was consistently high were those with fewer gulls. When gull control stopped, population of Oystercatchers decreased, but this was seen throughout the UK and may be due to other external factors.
[2] Boothby et al. (2019)	Deterrence	Experimented a new technique to deter gulls from tern nests using bamboo canes in the Farne Islands. Although authors found fewer predation attempts in the caned areas than in the control areas, canes did not reduce the probability of predation success per attempt.

Table 34. Key findings of the studies for each seabird or waterbird species within the avian predator management review. Focal species are highlighted in italics. The effect is colour-coded as follows: red or '=' = no effect, white or '+' = small effect but not enough to reflect a population increase, and blue or '++' = effect that led to a population increase (e.g. measured increase in productivity or population growth).

Management type	Species	Species group	Nesting ecology	Predator	Effect	Reference
Diversionary feeding	*Little Tern*	Tern	ground nesting	Raptors	++	Smart and Amar (2018)
	Northern Lapwing	Wader	ground nesting	Raptors	++	Mason et al. (2021)
Removal	*Atlantic Puffin*	Auk	burrow nesting	Gulls	=	Finney et al. (2001)
	Common Tern	Tern	ground nesting	Gulls	++	Guillemette and Brousseau (2001)
				Gulls	++	Morris et al. (1980)

Management type	Species	Species group	Nesting ecology	Predator		Effect	Reference
	European Storm Petrel	Petrel	burrow and crevice nesting	Gulls		++	Sanz-Aguilar et al. (2009)
	Audouin's Gull	Gull	ground nesting	Gulls		++	Paracuellos and Nevado (2010)
	Oystercatcher	Wader	ground nesting	Gulls		+	Harris and Wanless (1997b)
				Gulls	Crows	=	Parr (1993)
	Golden Plover	Wader	ground nesting	Gulls	Crows	=	Parr (1993)
	Northern Lapwing	Wader	ground nesting	Gulls	Crows	+	Parr (1993)
	Curlew	Wader	ground nesting	Gulls	Crows	+	Parr (1993)
	Redshank	Wader	ground nesting	Gulls	Crows	+	Parr (1993)
Deterrence	*Arctic Tern*	Tern	ground nesting	Gulls		=	Boothby et al. (2019)
Habitat modification	*Guillemot*	Auk	cliff nesting	Raptors		+	Parrish and Paine (1996)
	Common Tern	Tern	ground nesting	Gulls		++	Morris et al. (1980)

Removal techniques and their effect on seabirds and waterbirds varied strongly among the seven studies that tested this type of management. Techniques for gull control ranged from targeted and long-term culling to nest and/or first clutch removal, as well as egg pricking (piercing a small hole in the shell to prevent hatching). One study undertook this jointly on both gulls and crows (Parr, 1993). Targeted culling of gulls aims to remove specific individual gulls that are thought to contribute the highest proportion of predation of other species. Both studies that undertook this found significant increases in survival and/or breeding success of seabirds (Guillemette and Brousseau, 2001; Sanz-Aguilar et al., 2009). Sanz-Aguilar et al. (2009) observed that the removal of six specialised Yellow-Legged Gulls and ten additional individuals nesting in the proximity of a nesting site (a cave) used by European Storm Petrels led to a mean increase in adult survival probability from 0.75 to 0.89 (95%CI = 0.82–0.94) and to an increase in breeding success from 0.50 to 0.66. The specialist gulls were mainly territorial males and represented a small proportion of the population (ca. 1%). Guillemette and Brousseau (2001) similarly found that removing four male Herring Gulls and one Great Black-backed Gull decreased predation rates on Common Terns and increased their fledging success from 0 to 16% of chicks that hatched surviving to fledging. One individual gull accounted for 85% of all successful predation attempts made during the baseline period.

Non-targeted culling programmes seem to have a mixed effect on colonial birds. In Spain, a Yellow-legged Gull culling programme significantly increased the number of breeding pairs, area occupied and breeding success of the Audouin's Gull population (Paracuellos and Nevado, 2010). On the Isle of May, however, gull culling increased the number of breeding pairs of Oystercatchers but did not significantly improve their breeding success (Harris and Wanless, 1997b). In Kerloch moor, the removal of both Carrion Crows and Common Gulls did not have an effect on waders (Parr, 1993). Although the numbers of crows and gulls were significantly reduced, no young Golden Plover hatched, and breeding numbers continued to decline. Hatching success of Oystercatchers also did not increase, and although Lapwing, Curlew, and Redshank had higher hatching success, their breeding numbers did not increase. Authors believe that these results can be explained by the rising nest predation from foxes, which may have masked any benefits from the removal of the other predators.

Removal does not only include targeting adults but includes removing nests and/or egg clutches and preventing individuals to breed at sites close to other species. On the Isle of May, Finney et al. (2001) compared kleptoparasitism rates (when an individual 'steals' food from another) and the reproductive performance of Puffin. Specifically, the compared these variables among Puffins breeding in gull-occupied habitats with those nesting in areas where gull breeding was delayed through the removal of the first clutch. Overall, kleptoparasitism was lower within gull-free plots. However, the breeding performance (measured with breeding success, hatching date, peak weight, fledging period, fledging weight) was the same in all treatments. In addition to habitat modification, Morris et al. (1980) showed that the removal of Yellow-legged Gulls nests increased the breeding success of Common Terns.

Deterrence using a physical object was only measured in one study in the Farne Islands. Boothby et al. (2019) tested a new technique, using bamboo canes of 1.5 m in length at an approximate angle of 70° to the ground, to deter gulls from Arctic Tern nests. They measured predation rates and predation success using three treatments which included a control site, a site with a low density of canes, and a site with a high-density of canes. Authors found that gulls had lower predation rates (up to half) in caned sites compared to the control sites but that if an attempt took place, then canes did not affect whether it would be successful.

Two studies explored the effect of habitat modification on seabirds. The first, explored the effect of creating temporary silk-enhanced artificial trees ('silk forests') to protect Guillemots from Bald Eagles in the USA (Parrish and Paine, 1996). This predator represents more of a perceived rather than an actual threat, as it induces the desertion of Guillemots' nests on the cliffs, without necessarily consuming the eggs/chicks. However, during this period crows and gulls can predate the unprotected nests. In this experiment, authors showed that Guillemots colonised the artificial habitat and even showed twice the density of eggs and had lower flush rates during eagle attacks compared to those from the control sites. However, productivity did not increase as no chicks hatched on any site. Authors believe that the artificial habitat can increase productivity, but at a larger scale. The second study combined gull-removal techniques and the control of vegetation growth to enhance Common Tern productivity in Canada (Morris et al., 1980). They showed that Common Terns had higher breeding success rates, both of eggs hatched/eggs laid and chicks fledged/eggs hatched, during the year with management actions than during the control year, but only when comparing early nesters (the managed year had a longer breeding season so many pairs relayed. Overall, late nesters had lower success than early breeders).

5.5.4.5 Biases or Conflict of interest

The authors did not disclose any biases or conflicts of interest, and our investigation did not reveal any such concerns.

5.5.5 Discussion

Evidence suggests that, to some degree, the management of avian predators has a beneficial effect on at least one demographic parameter of seabird populations during the breeding season, albeit to varying degrees. The effectiveness of such management actions is influenced by the avian predator involved, the nesting ecology of the target seabird species, and most importantly, the type of management which, in turn, was contingent upon factors such as the specific predator species, prey species, and geographical location. The management types explored during this literature review encompassed temporary diversionary feeding of raptors, the use of gull-deterrent objects, the removal of gulls and their nests and habitat modifications, all of which are discussed in detail below.

5.5.5.1 Diversionary feeding

Diversionary feeding (DF) is a non-lethal, temporary method aimed at diverting the activity or behaviour of predator species away from actions that negatively impact a particular target population (Kubasiewicz et al., 2016). Distinct from supplementary feeding, which aims to improve the population viability or density of a particular species or population, DF does not seek to increase the density of the population (Kubasiewicz et al., 2016). Studies by Smart and Amar (2018) and Mason et al. (2021) demonstrated the efficacy of DF of raptors in reducing predation rates and doubling the productivity of Little Terns and Northern Lapwings, respectively. During DF years, Kestrels preferred to hunt wild mammals over Little Terns, suggesting that terns may be considered a riskier prey type and are only targeted when they are abundant or when mammal prey is scarce (Smart and Amar, 2018). These findings suggest that DF of certain raptors, such as Kestrels and Red Kites, can be a highly effective predation management tool that enhances productivity of ground-nesting colonial species that could consequently lead to population growths. During this review, no evidence was found regarding its applicability and efficacy on predator gulls and/or its potential for protecting non-ground nesting species (e.g. crevice and cliff nesters, such as auks).

DF proves particularly useful when both prey and predator species are of conservation concern, as it reduces the motivation for a predator to hunt natural prey without compromising the needs of either species (Smart and Amar, 2018). However, it can also cause unintended consequences (Martínez-Abraín and Oro, 2013). DF has the potential to attract or recruit new individuals, increasing predator abundance and density and thereby increasing predation rates (Cortés-Avizanda et al., 2016; Mason et al., 2021). It can also create dependence on human-provided food that may not be sustained once this food source is removed or depleted (Kubasiewicz et al., 2016), and, if it attracts a high density of individuals, it can increase the risk of disease transmission. Precautionary measures can, however, be taken to mitigate these risks. Mason et al. (2021), for example, propose implementing DF for a short period, beginning after most raptor pairs have chosen their nest sites and invested energy in egg laying and incubation and in a site close to where the highest prey chick predation occurs. Another solution could be to use DF during periods with peak predation rates (e.g. mid-breeding season). This timing is likely to reduce predation in the short-term. To reduce costs and prevent predators from becoming habituated to DF, authors also suggest implementing DF in alternating years.

When designing a successful and appropriate DF activity, Smart and Amar (2018) suggest considering several factors: the choice of food, feeding location, timing and method; determining the appropriate food quantity to provide; minimising food intake by non-target species; understanding the specific needs and preferences of the target species; maintaining consistency in the timing and frequency of the feeding; and aiming to provide 100% of their dietary requirements. However, it is important to note that many more studies are needed in order to properly understand the effectiveness of this management as a long-term conservation tool on several species (Kubasiewicz et al., 2016).

5.5.5.2 Removal

The predominant management action identified in this literature review involves the targeted or non-targeted removal of predators' nests, eggs, chicks and/or breeding individuals. The focus of such actions has primarily been directed towards large gulls, likely due to their population increase and distribution expansion resulting from fishery discards and landfill sites. Numerous long-term culling programmes have been implemented worldwide, aiming to reduce predator presence in specific sites. These programmes are generally conducted at the local population level and consist of the systematic lethal removal of large numbers of eggs, chicks, or breeding adults. This action assumes that all individuals contribute equally to, or are equally responsible for predation attempts, and targeting them accordingly.

Nonetheless, evidence suggests that the long-term success of gull control programmes is relatively low, as there is no guarantee of an increase in population size or breeding success, even when substantial efforts are undertaken, particularly for waders (Parr, 1993; Harris and Wanless, 1997b; Oro and Martínez-Abraín, 2007). The review identified only one successful event where non-targeted culling of gulls improved the breeding success of a smaller, threated seabird species (Paracuellos and Nevado, 2010). This occurred at a small, isolated colony, which authors believe was the reason of the success. However, Paracuellos and Nevado (2010) suggest that this action should not be seen as a viable long-term solution. Instead, they advocate for addressing the underlying factors that restrict predator populations as a more effective strategy.

Targeted (or selective) removal, on the other hand, has shown more significant beneficial effects on breeding success and survival in seabirds like terns and petrels (Guillemette and Brousseau, 2001; Sanz-Aguilar et al., 2009; Scopel and Diamond, 2017). This approach not only reduces overall project costs but also has a lesser impact on the predator population. Sanz-Aguilar et al. (2009) observed that specialist gulls with higher predation attempts were mainly territorial males and represented ca. 1% of the populations. These individuals can be individually identified and removed at the beginning of the prey species' breeding period due to their territorial behaviour, but this does not apply to juveniles or non-breeding individuals (Guillemette and Brousseau, 2001). It is important to note that even in cases where dominant individuals are successfully eliminated, continuous monitoring and culling programs remain necessary, as successive predatory gulls could replace one another when dominant individuals are removed (Guillemette and Brousseau, 2001; Votier et al., 2004).

If an avian predator, regardless of the nesting ecology of its prey, were to be identified and could be successfully removed, then, in theory, this management strategy should be effective. Nest removal and egg pricking could be additional activities that may reduce the predators breeding success (Morris et al., 1980; Smith and Carlile, 1993), though this did not work for Puffins (Finney et al., 2001). These actions however mean that adults remain alive at colonies and may continue preying on individuals.

5.5.5.3 Deterrence

The use of deterrent objects, including physical, acoustic, or chemical means, has been explored as a strategy to deter birds in areas such as landfills, airports, and agricultural sites e.g. (Baxter and Robinson, 2007; Cook et al., 2008; Soldatini et al., 2008; Peterson and Colwell, 2014). However, their application at seabird colonies remains relatively unexplored. A pilot study conducted by Boothby et al. (2019) examined the use of bamboo canes as a physical deterrent at a tern colony and found a reduction in predation attempts but no significant improvement in breeding success. It is important to note that this study had limited sample sizes, and further research with larger sample sizes over multiple breeding seasons is necessary to ascertain the potential effectiveness of such deterrent objects.

The overall aim of deterrent objects is to alter an avian predators' behaviour and discourage their presence in certain areas. Physical deterrent objects encompass a range of visual stimuli designed to elicit an aversive response in large birds which could include scarecrows, decoys, reflective materials, bamboo canes, or lasers (Peterson and Colwell, 2014; Alfarwi, 2021). Acoustic deterrents utilise various auditory signals, including distress calls, predator vocalisations, or avian alarm sounds, to repel birds (Thieriot et al., 2015). Chemical deterrents involve the use of substances that produce aversive or repellent effects. Understanding which deterrent would work at seabird colonies should be further tested and at this point it is difficult to conclude anything from the lack of evidence found in the literature review. Most likely, however, the degree of effectiveness and implementation must be highly species- and colony- specific. Important to consider that predators could habituate to certain deterrents over time, reducing their overall efficacy.

5.5.5.4 Habitat modification

An additional management approach that had not been initially considered was habitat modification, which emerged as a frequently employed strategy and was sometimes used as a complementary action. The results from habitat modification studies showed mixed effects but were overall beneficial. This approach encompassed diverse methods. One study, for example, used artificial 'silk forests', a temporary and reversible new habitat to reduce the threat perception of Common Guillemots by Bald Eagles (Parrish and Paine, 1996). The temporary nature of this method avoids any impact on Eagles and allows the habitat to revert to its original state after its removal, at the end of the breeding season. This type of action can be used as an interim solution while longer-term conservation measures take effect (Parrish and Paine, 1996).

Another technique of habitat modification involves managing vegetation growth in accordance with the nesting preferences of seabirds. Terns, for example, prefer nesting in areas with low vegetation as denser and taller vegetation can reduce visibility and increase the risk of entanglement (Morris et al., 1980). What vegetation or general habitat modifications should be undertaken should strongly depend on the specific preferences of the target species. Providing an appropriate level of vegetation in front or around Puffin burrows, for example, could aid in protecting pufflings and potentially reducing levels of kleptoparasitism from gulls. Modifying habitat of cliff-nesting species may present logistical challenges.

5.5.5.5 Knowledge gaps and future directions

It is evident from this review that evidence is lacking for many management actions, indicating a need for further research. To obtain a more comprehensive understanding of which actions are effective for different seabird species, future studies should focus on filling these knowledge gaps.

Although we included information on the effects of avian predator management on colonial waterbirds, our literature search was focussed on seabirds, and we are confident that much information on this was overlooked. Conducting a review that includes similar colonial species, such as waders, could provide valuable insights into the effectiveness of conservation actions. Results from this review could increase our understanding of the applicability and potential transferability of management strategies to different seabird species.

Furthermore, conducting reviews specifically focussing on the deterrence of target avian predators in non-seabird colony sites such as landfills and airports, could offer insight into the mechanisms that effectively deter these predators. For example, falconry, robots, pyrotechnics, and the playback of distressed calls have shown to successfully deter gulls from certain areas (Baxter and Allan, 2006; Baxter and Robinson, 2007; Cook et al., 2008; Soldatini et al., 2008; Thieriot et al., 2015; Storms et al., 2022). Translocation, the capture, transport and release of individuals from one location to another, could also be further explored as a management option (Ackerman et al., 2014), though this would be species-specific and would require a high cost. Understanding which deterrent methods are successful in repelling focal predator species could help identify potential strategies that could be adapted for use at seabird colonies, without negatively impacting the seabirds themselves.

5.5.6 Conclusion

Top-down effects from avian predators can be significant regulators of seabird populations (Anker-Nilssen et al., 2023). Overall, our findings indicate that, to some degree, the management of avian predators can have a beneficial effect on seabird populations during the breeding season, albeit to varying degrees. The effectiveness of such management actions is heavily influenced by factors such as the avian predator involved, the nesting ecology of the target seabird species, and most importantly, the management action (e.g. diversionary feeding, removal, deterrence, and habitat modification). Each management action possesses inherent advantages and disadvantages that require careful consideration during the planning and implementation stages and should always be tailored to the specific seabird species and avian predator in question. Considering this conservation action as strategic compensation becomes challenging due to its highly site- and species-specific nature and further complications arise when both the target seabird and predator species are of conservation concern.

Most of these management actions can be undertaken at small scales and during short periods of time, often aligned with the breeding season of the target seabird species, at relatively lower costs compared to other of the conservation actions explored in this report. However, the current lack of evidence on the short- and long-term effectiveness of avian predator management as a conservation tool requires further research (Kubasiewicz et al., 2016).

5.6 Ecological feasibility: Reduction of disturbance (at colony)

5.6.1 Summary

The systematic literature review and respective analyses provide evidence that, with a medium degree of confidence, management measures of disturbance at and around colonies have a low to medium effect on at least one demographic parameter of seabirds. We suggest that reducing disturbance at colonies could be beneficial for seabirds. However, due to uncertainties regarding population level benefits, further research is needed before being considered for use as strategic compensation.

5.6.2 Introduction and background

Following Coetzee and Chown (2016) and Allbrook and Quinn (2020), human disturbance to wildlife refers to any activity, event, or action conducted by humans that induce physical, behavioural, or physiological changes in individuals, potentially leading to short- or long-term stress or fitness responses. While human disturbance affects most coastal seabird species, its impact is relatively lower compared to other threats like invasive alien species, bycatch, and climate change (Croxall et al., 2012; Dias et al., 2019). Nonetheless, nesting seabirds, particularly those nesting in accessible locations, are highly vulnerable to human disturbance as they are bound to their nests and are exposed to disturbance occurring from water, land, and more recently, air. Factors contributing to disturbance at colonies include tourism, recreation, photography, research, pedestrians, pets, and vehicles on land and at sea. More recently, the increasing use of Unmanned Aerial Vehicles (hereafter UAVs) in ecological research, photography, and recreation (Brisson-Curadeau et al., 2017) has introduced a new aerial disturbance.

There is extensive evidence showing that human disturbance has negative impacts on nesting seabirds. Such disturbance can result in increased nest abandonment, extended foraging time, changes in foraging locations at times abandoning preferred areas, changes in behavioural responses (e.g. resting, vigilance, flushing, agitation), shifts in habitat use, higher energy expenditure, reduced incubation time, increased predation risk, site abandonment, reduced parental investment and, in some cases, direct mortality (Chardine and Mendenhall, 1998; Carney and Sydeman, 1999; Blanc et al., 2006; Price, 2008; Watson et al., 2014; Allbrook and Quinn, 2020). Some consequences are more challenging to detect as they are not visible, as disturbance can cause physiological impacts such increased stress and cardiac rhythm, and reduced immunity (Ellenberg et al., 2006). These effects can subsequently influence body condition, reproductive success, and overall fitness, with potential population-level implications such as changes in population trends or permanent colony abandonment (Carney and Sydeman, 1999; Blanc et al., 2006; Allbrook and Quinn, 2020).

To mitigate the impact of human disturbances on seabirds, a range of management measures have been proposed at seabird colonies (e.g. visitor regulations, use of warning signs, setting speed limits, and regulating the use of UAVs). Understanding the effectiveness of such management measures and their specific impacts on seabird physiology, demography, and behaviour, is a vital step in designing and implementing appropriate management measures to enhance seabird conservation. Understanding why and how birds respond to disturbance may give insights into how conservation managers may minimise the impact of human disturbance at seabird colonies.

Various seabird species exhibit varying degrees of sensitivity to human disturbance, with some species more susceptible than others (Yorio et al., 2001; Blumstein et al., 2005; Price, 2008; Chatwin et al., 2013; Bishop et al., 2022). While some species can adapt and minimise the effects resulting from disturbance, others may remain highly sensitive, making it essential to tailor conservation and management strategies based on the specific needs of each species. The aim of this review is to gather evidence on the effect of management measures to reduce disturbance at seabird colonies, with a particular focus on our focal species and to identify which seabird species would benefit most from different disturbance management measures.

5.6.3 Methods

This conservation action was associated with two research questions. The first research question, 'What are the potential population level benefits from reducing on-land and coastal disturbance at seabird colonies?', investigates the impact of disturbance management measures on seabirds when present at the colonies. The second question, 'What types of disturbance management measures will provide the strongest benefit?' aims to identify the measure/s that could have the strongest beneficial effect on seabirds. Note that this review focusses solely on mostly recreational disturbance occurring during the breeding season, and management actions will focus on reducing disturbance directly on land, or at sea, but close to shore, enough to disturb birds breeding on land.

A detailed description of the research question, keywords, search strings, and study selection (Figure 22) is provided in section 7 of Annex 1. Selection criteria can be found in Table A 2.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

Overall, 10 references were included for the final review.

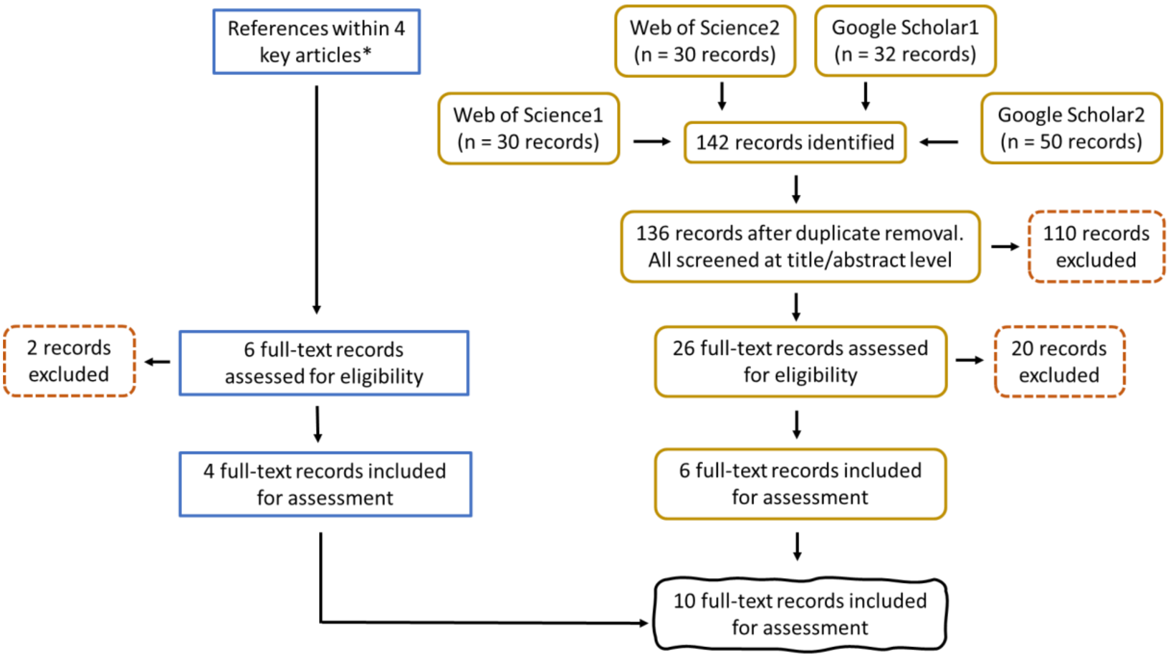

Figure 22. Flow diagram depicting the study selection process for the systematic review on reducing disturbance at and around the colony. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Batey (2013), Méndez-Roldán (2013), Dias et al. (2019) and Sutherland et al. (2021).

5.6.4 Results

5.6.4.1 General observations

We identified ten references that met our criteria of measuring the effect of disturbance at or close to seabird colonies. Nine of these studies were published in English, while one was published in Slovenian. The literature review yielded publications ranging from 2002 to 2022 (Figure 23A), with a median publication date of 2012. All records were research articles. Studies mostly conducted behavioural observations and experiments to test the degree of impact that land or sea disturbance had on seabirds. Half of the assessed studies focussed on the impact of disturbance on breeding success and the other half on behavioural responses, such as flushing rates or signs of agitation (Figure 23B). It is important to note that while behavioural responses are not demographic parameters *per se*, they can serve as potential drivers of demographic parameters. However, it is highly challenging to understand how changes in behaviour reflect on changes in population dynamics.

Seven studies conducted field experiments to directly test the degree of impact of certain management measures on seabirds at colonies, while the remaining three tested it indirectly (Figure 23C). Six studies researched visitor management at colonies (i.e. set-back distances, signage, and restriction of number of visitors), one study focussed on the effect of unmanned aerial vehicles (UAVs), and the rest tested measures relating to boat and kayak management close to colonies (i.e. set-back distances at sea and speed limits of vessels; Figure 23D). Two studies were conducted at St Abbs Head, Scotland, while the others were undertaken outside of the UK, in Canada, the USA, Ireland, Portugal, Slovenia, and Mexico (Figure 23E).

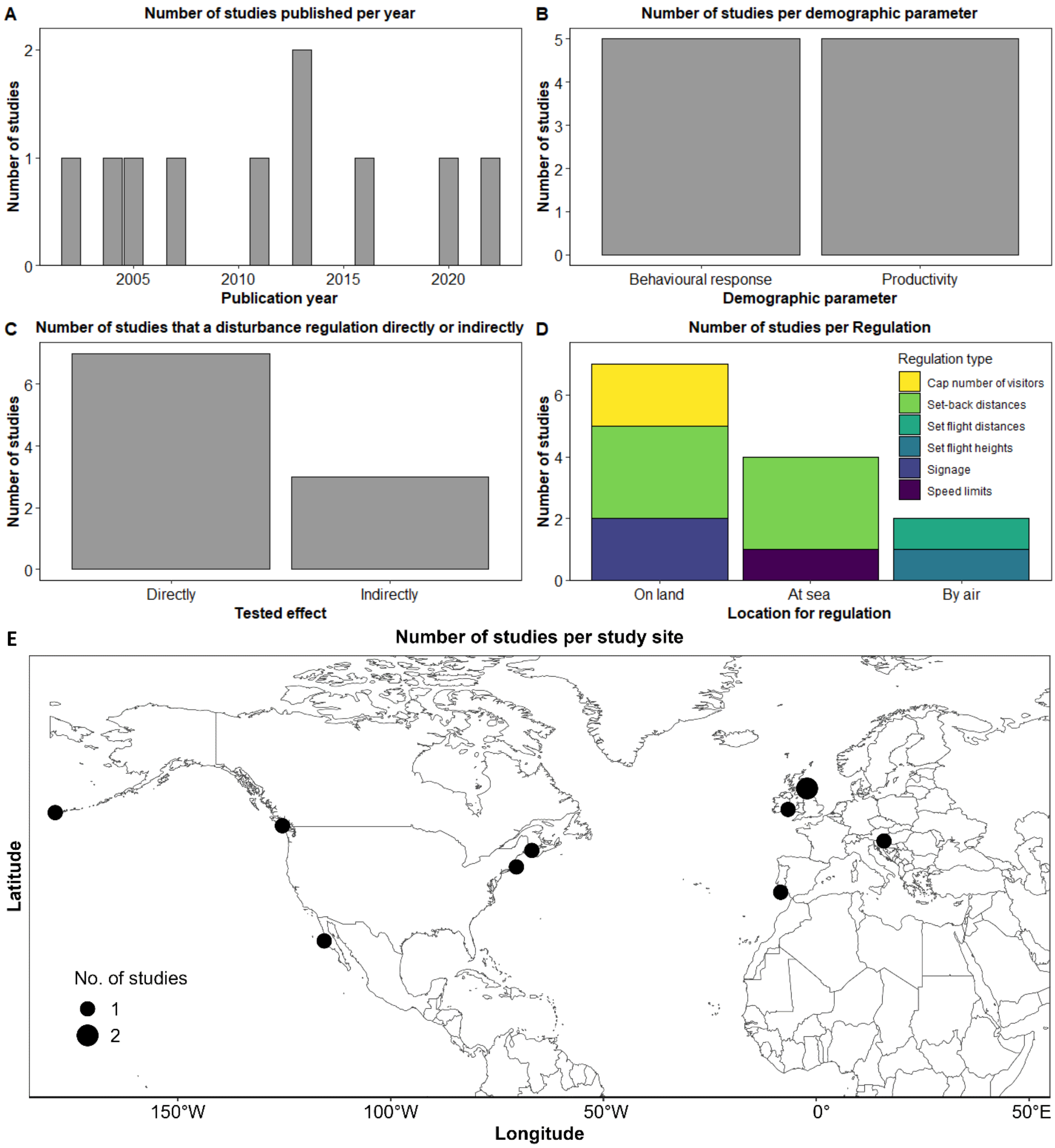

Figure 23. General observations of assessed records for disturbance at the colony review. A) number of studies published per year. B) number of studies per studied demographic parameter. C) number of studies that measured, directly or indirectly, the impact of a potential management measures on seabirds. D) number of studies per management type, and whether they were conducted on land, sea, or by flying objects. E) number of studies per study site.

Data was collected from multiple species, mostly on auks (Guillemot, Pigeon Guillemot, Black Guillemot, Cassin's Auklet), followed by gulls (Kittiwake, Black-headed Gull, Glaucous-winged Gull), terns (e.g. Common Tern, Roseate Tern, Little Tern), cormorants (Brandt's Cormorant, Double- crested Cormorant, Pelagic Cormorant), and Gannet. Some references researched multiple species.

5.6.4.2 Evidence scoring

The relevance, as well as the ecological efficacy scores for all ten references are shown in Table 35 (refer to Annex 4 for a detailed breakdown of the extracted data for each study). Overall, references were of low-medium relevancy for our assessment, with only two studies surpassing 20 points. Scores ranged between 15 and 23 out of a maximum possible score of 30, with a median score of 19.5 and a mean score of 19. Studies varied in their associated weight, ranging from 0.079 to 0.105 (Table 35). Out of the assessed studies, all suggested that measures to reduce disturbance at colonies could, potentially, have a positive effect on reducing unnecessary behavioural changes and on at least one demographic parameter of seabirds. Bishop et al. (2022), however, found that the effect of UAVs was species-dependent and, therefore, disturbance management measures may be more beneficial for some species over others.

Ecological feasibility: Reduction of disturbance (at colony)

Table 35. Relevance and ecological efficacy scores, as well as the type of regulation and whether it applies on land, at sea, or by air, and its effect on seabirds for each assessed study of the disturbance management at and around the colony review. Relevance scores (in bold) could have a potential score between 6 and 30 (6=studies of low relevancy, 30=studies of high relevance). Ecological efficacy scores (in bold) could have a potential score between 0 and 25 (lower scores reflect studies that did not find a significant effect of the disturbance management measure, or those with low statistical inference; higher scores reflect studies that found a strong beneficial effect of the management measure and high statistical inference). SI = Statistical inference and DE = Degree of effect. References are ordered from lowest to highest final ecological efficacy scores (total ecological efficacy score x weight).

		Relevance								Ecological Efficacy				
Reference	Management	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[1] Althouse et al. (2016)	Set-back distances (land)	5	1	1	1	5	2	**15**	0.375	0.079	3	1	**3**	0.236
[2] Ronconi and Clair (2002)	Set-back distances and speed limits (sea)	5	5	4	1	2	1	**18**	0.5	0.094	3	1	**3**	0.283
[3] Vogrin (2013)	Set-back distances (sea)	5	5	4	1	3	1	**19**	0.541	0.099	3	1	**3**	0.298
[4] Beale and Monaghan (2005)	Restriction of number of visitors (land)	5	1	5	5	3	1	**20**	0.583	0.105	3	1	**3**	0.314
[5] Chatwin et al. (2013)	Set-back distances (sea)	5	5	4	1	3	2	**20**	0.583	0.105	3	1	**3**	0.314
[6] Bishop et al. (2022)	UAV (air)	5	5	5	1	5	2	**23**	0.708	0.12	4	1	**4**	0.482
[7] Allbrook and Quinn (2020)	Use of signage (land)	5	1	1	4	5	1	**17**	0.458	0.089	2	3	**6**	0.534
[8] Beale and Monaghan (2004)	Set-back distances and restriction of number of visitors (land)	5	5	5	5	2	1	**23**	0.708	0.12	3	2	**6**	0.723

Ecological feasibility: Reduction of disturbance (at colony)

		Relevance								Ecological Efficacy				
Reference	Management	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[9] Albores-Barajas and Soldatini (2011)	Set-back distances (land)	5	5	2	1	2	1	**16**	0.417	0.084	3	3	**9**	0.754
[10] Medeiros et al. (2007)	Use of signage (land)	5	5	1	2	3	4	**20**	0.583	0.105	4	3	**12**	1.257
Total								**191**					**52**	**5.2**

The ecological efficacy, i.e. the likelihood that measures to manage disturbance on land, at sea, or airborne (e.g. UAV) around colonies is beneficial on at least one seabird demographic parameter, varied across studies. Overall, ecological efficacy scores were low, ranging from 3 (management measures at colonies had minimal effect on seabirds) to 12 (management measures at colonies had a medium effect on seabirds) out of a maximum possible score of 25. The median score was 3.5 (Figure 24). The lower scores observed can be attributed to the fact that the studies primarily focussed on measuring behavioural aspects rather than directly measuring the effects of management measures on demographic parameters (e.g. it is unclear how and to what degree higher flushing rates affect productivity and/or survival).

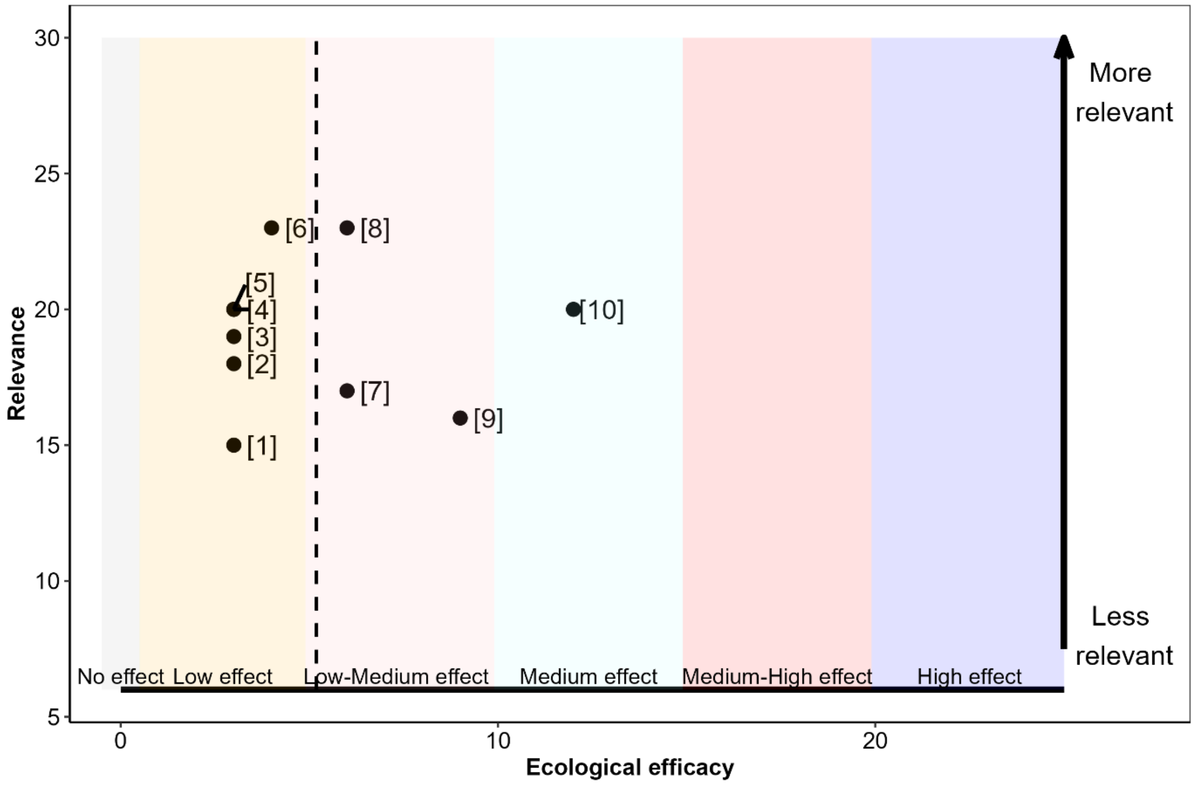

Figure 24. Ecological efficacy and relevance scores for each assessed study on the effect of management measures of disturbance at and around colonies. The numbers correspond to the study identifier, as indicated in Table 35. Colours are used to differentiate the magnitude of the effect that disturbance management measures have on at least one seabird demographic parameter. Vertical dashed line indicates the overall ecological efficacy of at-colony disturbance management measures.

The sum of all final weighted scores is 5.2 (i.e. the mean of ecological efficacy weighted by relevance), indicating that overall, the evidence suggests that management measures at-colony to reduce disturbance will benefit seabirds to a low-medium degree (Figure 24).

5.6.4.3 Overall confidence scoring

We estimated the median of the relevance index score, the independence and quantity of the evidence and the concordance between studies to obtain an overall score to assess the confidence in our findings (see Confidence). The total score for this measure was 9 out of the possible 15 (Table 36), suggesting that we have a medium degree of confidence that the assessed estimation of the ecological efficiency is an accurate reflection of the ecological efficacy of management measures to reduce disturbance at the colony.

Table 36. Assessment of the confidence in the evidence for management of at-sea disturbance.

Factor	Results	Score
Median relevancy	Median = 0.56	3
Independence and quantity of evidence	Studies are from several of authors and study systems, 10–15 studies	2
Concordance	SD = 0.9	4
		Total 9/15

5.6.4.4 Main findings: the effect of reduction of disturbance at the colony

In summary, our literature review and respective analyses provide evidence that, with a medium degree of confidence, management measures of disturbance at and around colonies has a low-medium effect on at least one demographic parameter of seabirds. This, however, needs to be treated with caution given that half of the studies recorded changes in behaviour responses towards disturbance, making it challenging to accurately quantify their impacts on demographic parameters (e.g. productivity and survival).

The key findings from the most relevant studies are summarised in Table 37. Most studies directly tested the effectiveness of management measures by recording the distance at which seabirds exhibited behavioural distress or flushing, as well as differences in productivity in relation to proximity to pathways. Indirect assessments were conducted by examining human responses (e.g. how close they got to nests) when signs were present, and relating it to differences in breeding success of nests at different distances of pathways.

On land, the management measures that were tested were setting a fixed set-back distance of visitors to nests, managing the number of visitors, and the use of signage to reduce visitor effects on nest disturbance. The most common on-land management measure involved estimating set-back distances and regulating the number of visitors allowed at a site. Most studies compared productivity between highly disturbed plots (i.e. plots closest to paths, which also received more visitors) and less-disturbed plots (i.e. plots farther away from paths and visitors).

Table 37. Summary findings of the five most relevant studies on the effect of management measures to reduce at-colony disturbance on seabirds, in order of decreasing relevance.

Reference	Management measure	Results summary
[8] Beale and Monaghan (2004)	Set-back distances and restriction of number of visitors (land)	Use of productivity observations, nest characteristics and human disturbance observations (number of visitors and distances to nests) to estimate differences in Guillemot and Kittiwake productivity at St Abbs Head, Scotland. Accounting for nest physical features, the presence of people had a strong negative effect on productivity on both species. For Guillemot, increasing the number of visitors by 8.5% resulted in a decline in productivity from 70.1% to 66.2%, while halving the visitor levels resulted in a new nesting success of 87.2%. When the number of visitors were kept constant, productivity was negatively correlated with the average distance people were from the nests. For Kittiwake, increasing the number of visitors by 8.5% resulted in a decline in productivity from 42.5% to 29.4%, while halving visitor levels resulted in an increase of productivity to 95.6%. Authors suggest that fixed set-back distances are likely to increase productivity on these species but may not be an appropriate conservation tool at sites where visitors strongly fluctuate spatially and temporally. Overall, need to ensure that when more visitors, longer set-back distances are set.
[6] Bishop et al. (2022)	UAV regulations (air)	In 2021, two models of UAVs were flown at different speeds and distances (slow vs fast, and close vs far) to record the behavioural response of Guillemot, Kittiwake and Cormorants during the incubation and chick-rearing period at the Alaska Maritime National Wildlife Refuge. Neither Cormorants nor Guillemot flushed or showed changes in individual behaviour during UAV flights. On the contrary Kittiwake did flush and had individual variation in activity budgets, although most of these birds were not incubating or brooding. At both the colony and individual level, there was a slightly greater behavioural responses to smaller UAVs and closer approaches.
[10] Medeiros et al. (2007)	Use of signage (land)	In Algarve, Portugal the productivity of Little Tern in 2003-5 was significantly higher on two beaches with information and warning signs and weekend wardening, compared to a beach without protective measures (50-91% productivity for 339 nests on the two protected beaches vs. 0-35% productivity for 153 nests on the unprotected beach). The presence/absence of protective measures was the most

Reference	Management measure	Results summary
		important predictor of productivity. The main causes of nest failure were predation, destruction by humans and dogs and abandonment.
[5] Chatwin et al. (2013)	Set-back distances (sea)	Experiments were undertaken in Vancouver Island at different roosting and nesting colonies of several species (e.g. Glaucous-winged Gull and Pigeon Guillemot). Experiments consisted of using motorboats and kayaks to estimate the distance when birds start to show an agitated behavioural response (not enough to flush birds) to the disturbance. Roosting seabirds were generally more sensitive than nesting birds to boat disturbance. At 70 m, species showed agitation. When nesting at 30 m (the closest vessels got to the colonies), gulls had a lower probability of agitation (8.3%), followed by Pigeon Guillemot (11.2%), Pelagic Cormorants (15.5%) and Double-crested Cormorants (21.6%). No differences were observed in the proportion of individuals showing agitation throughout the season. Kayaks could reach closer without causing agitation. Authors recommend establishing a single set-back distance, in this case 50 m, to enhance rule compliance among people.
[4] Beale and Monaghan (2005)	Restriction of number of visitors (land)	Use of observations to find the relationship between the number of visitors and Kittiwake and Guillemot productivity at St Abbs Head, Scotland. Daily failure rates for Kittiwake were weakly correlated with daily visitor numbers but indicated that capping daily visitor numbers slightly reduced overall productivity. Capping the visitor number at a maximum of 250 per day would result in one more failure per 100 nests. Guillemot productivity, on the other hand, were not significantly associated with visitor numbers. Capping the daily visitor numbers may have small conservation costs but only for some species.

Overall, nests located closer to paths had lower breeding success (Beale and Monaghan, 2004; Albores-Barajas and Soldatini, 2011; Althouse et al., 2016; Allbrook and Quinn, 2020). In St Abbs Head, Scotland, Kittiwake, in particular, seemed to be more susceptible to human disturbance than Guillemot (Beale and Monaghan, 2004; Beale and Monaghan, 2005). In Mexico, Cassin's Auklets, a burrowing auk, located within 30 m of paths had significantly lower breeding success (~0.45) compared to those located more than 50 m from paths, despite all having similar hatching rates (Albores-Barajas and Soldatini, 2011). Common Tern and Roseate Tern in Massachusetts, USA, exhibited higher flush rates in response to pedestrians than to researchers. The predicted flush probability increased from 0 to 6%

when researchers approached within 50 m. However for pedestrians, the predicted flush probability increased from 6% to ~35% (Althouse et al., 2016). The authors suggest that the speed, angle, and consistency of the approach may explain the differential responses of terns to pedestrians and researchers.

Two studies examined the effectiveness of signs in reducing human disturbance at seabird colonies. In Ireland, Allbrook and Quinn (2020) found that regulatory signage significantly influenced visitor behaviour, leading to a reduction in visitor proximity to Gannet nests when signs were present compared to periods without signs. This decrease in visitor proximity resulted in fewer birds displaced from their nests. Notably, photographers were the only visitor group that did not comply with the signage. Similarly, in Portugal, Medeiros et al. (2007) discovered that the presence of protective measures (warning signs and wardening) was the most important predictor of Little Tern nesting success. Birds were up to 34 times more likely to succeed when these measures were in place. Authors also found that earlier breeders were the most to benefit from the protective measures.

At-sea studies focussed on the behavioural response of seabirds to approaching vessels, primarily motorboats and kayaks. All three studies estimated the distance at which birds flushed in response to vessels. In Vancouver Island, roosting seabirds were generally more sensitive to boat disturbances than nesting birds (Chatwin et al., 2013). When birds were nesting and vessels approached at 30 m, Glaucous-winged Gulls showed a lower probability of agitation (8.3%), followed by Pigeon Guillemot (11.2%), Pelagic Cormorant (15.5%) and Double-crested Cormorant (21.6%). No agitation was recorded for any species at 70 m. Authors recommend setting a single set-back distance, which, at this site, is 50 m. Similarly, the flushing probability of Black Guillemot in Canada, decreased as boat approach distance increased, with the greatest flushing probability associated with fast boats and closer approach distances (Ronconi and Clair, 2002). In Slovenia, Black-headed Gulls flushed when motorboats approached within 67 m, returning after 11 minutes, and Common Tern flushed when the boats were at 73 m, returning within 5 minutes (Vogrin, 2013).

Only one study tested the impact of drones or UAVs at seabird colonies. Bishop et al. (2022) tested the effect of two models of UAVs flown at different speeds and distances on the behaviour of Guillemot, Kittiwake and Cormorants during the incubation and chick-rearing period in Alaska. Neither Cormorants nor Guillemot exhibited signs of flushing or changes in individual behaviour during UAV flights. In contrast, Kittiwake did flush, and there was individual variation in their activity budgets, although most of these birds were not incubating or brooding. At both the colony and individual level, there was a slightly greater behavioural response to smaller UAVs and closer approaches.

5.6.4.5 Biases or Conflict of interests

The authors did not disclose any biases or conflicts of interest, and our investigation did not reveal any such concerns.

5.6.5 Discussion

Our review highlighted that human disturbance in the vicinity of seabird breeding colonies, both nearshore and on land, can originate from various activities. These disturbances can have a wide range of impacts, ranging from minor to severe. Overall, we concluded that reducing disturbance could have a positive effect on seabird populations, however, the evidence available limits our confidence in this assessment with most studies measuring behavioural responses (e.g. avoiding flushing) rather than measures of population level impact (e.g. breeding success).

The level and types of disturbance for a given seabird colony will be site-specific and will depend on the range of activities present. Disturbance can originate from: land-based activities (e.g. humans and pets); sea-based activities (e.g. recreational watercraft); and aerial disturbances (e.g. UAVs such as drones). As such, managing disturbance will largely require site-specific measures, though there can be benefit in these being underpinned by national level regulations and guidance.

Regarding disturbance originating on land, largely from visitors at seabird colonies, the main actions identified include set-back distances, controlling the number of visitors, and signage. Signage alone has been shown to effectively improve visitor behaviour to reduce disturbance (Allbrook and Quinn, 2020). One study investigated the effectiveness of using wardening in addition to signage (Medeiros et al., 2007). Wardening is likely to be beneficial for sites experiencing higher visitor numbers and may be relatively resource-efficient if targeted at times of highest visitor traffic (weekends/peak holiday season). For most sites it is likely that using a combination of actions will be most effective.

Regarding inshore waters neighbouring seabird colonies, the studies we reviewed focussed on the behavioural responses of seabirds to approaching vessels, with potential management measures including set-back distances (nearshore exclusion zones) and speed limits. Studies generally found that higher speeds and nearer approaches were associated with larger behavioural response (Ronconi and Clair, 2002; Chatwin et al., 2013; Vogrin, 2013). Coastal buffers with exclusions zones may be possible to implement under existing legislation in Scotland as site-based management measures for SPA seabird colonies. Even relatively small buffers (tens to hundreds of meters) may be able to substantially reduce disturbance. This would require careful site-specific consideration, including *inter alia* the safety of water users (e.g. potentially increases danger for kayakers and stand-up paddleboarders if required to make wide detours into deeper waters further from the coast), impacts on visitor access (e.g. wildlife watching vessels), and some economic activity (e.g. creel fishing). Most of these impacts can likely be mitigated, for example, through exclusion zones only including the area closest to the coast with a wider zone including some restrictions (e.g. speed limits and craft type).

An increasing potential source of disturbance comes from UAVs (also known as drones), which may be operated by tourist visitors or for research purposes. Only one of the studies included in our review considered these (Bishop et al., 2022), which found contrasting behavioural responses between species, with Common Guillemot not showing any response while Black-legged Kittiwake showed rates of flushing. Counter-intuitively that study found a smaller UAV led to stronger reactions than a larger platform UAV. There are various regulations and recommendations for UAV use (Edney et al., 2023).

While several of the studies reviewed found species-specific responses, it may not be optimal to tailor management and regulation to specific species. Chatwin et al. (2013) suggest that a standard regulation (e.g. a single set distance for all species and all vessels) is easier for visitors to follow and more likely to result in a positive response.

As has been outlined, most studies of disturbance have relied on monitoring behavioural reactions, however, how these behavioural responses relate to population level impacts is generally unclear (Blanc et al., 2006). However, understanding how these sub-lethal effects lead to population level responses can be investigated via modelling studies, as has been used to investigate the impacts of displacement and barrier effects from offshore wind farms (Searle et al., 2018). Even if no behavioural reaction is observed there is still potential for sub-lethal effects, a study on Humboldt Penguin (*Spheniscus humboldti*) found elevated heartrates when people approached individuals (Ellenberg et al., 2006). This suggests that we should not assume that there is no disturbance just because there is no obvious behavioural response. While it is typically more challenging to monitor burrow or cavity nesting species, it is important to consider these species as they can be vulnerable to visitor disturbance (Bancroft, 2009; Watson et al., 2014; Watson et al., 2021).

It should also be noted that while in general we expect visitors to have some level of negative impacts on seabird populations, in some cases there may be beneficial impacts too. A study on Common Guillemot in Sweden found that removing visitors during the Covid-19 pandemic led to increased predation and disturbance by White-tailed Eagle (Hentati-Sundberg et al., 2021a). Such counter-intuitive effects, mean that any proposed measures should be considered carefully with a site and species-specific context considered.

5.6.6 Knowledge gaps and future directions

Overall, there is a lack of evidence of how behavioural changes impact demographic parameters. There is a need to better understand sub-lethal effects in seabirds in general, which is particularly relevant for understanding disturbance impacts. As has been noted above this can be investigated using bio-energetic models and our physiological understanding can be improved by use of dataloggers that record physiological metrics, like heartrate, or monitoring bio-markers of stress (e.g. corticosterone, see Watson et al. (2021)).

The majority of studies found here were from outwith Scotland and the UK, meaning that there is increased uncertainty when transferring these results to a Scottish context. There would be benefit in more studies on seabirds in the UK, especially on gulls and Razorbill which we found fewest studies for amongst the focal species.

5.6.7 Conclusion

The studies reviewed show that disturbance impacts at seabird colonies are highly species- and site-specific. Overall, there is relatively little specific relevant evidence available to appraise the potential benefit in conservation actions to reduce disturbance, though of those studies reviewed most did find a beneficial effect. Disturbance is hard to measure and relate to population level impacts, especially as responses are not always visible (e.g. stress), and behavioural studies are difficult to translate into effects on demography to understand population level impacts. This review suggests that there could be benefits to actions to reduce disturbance at seabird colonies. However, given the uncertainty in the population level benefits from these, and the species-species aspects, it would require further work to both understand impacts and what mitigations are most effective to have potential for use as strategic compensation. Given that disturbance is a highly site-specific, it would likely have most benefit investigated as project-specific compensation underpinned by detailed knowledge of target sites.

5.7 Ecological feasibility: Reduction of disturbance (at sea)

5.7.1 Summary

The systematic literature review and respective analyses provide evidence that, with a medium degree of confidence, the management of at-sea disturbance has a low to medium effect on at least one demographic parameter of seabirds. However, these findings should be interpreted carefully, as the results from these studies primarily focussed on behavioural aspects, making it challenging to translate such effects to impacts on demographic parameters (e.g. productivity and survival). As such, at this stage, we advise that there is not sufficient evidence to justify its progression as a potential strategic compensatory measure.

5.7.2 Introduction and background

Seabirds have evolved to spend most of their lives in marine environments (Young and VanderWerf, 2023). Throughout the breeding season, seabirds congregate at colonies on land but continue to rely primarily on marine resources for sustenance. Outside of the breeding season, they disperse widely, often covering extensive distances and having prolonged periods at sea without returning to land. The non-breeding season is crucial for resting, moulting, migrating and replenishing energy prior to the breeding season. Consequently, understanding and assessing the threats faced by seabirds during their time at sea is crucial for their effective conservation (Lieske et al., 2020).

Some of the main threats that seabirds encounter whilst at sea include bycatch, overfishing, winter storms, pollution, and disturbance (Yorio et al., 2010; Dias et al., 2019; Lieske et al., 2020). Following Coetzee and Chown (2016) and Allbrook and Quinn (2020), human disturbance to wildlife refers to any activity, event, or action conducted by humans that induce physical, behavioural, or physiological changes in individuals, potentially leading to short- or long-term stress or fitness responses. The primary source of potential disturbance to seabirds at sea is via vessel-related disturbance, affecting seabirds during various stages of their annual cycle, both during the breeding and non-breeding seasons (Bellefleur et al., 2009; Burger et al., 2019).

The presence and activities of different types of vessels, such as fishing vessels, commercial ships, cruise ships, and recreational boats, can disrupt the behaviour and foraging activities of seabirds (Velando and Munilla, 2011; Lieske et al., 2019). Noise, light and oil pollution, physical disturbance caused by vessel movements, and direct collisions can adversely affect an individual's foraging efficiency, especially during peak chick-rearing period, which may result in increased energy expenditure (Cianchetti-Benedetti et al., 2018; Lieske et al., 2020). Furthermore, vessels can have wider ecosystem effects (Abdulla and Linden, 2008), including displacing seabirds from important foraging locations, alter migration patterns and degrade habitats, potentially disrupting different aspects of the food chain, including their prey. Collectively, these impacts may lead to overall reduced reproductive success and survival among individuals.

Studying seabirds at sea is fundamentally challenging, due to the remote areas and difficult conditions, thus requiring specialised approaches including expensive research vessel access (Ballance, 2007). In addition to this disturbance can be challenging to detect as if there is no apparent behavioural response there can still be physiological impacts such increased stress and cardiac rhythm, and reduced immunity (Ellenberg et al., 2006). This has limited our understanding of how vessels at sea may disturb seabird populations. It is important to understand this risk though, given that vessel activity is increasing, with potential for increased risk to seabirds. Therefore, earlier studies have often focussed on expert judgement and vulnerability assessment approaches to quantify vessel disturbance risk (Certain et al., 2015; Lieske et al., 2019). However, with improving technology and remote monitoring it is becoming more possible to understand how birds respond to vessel presence at larger scales (e.g. Burger et al. (2019)). Certain management options are possible to mitigate for vessels disturbance which could reduce impacts on seabird populations.

The aim of this literature review is to gather evidence on the potential for at-sea vessel management to reduce disturbance impacts on seabirds and to what extent this could lead to population level benefits.

5.7.3 Methods

The conservation action, the reduction of disturbance at sea, is similar to the previous conservation action (see Ecological feasibility: Reduction of disturbance (at colony)). This review, however, will focus on the period when individuals are at sea, away from the colony during both the breeding and non-breeding period. It mainly focusses on marine vessels and on what management actions can be undertaken to decrease their impact on seabirds at sea. Therefore, the review was associated with two research questions. The first research question, 'What are the potential population level benefits from at-sea vessel management?', investigates the impact of disturbance management actions on seabirds whilst at sea. The second question, 'Which management action on what type of vessel provides the strongest benefit?' aims to identify the management action, as well as the type of vessel, that has the strongest beneficial effect on seabirds.

During a preliminary search, during the refinement of the search strings, it was clear that there was going to be limited evidence on the topic, as most studies focussed on the impact of at-sea disturbance on seabirds, rather than the effect of a specific management action. This observation is consistent with the findings of Sutherland et al. (2021), which also observed a lack of evidence regarding a list of management actions relating to at-sea disturbance on birds. Therefore, we focussed the search on two management actions: reducing vessel speed limits and shipping lanes.

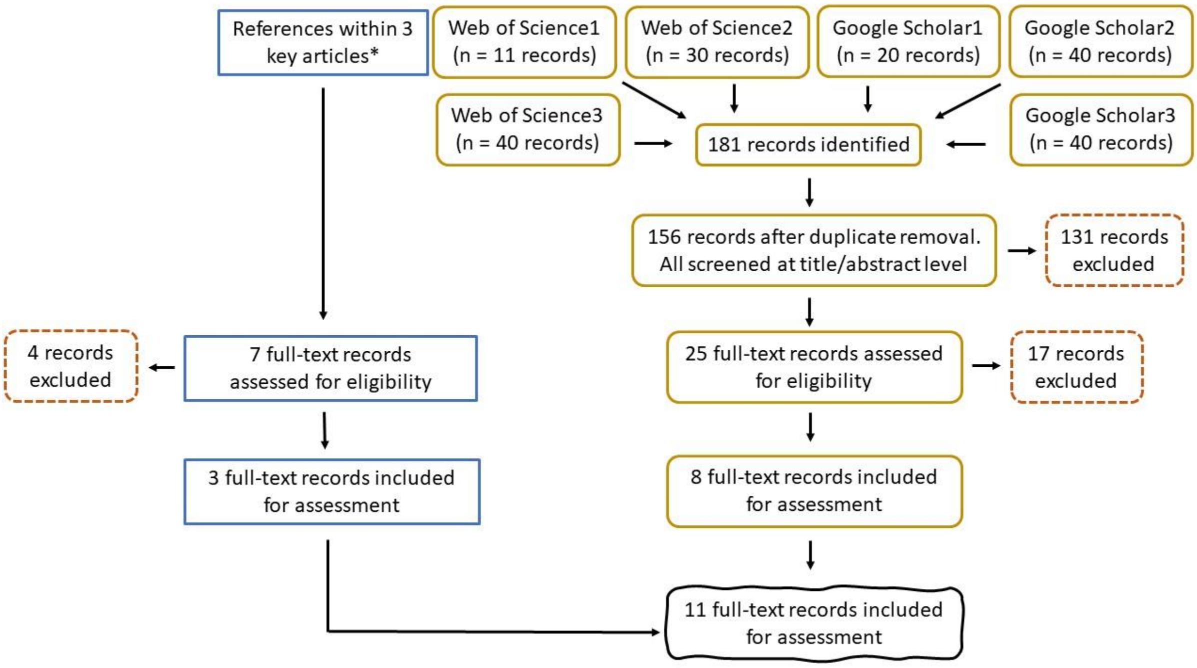

Figure 25. Flow diagram depicting the study selection process for the systematic review on reducing disturbance at sea. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Abdulla and Linden (2008), Furness et al. (2013), and MMO (2018).

A detailed description of the research question, keywords, search strings, and study selection (Figure 25) is provided in section 8 of Annex 1. Selection criteria can be found in Table A 2.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

Overall, 11 references were included for the final review.

5.7.4 Results

5.7.4.1 General observations

We identified 11 references that met our criteria of measuring the effect of at-sea disturbance on seabirds and waterbirds, all published in English. The literature review yielded relatively current publications ranging from 2005 to 2021 (Figure 26A), with a median publication date of 2011. All records were research articles. Studies mostly conducted behavioural observations and counts from vessels, airplanes, or in land to directly test the degree of impact of the management either on seabirds and/or waterbirds. The assessed studies focussed on the impact of at-sea disturbance on behaviour responses (e.g. whether they flew, dove, no response, distance moved, flush rates; 82% of studies), abundance and density (27% of studies), distribution (27%), foraging activities (18%), and resettlement rates (18%) (Figure 26B). It is important to note that all these are not demographic parameters *per se*, but potential drivers of demographic parameters and, therefore it is difficult to understand the impact that behavioural changes at sea will have on demographic parameters that will impact populations directly, such as productivity and survival.

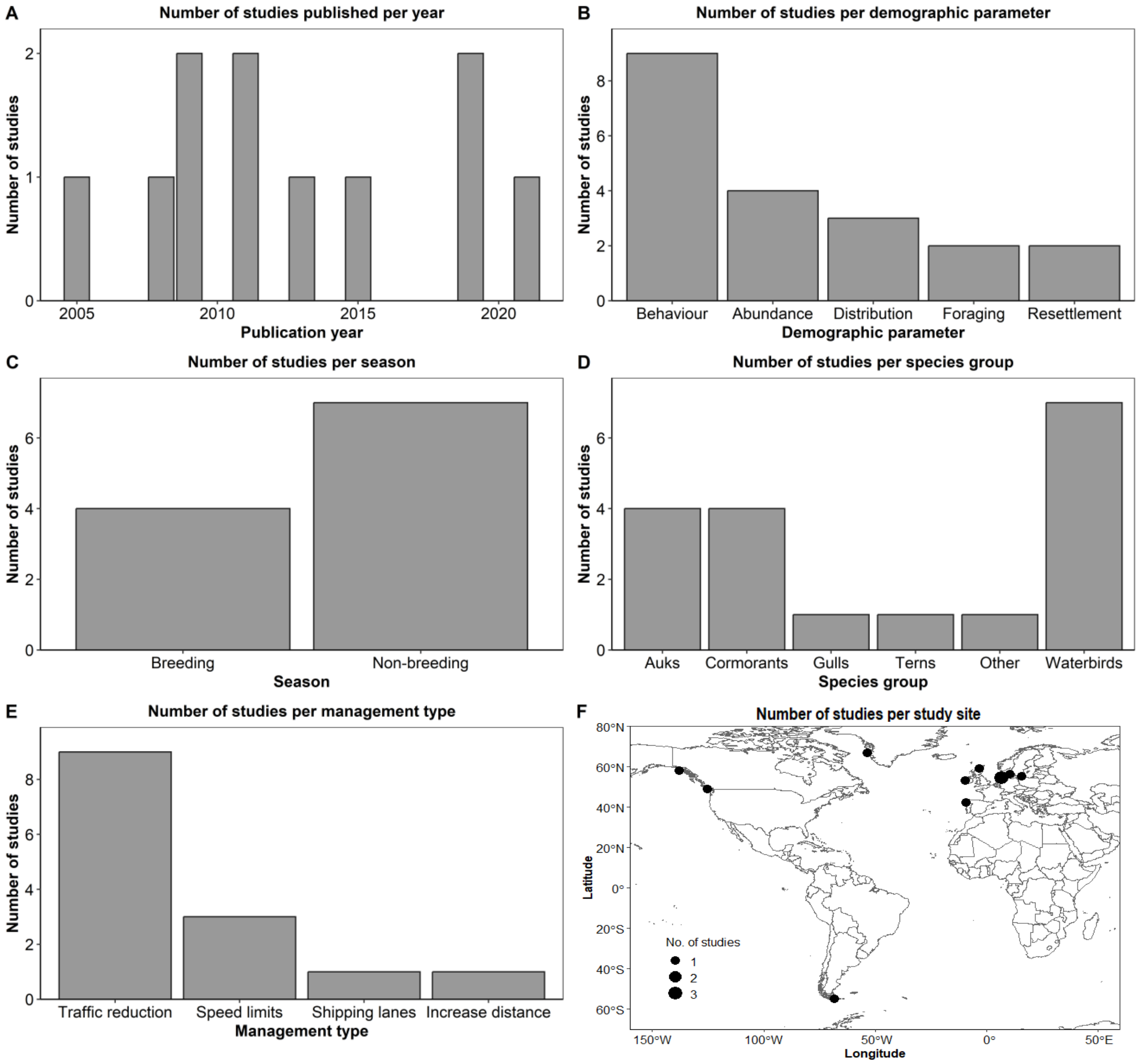

Figure 26. General observations of assessed records for disturbance at sea review. A) number of studies published per year. B) number of studies per studied demographic parameter; other = density and flush distance. C) number of studies per season (e.g. breeding or non-breeding). D) number of studies per species group; shags are included within the 'Cormorants' group; other = Gannet and Fulmar. E) number of studies per management type. F) number of studies per study site.

Most studies were undertaken during the non-breeding season (Figure 26C). Studies researched the effect of at-sea disturbance on diverse seabird and waterbird species groups (Figure 26D); mostly on waterbirds (e.g. grebes, ducks, scoters, divers), followed by auks (e.g. Guillemot, Razorbill, Black Guillemot, Marbled Murrelet, Kittlitz's Murrelet) and cormorants (e.g. European Shag, Rock Shag, Imperial Cormorant), followed by gulls (e.g. Kittiwake), terns (e.g. Common Tern, Arctic Tern), and other species like Fulmar and Gannet . Note that most records researched multiple seabird and/or waterbird species.

Records explored a range of management types (Figure 26E). Specifically, nine studies explored the effect of vessel traffic on birds, three studies explored the degree of vessel disturbance at different speeds, one study focussed on the effect of shipping lanes, and another investigated the extent of vessel disturbance at different distances. Due to the nature of this conservation action, these management types were all indirectly tested. For instance, studies opportunistically observed vessels operating at different speeds and subsequently measured their impact, albeit without directly testing the management type (e.g. 'reducing speed limits'). Data was collected from multiple seas, coasts, channels, and bays across the globe, close to Germany, Spain, Greenland, Ireland, the UK, Denmark, Argentina, Canada and the USA (Figure 26F). Only one study was undertaken within the UK, specifically in Orkney and investigated the behavioural responses of waterbirds to marine traffic.

5.7.4.2 Evidence scoring

The relevance, as well as the ecological efficacy scores for all 11 references are shown in Table 38 (refer to Annex 4 for a detailed breakdown of the extracted data for each study). Overall, references were of low-medium relevancy for our assessment, with only one study surpassing 20 points. Scores ranged between 12 and 23 out of a maximum possible score of 30, with a median score of 14 and a mean score of 16. For this reason, studies varied in their associated weight, ranging from 0.070 to 0.134 (Table 38). Out of the assessed studies, all but two suggested that vessel management to reduce disturbance could, potentially, have a positive effect on at least one demographic parameter of seabirds or waterbirds.

Ecological feasibility: Reduction of disturbance (at sea)

Table 38. Relevance and ecological efficacy scores, as well as the management action and its effect on seabirds or waterbirds for each assessed study of the disturbance management at sea review. Relevance scores (in bold) could have a potential score between 6 and 30 (6=studies of low relevancy, 30=studies of high relevance). Ecological efficacy scores (in bold) could have a potential score between 0 and 25 (lower scores reflect studies that did not find a significant effect of at-sea disturbance management, or those with low statistical inference; higher scores reflect studies that found a strong beneficial effect of at-sea disturbance management with high statistical inference). SI = Statistical inference and DE = Degree of effect. References are ordered from lowest to highest final ecological efficacy scores (total ecological efficacy score x weight).

		Relevance									**Ecological Efficacy**			
Reference	Management	Type	Direct	Species	Location	Year	Sample size	**Total**	**Score (0-1)**	**Weight**	SI	DE	**Total**	**Final score**
[1] Rosciano et al. (2013)	Traffic reduction	5	1	1	1	3	1	**12**	0.250	0.070	1	0	**0**	0
[2] Gittings et al. (2015)	Traffic reduction	3	1	1	2	5	1	**13**	0.292	0.076	0	0	**0**	0
[3] Jarrett et al. (2021)	Traffic reduction	5	1	2	5	5	2	**20**	0.583	0.116	3	1	**3**	0.349
[4] Merkel et al. (2009)	Traffic reduction	5	1	1	1	3	2	**13**	0.292	0.076	3	2	**6**	0.453
[5] Bellefleur et al. (2009)	Traffic reduction and speed limits	5	1	2	1	3	2	**14**	0.333	0.081	3	2	**6**	0.488
[6] Agness et al. (2008)	Traffic reduction and speed limits	5	1	2	1	3	2	**14**	0.333	0.081	3	2	**6**	0.488
[7] Larsen and Laubek (2013)	Increasing distance to birds	5	1	1	2	3	4	**16**	0.417	0.093	3	2	**6**	0.558
[8] Burger et al. (2019)	Traffic reduction and speed limits	5	1	1	2	5	4	**18**	0.500	0.105	3	2	**6**	0.628
[9] Schwemmer et al. (2011)	Shipping lanes	5	1	1	2	3	3	**15**	0.375	0.087	4	2	**8**	0.698
[10] Velando and Munilla (2011)	Traffic reduction	5	1	1	2	3	2	**14**	0.333	0.081	3	3	**9**	0.733
[11] Fliessbach et al. (2019)	Traffic reduction	5	1	5	2	5	5	**23**	0.708	0.134	5	2	**10**	1.337
Total								**172**					**60**	**5.7**

The ecological efficacy, i.e. the likelihood that the management of disturbance at sea is beneficial on at least one seabird or waterbird demographic parameter, varied across studies. Overall, ecological efficacy scores were low, ranging from 0 (the management of disturbance at sea would not have an effect on birds) to 10 (the management of disturbance at sea has a medium effect on bird colonies) out of a maximum possible score of 25. The median score was 6 indicating that the effect varied according to each study (Figure 27). The lower scores observed can be attributed to the fact that the studies primarily focussed on measuring behavioural aspects rather than directly measuring the effects on demographic parameters (e.g. it is unclear how and to what degree higher flushing rates during the non-breeding season affect survival).

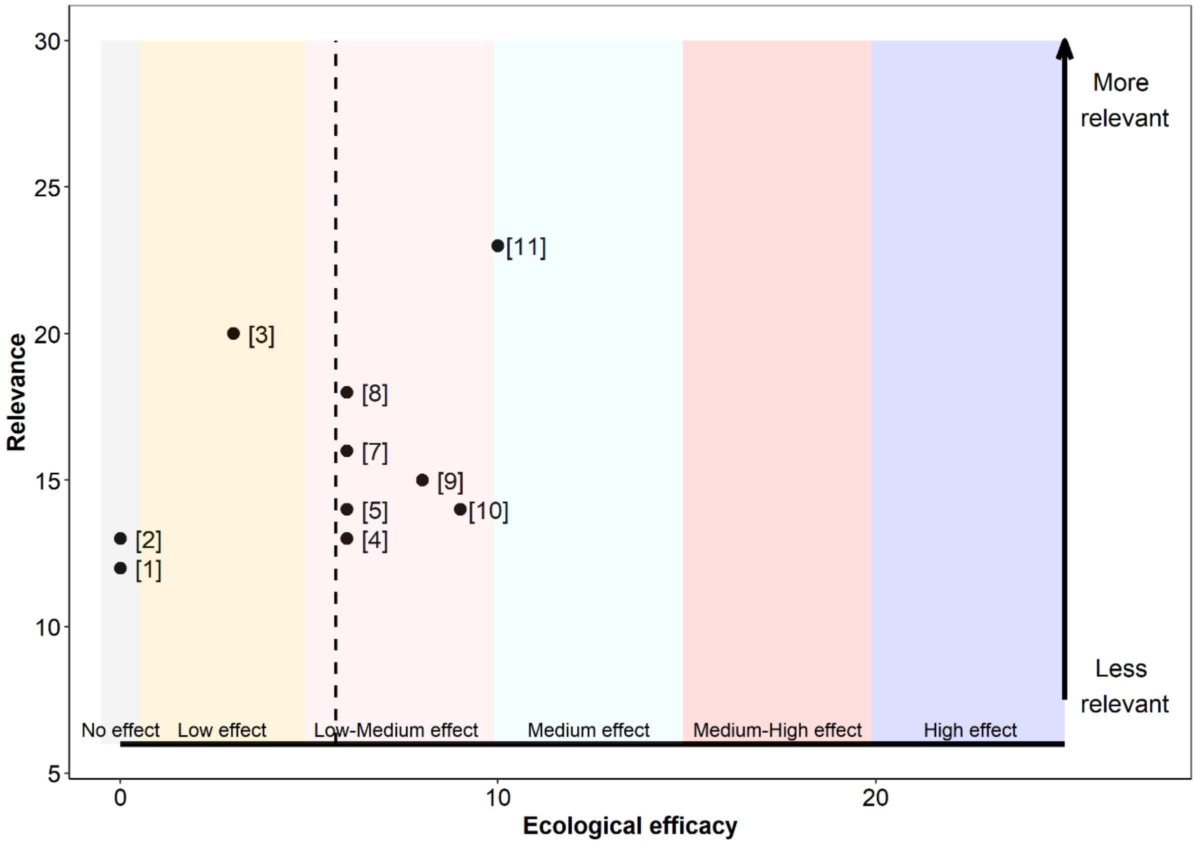

Figure 27. Ecological efficacy and relevance scores for each assessed study on the effect of at-sea disturbance management. The numbers correspond to the study identifier, as indicated in Table 38. Colours are used to differentiate the magnitude of the effect that at-sea disturbance management has on at least one seabird demographic parameter. Vertical dashed line indicates the overall ecological efficacy of at-sea disturbance management.

The sum of all final weighted scores is 5.7 (i.e. the mean of ecological efficacy weighted by relevance), indicating that overall, the evidence suggests that at-sea disturbance management will benefit seabirds to a low-medium degree (Figure 27), but this is through indirect evidence and difficult to be certain of – treat with caution.

5.7.4.3 Overall confidence scoring

We estimated the median of the relevance index score, the independence and quantity of the evidence and the concordance between studies to obtain an overall score to assess the confidence in our findings (see Confidence). The total score for this measure was 8 out of the possible 15 (Table 39), suggesting that we have a medium degree of confidence that the assessed estimation of the ecological efficiency is an accurate reflection of the true ecological efficacy of the management of at-sea disturbance.

Table 39. Assessment of the confidence in the evidence for management of at-sea disturbance.

Factor	Results	Score
Median relevancy	Median = 0.33	2
Independence and quantity of evidence	Studies are from several of authors and study systems, 10–15 studies	2
Concordance	SD = 0.88	4
	Total	8/15

5.7.4.4 Main findings: the effect of avian predator management

In summary, our literature review and respective analyses provide evidence that, with a medium degree of confidence, the management of at-sea disturbance has a low-medium effect on at least one demographic parameter of seabirds. This, however, needs to be treated with caution as the results from these studies are mainly behavioural, making it challenging to accurately quantify their impacts on demographic parameters (e.g. productivity and survival).

The key findings from the most relevant studies are summarised in Table 40. Most studies indirectly tested the effect of vessel management at sea on seabirds and/or waterbirds. While these studies did not implement explicit management actions (e.g. setting speed limits), they compared the responses of birds under different conditions (e.g. response to boats that were going at different speeds). Results from these studies can therefore provide insights into the potential effects of specific management actions.

Most studies found that birds were more abundant with no or little concurrent ship traffic, this is proven with Red-throated divers (Burger et al., 2019), European Shags (Velando and Munilla, 2011), Marbled Murrelets (Bellefleur et al., 2009) and other waterbirds (Schwemmer et al., 2011). Red-throated divers flushed shorter distances when fewer ships were present (Burger et al., 2019). European Shags, Common Eiders and Kittlitz's Murrelets reduced foraging once a boat was within the vicinity and, in most cases, birds flew away (Agness et al., 2008; Merkel et al., 2009; Velando and Munilla, 2011). These events increased with higher boat traffic, substantially reducing the time spent foraging. This also meant that when more boats were present, the probability of individuals being excluded form the best feeding areas also increased (Velando and Munilla, 2011). In the case of Common Eiders, there was a cumulative effect of repeated disturbances on the feeding activity if disturbances were close in time and space (Merkel et al., 2009). Kittlitz's Murrelets spent more time loafing and less time diving in days when there was no vessel traffic (Agness et al., 2008) and Great Northern Divers didn't seem to flush in response to boat

Table 40. Summary findings of the five most relevant studies on the effect of the management of at-sea disturbance on seabirds and waterbirds, in order of decreasing relevance.

Reference	Management type	Results summary
[11] Fliessbach et al. (2019)	Traffic reduction	Use of ship-based counts and observations to calculate a Disturbance Vulnerability Index (DVI) for 26 species of seabirds and waterbirds in the German North Sea and Baltic Sea. Disturbance responses to ships differed strongly between species. Species with long escape distances were also among the species with the highest proportion of escaping birds. Overall, flushing was the most common disturbance response (73% of all birds), compared with 1% that escaped by diving. The highest total proportions of birds with observed disturbance responses were divers, some auks, and other waterbirds. The lowest were gulls and Northern Fulmars. Regarding auks, the highest proportion of flushed individuals was among Black Guillemots (90%), compared to Razorbills (65%) and Guillemots (17%). The proportion of individuals that dived was higher among Guillemots (20%) compared with Razorbills (13%) and Black Guillemots (2%). Divers and mergansers escaped longer distances, compared to seaducks, Razorbills and Black Guillemots. Gulls and Guillemots flushed lesser distances. Divers and Black Guillemots had higher DVI values, followed by Razorbills, grebes, and mergansers, and terns and gulls had the lowest values.
[3] Jarrett et al. (2021)	Traffic reduction	Comparative evidence on the behavioural responses of waterbirds to marine traffic in Orkney. Overall, diver species showed high sensitivity to disturbance. Red-throated Diver, Black-throated Diver and Slavonian Grebe were the most likely species to exhibit a response to passing vessels. While Red-throated Divers and Slavonian Grebes were highly likely to flush, Black-throated Divers and Great Northern Divers rarely took flight, instead favouring swim or dive responses. In rougher sea conditions birds were more likely to take flight, and the propensity to respond declined across the wintering period.
[8] Burger et al. (2019)	Traffic reduction and speed limits	Use of aerial surveys, tagging and ship data to assess effects of ship traffic on Red-throated Divers in the German Bight of the North Sea. Divers were significantly more abundant in areas with low-frequency ship traffic. In areas where high-speed vessels (> 40 km/h) passed, very few

Reference	Management type	Results summary
		individuals were subsequently observed, and no or little increase in diver numbers was found. The fastest recovery of diver abundance was found for ships sailing at medium speed. Relocation distance of divers was shorter when no ships were present as compared to when one or more ships were present within the 3 km radius. Authors note that results from another study show no long-term declines of the population.
[7] Larsen and Laubek (2013)	Increasing distance to birds	Disturbance effects of high-speed ferries on wintering Common Eiders and Common Scoters in the Kattegat Sea. For Common Eiders: 90% of flocks flew or dove in response to an approaching ferry within 100 m. A proportion of flocks (> 10%) located within 400 m took flight in response to a passing ferry, and distributional impacts, including birds responding by swimming, were occasionally suggested within 500–1,000 m. High-speed ferry disturbance, had the potential to reduce habitat use within 500 m of the ferry route. Common Scoters tended to take flight further from the ferry route than Common Eiders, but data were limited and no strong conclusions could be made. The results show that high-speed ferries may be an important source of disturbance that should be given due attention when the cumulative effects of offshore activities on site use by sea ducks are considered.
[9] Schwemmer et al. (2011)	Shipping lanes	Effects of shipping lanes on six species of waterbirds in German offshore waters. Divers preferred areas between shipping lanes and avoided shipping lanes. Most birds flew away after disturbance, and distances varied between species and individuals. Individual numbers were lowest immediately after a disturbance. Larger flock sizes covered more distance when flushed. Indications of habituation as within shipping lanes some birds did not flush. Unclear whether birds could habituate to free-ranging ships.

traffic, even when these passed within <20 m from individuals (Gittings et al., 2015). Faster and closer boats caused a greater proportion of birds to flush, and at further distances on (Agness et al., 2008; Bellefleur et al., 2009; Larsen and Laubek, 2013; Burger et al., 2019).

Schwemmer et al. (2011) studied the impacts of shipping lanes on waterbird species in German offshore waters and found that divers preferred areas located between shipping lanes while actively avoiding the shipping lanes themselves. Some indications of habituation were observed within the shipping lanes, as certain birds did not flush in response to passing ships. However, it remains uncertain whether waterbirds can fully habituate to the presence of freely moving ships.

Fliessbach et al. (2019), however, found that their estimated Ship Traffic Disturbance Vulnerability Index varied strongly amongst species with Black Guillemot being more susceptible to vessel disturbance followed by Razorbill, Guillemot, Gannet, Kittiwake, gulls, and terns. Similarly, Jarrett et al. (2021) found differences in the likeliness and behaviour to respond to passing vessels; Red-throated Diver, Black-throated Diver, and Slavonian Grebe, for example, were most likely to respond compared to other waterbirds, and while Red-throated Diver and Slavonian Grebe were highly likely to flush, Black-throated Diver and Great Northern Diver were more likely to swim or dive.

5.7.4.5 Biases or Conflict of interests

Of the 11 studies, three include potentials for conflicts of interests (note we do not make judgement on whether these lead to an actual conflict of interest or influence study findings but provide the information for the readers' awareness). Two studies were wholly or partly funded by Federal Ministries (Schwemmer et al., 2011; Burger et al., 2019) and one article was funded by a Harbour Company (Gittings et al., 2015). The authors of the other studies did not disclose any potential biases or conflicts of interest.

5.7.5 Discussion

We did find evidence that seabirds could benefit from reducing at-sea disturbance. However, this was based on relatively few studies (only 11 met our study inclusion criteria), and the majority of these looked at behavioural responses rather than measures that are closer to population level impacts. This is akin to the findings we encountered during the Ecological feasibility: Reduction of disturbance (at colony) review, where there were the same general limitations with the evidence base available.

For this study, we focussed on the focal species and similar seabird species, however, given the lack of studies, we also included waterbird species such as Diver species (*Gavia* spp.) and sea ducks for which there was more evidence available, see e.g. (Merkel et al., 2009; Schwemmer et al., 2011; Burger et al., 2019). Diver species are known to be particularly vulnerable to vessel activity showing strong displacement responses, so have been the focus of various studies around their behavioural responses and their energetics (to better understand potential for physiological impacts) (Burger et al., 2019; Vilela et al., 2021; Thompson et al., 2023). However, whether this leads to a population level impact is unclear (Vilela et al., 2021). When considering management measures for seabirds aiming to reduce at-sea disturbance, it is important to also take into account these other species groups. This involves ensuring that any measures implemented do not lead to unintended consequences for other species, but also to learn from measures developed for better-studied groups.

There are a range of potential vessel management measures that could reduce disturbance. Bellefleur et al. (2009) identified three broad potential actions (in the context of reducing disturbance on Marbled Murrelets) most of which have also been considered in other studies (Lynch et al., 2010; Burger et al., 2019; Studwell et al., 2021): (1) limiting boat speed in nearshore areas; (2) spatial management of vessels to direct activity away from areas with the highest bird densities (e.g. using shipping lanes or area closures); (3) seasonal closures to boat traffic during periods of greatest activity. In addition to these broad measures that could apply to all vessels, large infrastructure projects, such as offshore wind farm construction and maintenance are often required to develop vessel management plans to mitigate the risk of disturbance.

The regulation and management of specific aspects of vessel traffic have the potential to provide some benefits in terms of survival and productivity in seabirds but there is a lack of specific evidence, especially to be able to predict the level of benefit to specific species. Evidence suggests that some species are more vulnerable to vessel activity than others (Fliessbach et al., 2019; Jarrett et al., 2021), though this is based on behavioural responses, so whether these translate to greater population level impacts is unclear. As discussed in further detail in Ecological feasibility: Reduction of disturbance (at colony), it is challenging to directly link the effects of disturbance and decreased feeding to population level responses. Studies using novel biologging devices to record behaviour and physiology at sea (Ropert-Coudert et al., 2012) can provide more direct measures than observational studies, e.g. of heart rate which is related to stress responses and energy expenditure (e.g. Ellenberg et al. (2006)). Behaviour and energetics of free-moving seabirds could then be related to vessel presence and movements, in a similar way to what has been done for studies relating to interactions with fishery vessels (Votier et al., 2010). This general approach has been applied for Red-throated Diver in Burger et al. (2019). There is potential to apply this to a wider suite of species, and, depending on the tracking already collected, it may be possible to do such analyses using existing datasets.

5.7.6 Conclusion

Overall, while our review indicates that reducing disturbance at sea would benefit seabirds, there was insufficient evidence to be able to come to clear conclusions on what actions may be helpful and what level of benefit could be anticipated. There is evidence of vessel presence and activity leading to behavioural response in marine birds, but few studies have gone on to link this to population level impacts. As such, at this stage, we advise that there is not sufficient evidence to be able to progress as a potential strategic compensatory measure. However, given that there is evidence that vessels can affect seabird behaviour, we advise that further research should be conducted to understand how disturbance effect varies between species, whether this leads to population level responses, and what actions may best reduce impacts.

6 Scoping and targeted reviews

For the proposed compensatory measures (Table 4) that could not readily be allocated to conservation actions, we undertook scoping reviews (see: Methods). For longline bycatch mitigation, however, where recent comprehensive work exists, we summarised the findings of these studies through a targeted review.

There is a dedicated section for each review, commencing with a list of the focal species identified in Table 4 and Table 6. This is followed by a general description of the key types of actions falling under each topic, identification of key sources, and discussion on potential conservation actions, followed by a conclusion. At the end of the section, there is a table summarising details of the identified conservation actions (Table 41).

6.1 Manage supporting habitats that relate to prey availability for seabirds

Focal and *secondary* species: Large gulls, Gannet, petrels, Guillemot, Razorbill, Puffin, *terns*

Actions identified: Habitat creation and restoration (e.g. seagrass) (CA1); Protection of spawning and nursery habitat (CA2).

This topic relates to actions aimed at improving or restoring habitats that support the prey species of seabirds. By doing so, these actions would increase prey abundance and, ultimately, enhance their availability to seabirds.

Seabird populations are sensitive to the abundance and availability of prey fish, as was outlined in the report sections focussed around prey fishery management (see Ecological feasibility: Sandeel fishery closure and Ecological feasibility: Fishery closure or enhanced management of prey fisheries (Sprat, Herring, and Mackerel)). As explained elsewhere in the report, establishing a direct link between prey abundance and positive impacts on seabird populations is challenging given the complexities within the ecosystem (illustrated in Figure 28). As such, managing prey-supporting habitats becomes even more challenging to directly correlate with population-level responses in seabird populations, which means that such measures may be difficult to develop as compensatory measures. Nevertheless, supporting habitats is crucial for seabird prey species and associated conservation actions would, in principle, lead to beneficial impacts for seabird populations.

The types and distribution of essential fish habitat supporting key fish species in Scottish Waters were recently reviewed in a Scottish Government commissioned report (Franco et al., 2022). This report reviewed many fish and shellfish species, including several which are prey species of seabirds, during at least part of their life cycle, e.g. Lesser Sandeel, Herring, gadoid species, Sprat, and Mackerel. This review builds on earlier studies which have focussed on individual species, e.g. Sandeel (Langton et al., 2021). Critical fish habitat depends on a variety of biotic (e.g. maerl beds and seagrass beds) and abiotic (e.g. substrate and water depth) factors. The types of habitats used by fish can vary across different life stages and, for migratory species, this can mean that the abundance of fish in one area is linked to conditions in a more distant area. This complexity adds difficulty when considering how this can translate in prey availability to seabirds.

We identified two high level conservation actions relating to management of supporting habitat related to prey availability in seabirds: habitat creation and restoration, and protection of spawning and nursery habitat. Each of these include a wide variety of more specific actions, e.g. habitat creation includes multiple habitat types, with one of the most widely considered being seagrass beds.

For habitat creation and restoration for inshore waters, NatureScot have produced guidance that outlines many of the points that need to be considered when developing such projects, including both ecological and practical considerations (NatureScot, 2022; 2023f). The Scottish Government, on the other hand, have produced guidance on the marine licensing considerations (Scottish Government, 2023b).

The creation and restoration of seagrass beds is one of the more developed types of marine habitat creation and restoration, which has previously been considered in the context of project-specific compensation for offshore windfarms (e.g. Hornsea Project Four). Seagrass beds have been identified as providing some of the most suitable habitat for nursery stages of several fish species in Scottish Waters (Franco et al., 2022). At the same time, seagrass beds have been associated with supporting bird populations through increased marine productivity (Unsworth and Butterworth, 2021). There is currently one such seagrass restoration project (also including oysters) underway in the Firth of Forth in Scotland, the Restoration Forth project led by WWF running between 2022-2024.

While habitat creation and restoration has promise, it is important to recognise that not all marine habitats can be recreated or restored (Tillin et al., 2022). This may limit the size of the possible benefit to seabird populations. For example, maerl beds are one important habitat type which are considered to be difficult to recover (Barbera et al., 2003). Tillin et al. (2022) provide a useful review of the principles that need to be considered to identify whether a habitat is possible to restore (there in the context of identifying what habitat is irreplaceable).

The protection of spawning and nursery habitat focusses on either removing existing pressures or avoiding potential future pressures to habitat (Aguilar and Blanco, 2019). For soft substrates, such as sand and gravel, fisheries using bottom trawling can negatively impact seafloor habitat with the extent of this varying between different gear types and sediments (Rijnsdorp et al., 2020). For Sandeel, their abundance is negatively correlated to the intensity of bottom trawling present in an area (Tien et al., 2017). For protected areas (e.g. SACs), additional regulations can be introduced to prohibit damaging gear types, as has been done recently via a bylaw prohibiting bottom towed fishing gear within the Dogger Bank SAC (MMO, 2022). Such management measures could potentially be introduced for other areas identified as being sensitive to such bottom gears.

There is an evidence base confirming the importance of supporting the habitat of seabird prey fish species and, therefore, conservation actions that could act to protect, restore, and create such habitats could ultimately lead to seabird population level responses. However, the uncertainties are very high meaning that it will rarely be possible to produce confident quantitative predictions of seabird population level responses to individual initiatives. It is therefore not clear that such measures would be suitable as compensation. However, given the potential for benefits to seabird populations, further research and investigation would be justified. An addition to improving the scientific evidence base, essential for using such measure as compensation, would be to develop a framework around which such ecosystem-based measures could be linked to seabird population level responses with sufficient confidence to justify deployment as compensation.

6.2 Reducing disease spread (including HPAI)

Focal species: All seabird species

Actions identified: Carcass collection during disease outbreaks (CA3); Managing standing water (CA4); Vaccination of wild birds (CA5); Rehabilitation of sick birds (CA6).

Birds are vulnerable to a variety of infectious diseases, with a diversity of emerging diseases increasing the future threat to wild bird populations (Bogomolni et al., 2006; Robinson et al., 2010). Botulism and HPAI, for example, have caused significant mortalities within UK seabird populations (Coulson, 2015; APHA, 2019; Klaassen and Wille, 2023; Lane et al., 2023; Pearce-Higgins et al., 2023). Depending on the disease and the context, some effective interventions exist to reduce its spread, thereby reducing population level impacts. However, in general the options are limited, particularly when dealing with seabirds breeding at remote locations.

Avian botulism is a disease leading to paralysis in birds arising from ingestion of a bacterial toxin produced by *Clostridium botulinum*. Outbreaks occur where there are suitable conditions for the bacteria to multiply, particularly in conditions of poor water quality (e.g. putrefying plant or animal material) (APHA, 2019). There have been sporadic outbreaks of botulism in seabirds in the UK, mostly affecting gulls (Coulson, 2015; APHA, 2019). However, there seems to have been a reduction in these occurrences following changes in landfill practices (Coulson, 2015). Best practice recommendations exist for dealing with outbreaks of botulism, with the key conservation actions identified being: the management of water bodies to reduce suitable conditions for the bacteria; collection of dead and sick birds; and rehabilitation of sick birds (WWT, 2012; APHA, 2019). There is, therefore, potential for a programme of measures to be effective in decreasing the frequency and severity of avian botulism outbreaks, and to rehabilitate sick birds. However, it is unclear to what extent such measures can be increased. If further action is both possible and effective, it may have some potential as a compensatory measure. This would require a detailed feasibility assessment.

Avian influenza is endemic to seabird populations (Granter et al., 2010; Montalvo-Corral et al., 2010; Wille et al., 2013), with recent highly pathogenic strains emerging, resulting in significant wild bird mortality (Klaassen and Wille, 2023). Since 2021, there has been an outbreak of HPAI within the UK, which has caused significant mortality among seabird populations (Lane et al., 2023; Pearce-Higgins et al., 2023). This outbreak is part of a global epidemic now impacting nearly all continents (Klaassen and Wille, 2023). Currently there are no universally accepted approaches for reducing the spread of HPAI, however there is a significant amount of ongoing research which may lead to identifying effective interventions. If these are identified and they are practical to implement in UK seabird populations, then there could be potential as a compensatory measure. Some candidate interventions have been proposed and, to a limited extent, trialled (reviewed in Pearce-Higgins et al. (2023)).

Carcass collection has been proposed with some evidence that this may reduce outbreak severity (Knief et al., 2023), though its efficacy remains unclear (Pearce-Higgins et al., 2023). NatureScot's Scientific Advisory Committee advises that the benefits, if any, are likely to be small unless demonstrated that much of transmission occurs from carcasses and that they can be removed at scale and rapidly (NatureScot, 2023g). There is general agreement that good biosecurity protocols would be justified, however these are unlikely to significantly reduce overall mortality. Vaccination may be a future option as a vaccination is being trialled currently on California Condors with promising early results (U.S. Fish and Wildlife Service, 2023). However, vaccinating large number of wild birds would be impractical. Nonetheless, it may have potential in more limited cases, such as in cases where there are small remnant populations at sites that could be protected. Overall, reducing the risk from HPAI outbreaks in wild bird populations will be largely reliant on actions to reduce the emergence of new strains from poultry production worldwide.

There are conservation actions identified for avian botulism but limited options currently available for HPAI. Further research and monitoring are required to identify whether there are effective interventions available for HPAI in wild birds. If these are identified, there may be scope for compensatory measures to allow these to be deployed at scale. However, even if options are identified, their practicality in seabird populations is likely to be constrained due to the nature of seabird colonies (e.g. steep cliffs, relatively inaccessible locations). Overall, it appears that there is limited scope for the reduction of disease spread to be developed as a compensatory measure.

6.3 Habitat Management (terrestrial breeding colonies)

Focal and *secondary* species: Gannet, Guillemot, Razorbill, Puffin, gulls, *terns*

Actions identified: Construction of coastal defence structures to reduce impact of storm events (CA7); water management to reduce flooding of burrow nesting seabirds (CA8); vegetation management to improve breeding habitat quality (CA9).

Habitat quality influences both the number of seabirds breeding at a site and their productivity. Therefore, habitat management actions can have potential to increase the breeding numbers and productivity of seabirds. Key aspects include how breeding habitat withstands extreme weather events and the presence of vegetation. To what extent these can be managed will be highly site-specific.

Seabirds breeding on coastal sites in exposed areas can experience nesting failure following summer storms, with one such event on the Isle of May leading to failure rates of 10–29% for species nesting in exposed areas (Newell et al., 2015). Such events are likely to increase in the future owing to climate change, with sea-level rises and increasing frequency and severity of storm events. Options to mitigate the impacts of these events at most seabird colonies are likely to be limited. Two potential options include coastal defence structures, such as boulders placed at cliff bases to reduce wave energy, and managing habitat to create new breeding spaces (e.g. vegetation clearance). There may also be potential for restoration or establishment of sub-sea habitats (e.g. kelp forest) that can increase wave attenuation, though it would be quite site-specific whether habitat is suitable, and the level of potential benefit in terms of reducing storm impacts is unclear (Elsmore et al., 2023).

Extreme rainfall events can lead to nesting failure through flooding in burrow nesting seabirds, including Manx Shearwater and Puffin (Thompson and Furness, 1991; Rodway et al., 1998). Climate change is increasing the frequency of extreme weather, so there is an increasing risk of flooding events. At some sites it may be possible to reduce flood risk through water management and drainage schemes; this would require site-specific investigation.

Vegetation can affect habitat quality, especially for burrow and ground nesting seabirds (Lamb, 2015). Interestingly, there is some evidence of positive feedback loops between the vegetation community and the abundance of seabirds at a site, with one study in Canada finding that when there is a greater population of Leach's Storm Petrel there is more suitable vegetation (Duda et al., 2020). Tree Mallow (*Lavatera arborea*) is a native plant to the UK but can have significant negative impacts on seabird colonies, particularly on burrow-nesting Puffin (Fischer and Van Der Wal, 2007). Favourable conditions over recent decades have led to increases in Mallow (Van Der Wal et al., 2008), prompting projects aimed at its removal, such as those around the Firth of Forth. While Mallow has been largely removed from the island of Craigleith (The SOS Puffin Project), apparently leading to an increase in the number of breeding Puffin, some plants persist in inaccessible areas of the island, and a seedbank remains, necessitating ongoing management (Anderson, 2022). Further Mallow removal is planned for two further Firth of Forth islands, Fidra and Inchmickery, as part of a new project (RSPB).

Overall, there are several potential conservation actions to improve seabird breeding habitat quality. However, some of these are relatively well demonstrated (e.g. Tree Mallow removal), while others are much more speculative (e.g. flood management and wave defences). Further work would be useful to scope out, in detail, what habitat management options exist and to identify suitable sites where these could be deployed. There is likely some scope for these actions to be used as strategic compensation, so further consideration could be worthwhile.

6.4 Bycatch mitigation in longline fisheries

Focal species: Gannet, Fulmar

Actions identified: Mitigation of bycatch in longline fisheries (CA10)

In Scottish Waters, there is a floated-demersal longline fishery (also referred to as 'piedra bola') which primarily targets European Hake (*Merluccius merluccius*). This is a unique type of longline fishery gear composed of longlines with a series of baited hooks interspersed with weights and floats that act to hold the hooks up above the seabed. Analyses of bycatch rates in UK Waters have identified concerning levels of bycatch of seabirds in this fishery, particularly of Fulmar and, to a lesser extent, Gannet (Northridge et al., 2020; Northridge et al., 2023). This followed on from earlier work mapping fishing activity, its overlap with seabird distributions, and species-specific bycatch risk that suggested longline fisheries could be of concern, i.e. a vulnerability assessment (Bradbury et al., 2017).

The incidental bycatch of seabirds by fisheries has been identified as one of the top three threats to seabird species globally, and the threat with the greatest average level of impact (Dias et al., 2019). Longline fisheries, in particular, have a high risk of seabird bycatch (Anderson et al., 2011), a phenomenon that has been extensively studied in albatross and petrel species in the southern hemisphere but has received less attention in the North-East Atlantic. Seabirds are attracted to fishing vessels for offal, bait, discards, and also for the catch itself, depending on the fishery and the seabird species.

Bycatch rates have been estimated based on a UK fishery observer programme[5], which deploys observers onto UK registered vessels operating out of UK ports, predominantly in the north-west of Scotland. Estimates of bycatch rates have high levels of uncertainty due to relatively low observer coverage and a non-systematic sampling approach (sampling has been undertaken on a 'sporadic and opportunistic basis'), with coverage of ca. 0.5% (Kingston et al., 2023), which falls well below the recommended minimum of >20% (Babcock et al., 2003). In any given year, there are ca. 500 trips made by UK registered longline vessels, but between 2010–2021 only 23 trips were observed (including 201 hauls) (Kingston et al., 2023). Kingston et al. (2023) produced the most up-to-date bycatch estimates, including year-specific estimates. For Fulmar, estimates were of >1000 individuals for most years, with levels increasing in recent years due to higher fishery activity. For Gannet, estimates were around 50 individuals/year but increased >100 individuals/year in recent years. In addition, there are small numbers of Great Skua (ca. 10 individuals/year) and Great Shearwater (ca. 15-25 individuals/year). It should be noted that non-UK registered vessels also operate in UK waters and are not included within these bycatch estimates, so total bycatch mortality is likely to be significantly higher.

It should also be noted that there are likely to be sub-lethal impacts for surviving birds (e.g. physical injury and stress). Bycatch monitoring exclusively records mortality, and not live-caught birds that are released. The level of live bycatch is unclear; if bycatch primarily occurs during setting, which is likely, then most birds would be dead due to drowning. However, some birds will likely be bycaught live as gear is recovered and/or during deployment if the gear does not fully sink with birds remaining at the surface. Therefore, benefits from bycatch mitigation may be greater than anticipated solely from bycatch morality estimates.

Estimates of the population level impacts of these revised bycatch rates have not been produced, however, based on bycatch levels previously assessed (Northridge et al., 2020), which were somewhat higher than the revised estimates, population viability analyses were undertaken (Miles et al., 2020). This indicated that Fulmar populations would be somewhat larger in the absence of bycatch mortality (whole UK ca. 7% after 25 years), while for Gannet numbers were lower, but still potentially significant (up to 1% after 25 years)[6]. Bycatch

[5] UK Bycatch Monitoring Programme (BMP). 'Cetacean Bycatch Observation Scheme' which includes summary indicators also for seabird and shark bycatch.

[6] Note for Gannet the analysis of Miles et al. (2020) also included bycatch in gillnet fisheries.

impacts will not be spread evenly, with the fishery concentrated along the shelf edge to the west and north of Scotland, and around the Shetland Isles. Therefore, we can anticipate that Gannet and Fulmar populations breeding in these areas are likely to be experiencing the highest bycatch rates so would benefit from bycatch mitigation.

Bycatch is one of the most tractable threats to seabird populations with multiple bycatch mitigation methods developed with success in decreasing bycatch rates substantially (Anderson et al., 2011; Løkkeborg, 2011; Melvin et al., 2014). Reducing bycatch rates can also be economically advantageous to the fisheries by reducing costs from lost bait, gear damage, and time lost extracting bycaught birds (Kühn, 2016; Avery et al., 2017). Trials of various bycatch mitigation measures have successfully decreased rates of bycatch, specifically in Fulmar (Løkkeborg and Robertson, 2002; Fangel et al., 2016; Kühn, 2016). A key issue for the fishery operating in Scotland is that the sink-rate of the gear (i.e. how quickly the hooks move into deeper water where less accessible to seabirds) is relatively low due to the configuration of weights and floats used with the gear (Rouxel et al., 2022) which, if increased, could substantially decrease the time when gear is accessible to birds and also improve the efficacy of other mitigation measures (bird-scaring lines/streamer lines). Options for mitigating bycatch in this fishery are further explored by Kingston et al. (2023).

We conclude that there is evidence that bycatch rates are substantial and likely to lead to population level impacts in Fulmar and, to a lesser extent, in Gannet. Bycatch mitigation methods are available and could likely decrease bycatch rates substantially. While other issues would need to be considered when deciding whether to pursue this as a strategic compensatory measure (explored further in: Practical feasibility: Bycatch mitigation), it is clear that this is an ecologically feasible conservation action that could potentially operate as compensation for Fulmar and Gannet.

6.5 Large gull management

Focal species: Large gulls (Great Black-backed Gull, Lesser Black-backed Gull, Herring Gull)

Conservation actions identified: Reduce level of licensed control (CA11); SPA designation of non-traditional colonies (CA12); Establishing artificial colonies (CA13); Translocation of eggs/chicks from non-traditional to traditional or artificial colonies (CA14).

Large gulls, including Great Black-backed Gull, Lesser Black-backed Gull, and Herring Gull are generalist species foraging on both marine and terrestrial habitats. They are also opportunistic, making use of both natural and anthropogenic food sources. Amongst the three species, Great Black-backed Gull are the least generalist being associated principally with coastal and marine habitats (see Species accounts). This flexibility in ecology and their adaptation to live alongside humans can lead to conflicts (Ross-Smith et al., 2014; Smith, 2020; Rock, 2022). As predators there is also potential for conservation conflicts between conserving other species and gull conservation (Donehower et al., 2007; Scopel and Diamond, 2017; Langlois Lopez et al., 2023), which is considered elsewhere in this report (see Ecological feasibility: Avian predator management and Practical feasibility: Avian predator management). While the three species are protected, exemptions are made with licences being issued for the control of these species (either of adults or eggs/chicks). There have been substantial changes in the licensing regime for gull control in recent years, however it is likely that control still has substantial population level impacts. Changes in the approach to control could therefore realise population level benefits for these species.

Traditionally, the three gull species primarily nested at coastal sites and some riparian areas. Over recent decades, however, they have increasingly nested in non-traditional sites, particularly in urban and industrial areas (Ross-Smith et al., 2014; Burnell, 2021; Rock, 2022). Previous national seabird censuses have not fully covered non-traditional nesting sites, so we lack data on how the relative abundance of traditional and non-traditional nesting sites have changed over time. Nonetheless, there has been an observed increase in the proportion of the population nesting in non-traditional sites. The most recent seabird census provided population counts for traditional (termed 'natural') and non-traditional (termed 'urban') sites for Herring Gull and Lesser Black-backed Gull (Burnell et al., 2023). For both species, most individuals now nest on non-traditional sites. However, in Scotland, the proportion of gulls nesting on non-traditional sites is proportionally lower than in England, largely owing to less available urban areas. Nevertheless, the nesting density on non-traditional sites is higher in Scotland. Counts for non-traditional sites were not provided for Great Black-backed Gull, which are still largely restricted to traditional sites. However, it was noted that some individuals do nest on non-traditional sites, and this occurrence is likely to increase over time (Rock, 2022).

Several SPA designations in Scotland include large gulls as feature species (Table 14), however currently no non-traditional sites used by gulls have SPA protection. There is precedent for the protection of non-traditional nesting sites through SPA designation, with Imperial Dock Lock, Leith SPA designated for breeding Common Tern (*Sterna hirundo*) (NatureScot, 2023e). The site designation describes this as "… [a] man-made structure at the mouth of the Imperial Dock in the heart of the Port of Leith and lies within the City of Edinburgh Local Authority area…". For SPA qualifying species there are a variety of criteria that sites need satisfied to be considered for SPA designation (JNCC, 2023), these include any area used regularly by 1%, or more, of the Great Britain species population, with several secondary criteria including an assessment of the 'naturalness' of a site. Consideration could be given to designating key non-traditional nesting sites that meet SPA designation criteria. This would afford additional protection to the birds connected with these sites. Overall, designating new SPAs would likely enhance the coherence of the national site network, so has potential as strategic compensation. As mobile species, birds from key non-traditional sites would then be subject to HRA regulations; though apportioning effects of a potential plan or project between SPA and non-SPA colonies for gulls is complex given the mix of traditional and non-traditional colonies (Quinn, 2019).

A variant on designating existing non-traditional colonies would be to establish artificial colonies near existing non-traditional colonies to divert breeding gulls away from sites where they are not wanted (e.g. urban rooftops). Artificial colonies could be established e.g. on the edge of cities by protecting areas of open land from predation through predator exclusion fencing (Dalrymple, 2023). This would be a novel approach and would require substantial preparatory work to establish the practical feasibility. Such sites could then eventually be designated as SPAs once they meet designation criteria. This approach would fit well with a broader 'landscape approach' to the management of gulls in urban areas (see Belant (1997)).

Historically, large gulls were included on NatureScot's general licence (NatureScot, 2023c), which permitted authorised persons to undertake various otherwise illegal control methods (e.g. nest removal and culling of adults). Since April 2020 large gulls were removed from NatureScot's general licence, with a new licensing regime introduced with it now necessary for authorised persons to apply for individual licenses if they wish to use control methods, these must either be on grounds of preventing serious damage ('to prevent serious damage to livestock and foodstuffs for livestock') (NatureScot, 2023b) or for public health and safety and air safety (NatureScot, 2023a). Together with these licensing changes, there has been increased emphasis on considering alternative methods to reduce issues with gulls with guidance issued by NatureScot (NatureScot, 2023d) and associated guidance issued by many Scottish councils (e.g. Aberdeen City and West Dunbarton). It is not yet known how this has impacted the level of lethal control, but it is likely that this has reduced the number of lethal control of adult gulls. Some level of illegal control may also occur, although to what extent is unknown. While the licensing regime has already been substantially changed in recent years, there is still potential to refine this further, e.g. by requiring greater consideration of preventative and alternative non-lethal methods before being granted licenses. This would need to be scoped out and a feasibility study undertaken to establish what specific actions could be undertaken and to understand what level of benefit, in terms of reducing population level impacts on large gulls from licensed control, would arise. Without more detailed assessment it is not clear how viable this may be as a compensatory measure.

An alternative to destroying eggs and chicks of gulls (under licence, as above) would be to translocate these to either traditional colonies or artificial colonies. This could act to boost traditional colonies or increase the rate at which artificial colonies establish. Translocation can be an effective seabird conservation tool, though it is resource intensive and there are only a few recorded cases of its use in the conservation of gull species (Spatz et al., 2023b). While it likely would be possible, its feasibility would need to be investigated for the relevant gull species to ascertain whether it could be scaled up to achieve conservation gains required to be suitable as a strategic compensatory measure.

Overall, there is a need for an integrative approach to gull conservation across populations using both traditional and non-traditional nesting sites. This must also consider ways of mitigating and, where possible, avoiding the various potential conflicts between gulls and humans. Further action could be developed to reduce conflict, e.g. by addressing waste management in towns and using a landscape approach (e.g. building design to reduce nesting suitability) (Belant, 1997; Smith, 2020). There is a negative perception of gulls which is greatest in Scotland and northern England in the UK (Baker et al., 2020), though the same study indicated that gulls are tolerated more than most other perceived 'pest' species. Public perception of gulls could likely be improved through engaging with local communities which would lead to greater tolerance with potential to reduce demand for control methods

(Quinn, 2019). Any work around urban nesting gull populations would require working alongside local councils, particularly in those areas where gull conflict is perceived. A wider review of gull ecology, with due consideration to how this is adapting over time, would inform an integrative and adaptive approach. Studies to better understand the metapopulation dynamics of gulls and how traditional and non-traditional populations are linked (e.g. rates of emigration between these) would be beneficial. More tagging of gulls from both traditional and non-traditional nesting populations would also be useful to inform on the connectivity between traditional and non-traditional nesting gulls and different habitats (Ross-Smith et al., 2014; Quinn, 2019).

We have identified several options that could afford more protection to large gulls, particularly those not originating from traditional nesting sites. Some of these conservation actions may have potential to be developed into strategic compensatory measures. However, we advise that there is a need for a wider review of our approaches for conserving gull populations and how traditional and non-traditional nesting sites are considered.

6.6 Conservation actions identified from scoping and targeted reviews

Table 41. Conservation actions identified in the scoping reviews, with a preliminary assessment for each against several criteria. Note these findings are preliminary only as these are based on a high-level assessment. The assessment is in the context of using such actions as compensatory measures. Note that the assessment against the criteria included may differ in other contexts (e.g. for broader seabird conservation purposes). Potential is also assessed in the short- to medium-term only, some actions may have potential in the longer term but would require significant research and development.

Conservation Action number	**Conservation Action**	**Topic**	**Description**	**Species most likely to benefit**	**Key issues**	**Research and monitoring recommendations**	**Potential (low-medium-high)**
CA1.	Habitat creation and restoration (e.g. seagrass)	Prey supporting habitat	Creation and restoration of marine habitat (e.g. seagrass) that support seabird prey species.	Species most reliant on forage fish (auks and terns)	Linking such initiatives with seabird population responses. Limited range of habitats that can be created or restored.	Develop a framework around which ecosystem-based measures could be linked to seabird population level responses.	Medium
CA2.	Protection of spawning and nursery habitat	Prey supporting habitat	Protection of key seabird prey species supporting habitat from degradation and damage from e.g. prohibition of bottom towed	Species most reliant on forage fish (auks and terns)	As above	As above	Medium

Conservation Action number	Conservation Action	Topic	Description	Species most likely to benefit	Key issues	Research and monitoring recommendations	Potential (low-medium-high)
			fishing gear in specific areas.				
CA3.	Carcass collection during outbreaks	Reducing disease spread	For diseases that are contagious from dead birds (e.g. avian botulism and potentially HPAI).	Many species but especially gulls (for botulism)	Impractical for many seabird colonies located in inaccessible locations. Efficacy for reducing disease spread is still relatively unknown for HPAI. Human health risk from handling.	Carcass collection trials. Analyses to better understand the risk factors behind significant disease outbreaks.	Low-medium
CA4.	Managing standing water	Reducing disease spread	Standing water can act as a reservoir for contagious diseases (some evidence for HPAI, and strong evidence for avian botulism).	Many species	Practicality will be highly site-specific. In general, it is likely to be practical at some sites.	Requires further research to develop specific recommendations for HPAI. Best practice recommendations already exist for avian botulism.	Low-medium

Conservation Action number	Conservation Action	Topic	Description	Species most likely to benefit	Key issues	Research and monitoring recommendations	Potential (low-medium-high)
			For HPAI improving water turn-over may be effective and filling in areas that hold standing water following heavy rainfall.				
CA5.	Vaccination of wild birds	Reducing disease spread	Vaccination trials are underway for HPAI so theoretically there is potential to vaccinate wild birds.	Many species	Unlikely to be practical to deploy at scale. May have some limited application (e.g. protecting small remnant populations).	Monitor progress of vaccination trials and review potential and applicability to seabird populations.	Low
CA6.	Rehabilitation of sick birds	Reducing disease spread	Reduce severity of disease outbreaks through rehabilitation of sick birds. This is demonstrated	Many, but especially gulls (for avian botulism)	For highly contagious diseases (e.g. HPAI) there are high risks of cross-infection. There are also	Consider feasibility of increased rehabilitation including estimating population level benefits (required to be suitable as a	Low-medium

Conservation Action number	Conservation Action	Topic	Description	Species most likely to benefit	Key issues	Research and monitoring recommendations	Potential (low-medium-high)
			for avian botulism. Unproven for HPAI.		human health risks for some diseases which would proscribe its use (potentially for HPAI).	compensatory measure).	
CA7.	Coastal defence structures to reduce impact of storm events	Habitat Management	Use of coastal defence structures (e.g. rock dumping at base of cliffs to absorb wave energy) to reduce impacts on cliff-nesting seabirds.	Cliff nesting species, especially Kittiwake	Practicality will be highly site-specific. For many natural sites it is likely that gaining permission to place wave defences would not be granted (coastal heritage etc).	Investigate to what extent it could reduce loss of nests and its practical feasibility.	Low
CA8.	Water management to reduce flooding of burrow nesting seabirds	Habitat Management	Reduce flood risk through water management and drainage schemes.	Burrow-nesting species (Puffin and Manx Shearwater)	Practicality will be site-specific. The population level benefits to be gained are not clear.	Detailed ecological and practical feasibility would need to be assessed.	Low

Conservation Action number	Conservation Action	Topic	Description	Species most likely to benefit	Key issues	Research and monitoring recommendations	Potential (low-medium-high)
CA9.	Vegetation management to improve breeding habitat quality	Habitat Management	Removal of Tree Mallow is beneficial to Puffin. Vegetation management also likely to be beneficial for some ground-nesting species.	Puffin and some ground-nesting species	Requires ongoing management. Scale of potential deployment is unclear, there would need to be site-specific assessments.	See key issues	Low-medium
CA10.	Mitigation of bycatch in longline fisheries	Bycatch	Reducing the rates of bycatch in floated demersal longline fisheries through various bycatch mitigation methods.	Fulmar, Gannet	The longline fishery operating has a relatively unique gear, which means that methods developed for bycatch mitigation in other longline fisheries may not be directly transferable.	There is a need for improved monitoring to better quantify bycatch rates. Bycatch mitigation trials are required to identify the most effective mitigation methods.	High

Conservation Action number	Conservation Action	Topic	Description	Species most likely to benefit	Key issues	Research and monitoring recommendations	Potential (low-medium-high)
CA11.	Reduce level of licensed control	Large gull management	Reduce the numbers of adult gulls lethally controlled or nests/eggs/chicks taken through licensed control.	Large gulls	It is unclear what level of effect the current licensing regime may be having on gull populations. Key stakeholder engagement will be necessary for successful implementation of a reduced gull licensing regime.	Further develop alternatives to lethal control. Better monitoring in place for non-traditional colonies.	Low-medium
CA12.	SPA designation of non-traditional colonies	Large gull management	Currently only traditional gull colonies have SPA protection, consider protection also of key non-	Large gulls	Whether non-traditional colonies could satisfy SPA designation criteria. To what extent SPA designation	Investigate potential for SPA designation of non-traditional colonies. Requires population counts of non-traditional colonies.	Medium

Conservation Action number	Conservation Action	Topic	Description	Species most likely to benefit	Key issues	Research and monitoring recommendations	Potential (low-medium-high)
			traditional colonies.		would lead to actual improvements in protection is unclear.		
CA13.	Establishing artificial colonies	Large gull management	Establish artificial gull colonies to reduce use of opportunistic sites (e.g. building roofs).	Large gulls	May be difficult to gain popular support for artificial colonies. To what extent these would reduce conflict. with humans is unclear.	Investigate the practical feasibility of developing artificial gull colonies.	Low-medium
CA14.	Translocation of eggs/chicks from non-traditional to traditional or artificial colonies	Large gull management	In place of lethal control, translocate eggs and chicks to traditional or artificial colonies.	Large gulls	Practical feasibility to deliver at scale.	Investigate practical feasibility to identify potential to scale up.	Low

7 Practical feasibility reviews

7.1 Selection of actions to include for practical feasibility reviews

As outlined in the methods, the initial list of compensatory measures was, where possible, refined to corresponding conservation actions. Measures that corresponded to clear conservation actions were assessed through a systematic literature review process and evaluated on their ecological feasibility. Where it was not possible to identify corresponding conservation actions directly from the initial compensatory measures, scoping reviews were conducted to identify and evaluate potential conservation actions. Additionally, bycatch mitigation was explored through a targeted review. For those actions where systematic or targeted reviews were conducted could practical feasibility also be assessed.

The actions reviewed through systematic literature reviews, and of which the ecological feasibility was assessed, were presented to the steering group (meeting held 22nd June 2023) with discussion held on which actions should proceed to WP2 for assessment of practical feasibility. Following the steering group meeting, discussion with the project management group led the agreement to include seven of the eight possible conservation actions. This was based both on outcomes of the ecological feasibility assessment and the opinions of the steering and project management groups. Actions that were considered to build resilience but not necessarily lead to a compensatory effect (i.e. those not forecasted to increase breeding birds but that would potentially reduce vulnerability to short-term impacts) were also included. The final seven actions included are (i.e. 7/8 actions possible, with Disturbance - at sea excluded):

1. Sandeel fishery closure
2. Fishery closure or enhanced management of prey fisheries
3. End of the Gannet harvest at Sula Sgeir
4. Mammalian predator eradication and/or management
5. Avian predator management
6. Reduction of disturbance (at colony)
7. Bycatch mitigation in longline fisheries – automatically included though a targeted review was undertaken

Disturbance at sea was excluded due to there being a consensus that, at this time, there is insufficient evidence to have confidence that this action could lead to a meaningful scale of compensation.

For each action included there is a corresponding practical feasibility chapter, except for the two prey fishery related actions (i.e. Sandeel fishery closure and fishery closure or enhanced management of prey fisheries). These were combined into a single chapter due to many of the principles shared between the two. Given that Mackerel was excluded during WP2, this chapter is termed ‘Closure and management of forage fisheries (Sandeel, Herring, and Sprat)’.

7.2 Practical feasibility: Closure and management of forage fisheries (Sandeel, Herring, and Sprat)

***Note:** This review was prepared prior to the announcement in early 2024 of the full closure of Scottish Waters to Sandeel fishing. At the time of finalising this report (March 2024), the Scottish Government had recently announced a forthcoming closure of the Sandeel fishery throughout Scottish Waters (Scottish Government, 2024). The UK Government had also made a similar announcement closing Sandeel fisheries in the UK portion of the southern North Sea (ICES Area 4) (UK Government, 2024). Neither announcement was made with reference to strategic compensation for offshore wind. With respect to the use of the Sandeel fishery closure as compensation, the Scottish Government has stated[7]: "Scottish Ministers will consider the suitability of any measures proposed as compensation as part of a case for derogating from the Habitats Regulations at the appropriate stage in the process, if and when such a derogation case may be required. This applies to any closure of the Sandeel fishery in Scottish waters which may be proposed as a compensation measure for offshore wind farm developments." This report has not been fully updated to reflect these changes as the text was prepared prior to the announcement.*

7.2.1 Summary

In this section, we present the practical feasibility of two conservation actions: 'Sandeel fishery closure' and 'fishery closure or enhanced management of prey fisheries'. These two actions are grouped into one chapter due to them sharing the same key principles however, where relevant, we distinguish between the different foraging fish species and their associated fisheries. The focal species include Kittiwake, large gulls, auks, and Gannet.

Forage fish are small, schooling fish that link primary producers and higher trophic levels. 'Prey fish' is a more general term for fish consumed by any predator as a primary food source. Here, we specifically focus on the fisheries management of forage fish as opposed to prey fish, given the crucial importance of these highly abundant low trophic level fish as a primary food source for seabirds as well as for other marine predators. Mackerel was excluded from this section as there was less evidence for fisheries affecting their availability to seabirds. Therefore, this section focusses on the three forage fish species of most importance to seabirds in Scotland. Due to the challenges associated with studying seabird diets during the non-breeding season, when birds are at sea, migrating and away from breeding colonies, there is limited knowledge about their diets during this period. Therefore, in this section, we focus primarily on the breeding period.

There has been considerable interest on Sandeel fishery closures over the past several years, with the recent consultations in both England and Scotland both including new assessment on the ecosystem effects of Sandeel fisheries management in UK and Scottish waters, respectively. Internationally, the availability of forage fish, including Sandeel, has been identified as a driver of high breeding failure of surface-feeding seabirds in the North Sea (OSPAR, 2017).

[7] Response from Gillian Martin (then Minister for Energy and the Environment) on 18 January 2024 to Question S6W-24369.

Other prey fisheries management, however, have not received as much attention despite being subject of broader policy commitments. For example, the Scottish Government has fishery policy objectives for restricting or prohibiting the fishing of species that are 'integral components of the marine food web', including Sandeel (Scottish Government, 2020a). Similarly, EU and UK fishery delegations recently noted the ecological significance of forage fish species (namely Sandeel, Norway Pout, Herring, and Sprat) as important food sources for seabirds and other marine predators (DEFRA, 2023b). In this section, we provide a high-level summary of the information available on the topic. For more in-depth information, we recommend: the Scottish Sandeel fishing consultation, Engelhard et al. (2013), Heath et al. (2017), and Searle et al. (2023a).

Table 42. Summary of practical feasibility for closure and management of forage fisheries (Sandeel, Herring, and Sprat). Further detail is provided following the table.

	Closure and management of forage fisheries (Sandeel, Herring, and Sprat)
Description	Implementing Sandeel fishery closures, as well as closures or enhanced management for Sprat and Herring fisheries within Scottish waters.
Uncertainty	The abundance of forage fish is not only regulated by industrial fisheries, but also by predatory fish populations, competition for food sources, the condition of spawning and nursery habitat, and changes in environmental conditions (Figure 28). Consequently, predicting the response of forage fish populations to fishery closures, or any other form of fishery management, is highly challenging. It is even more challenging to quantify and predict the broader effects of forage fisheries management on the demography of the predator species themselves (here focussing on seabirds). While forage fisheries management, including closures, aim to increase the abundance of fish, it is important to note that the relationship between fish biomass and seabird demography is not linear (i.e. an increase in fish biomass does not guarantee an increase in seabird breeding productivity and/or survival). Therefore, quantifying and predicting its effects on seabirds involves a significant degree of uncertainty. Additionally, most studies of fishery management in Scotland have focussed on the North Sea populations, therefore, there is increased uncertainty when extrapolating to other parts of Scotland, especially to the west coast, which has a contrasting ecology.
Species benefitting	Focal species: If forage fisheries management were to ensure an increase in Sandeel, Herring and Sprat availability, Kittiwake and auks would likely benefit. As the intake and quality of forage fish increases, the breeding success and survival of the focal species are also expected to increase. On the other hand, large gulls are generalist predators and opportunistic

For detail see: Ecological effects of implementing action	feeders and Gannet feed on a range of prey fish, from Sandeel to Mackerel. As a result, they may exhibit greater resilience in the absence of fisheries management, and the benefits to these species could be considerably lower compared to the other focal species. Nevertheless, if prey availability is improved this could potentially partially buffer the effects of the ongoing HPAI outbreak and changing environmental conditions. Other species: Other specialised seabirds that rely on Sandeel, Herring and/or Sprat, or on other fish that rely on these forage fish will most likely show some degree of benefit in their breeding success and overall survival rates. Such species include terns, which are known to be limited by prey due to their short foraging ranges, Red-throated Diver, Fulmar, Shag, and skuas.
Scale and degree of population benefit	Assuming that all other variables (e.g. predation, environmental conditions) remain stable, enhanced forage fisheries management could have a significant positive impact on seabird breeding success and adult survival, particularly for species with highly specialised diets focussed on forage fish, such as Kittiwake and auks. These effects may be observable at local, regional, and national levels depending on the forage fish species, the scale of fisheries management (i.e. regional, national, or international), and the current fishery impacts. However, due to inherent uncertainties within the ecosystem and the unpredictability of future conditions and population responses, the overall impact remains uncertain. If conditions were to deteriorate significantly, effective fishery management could contribute to enhancing ecosystem resilience, potentially reducing seabird population rates of decline, and promoting stability in the marine ecosystem. Given that management is expected to operate on large spatial scales, seabird colonies from numerous Special Protection Areas (SPAs) could potentially benefit. Effects are expected at a medium- and long-term scale, as it takes time for the response and recovery of forage fish populations and for an increase in seabird breeding success to translate into population size increases.
Other ecological and social benefits	The closure or management of forage fisheries also have the potential to: • Enhance the resilience of the marine environment and deliver broader ecosystem benefits for a range of species. • Increase the populations of other top predators in the wider marine environment, such as marine mammals and other fish species, as well as of threatened and vulnerable species that rely on forage fish as a food source. • Increase tourism and recreational opportunities (e.g. where marine mammal and seabird populations increase).

	• Benefit the fishing industry resulting from potential increased stock of other commercially valuable species dependent on forage fish.
Sequence of steps to implement For detail see: Steps for implementation	1. Collation of baseline information on forage fish, fisheries, and seabirds: • To determine whether changes in fisheries management would be likely to have ecological benefits for a given location, there must first be good baseline knowledge of the dynamics between forage fish, fisheries, and seabirds. 2. Conduct formal and informal consultation: • Conduct both formal and informal consultation with key stakeholders, including fisheries managers in Government, conservation departments within Government, fishing communities, international/EU fishing organisations and advisory bodies (e.g. ICES), regional seas conventions (e.g. OSPAR), conservation organisations, and local authorities, to gather input and discuss the implications and practicalities of potential management measures. • A public consultation would then usually be required. 3. Decision on whether to proceed with conservation action (changes in fisheries management): • Evaluate and incorporate feedback from the consultations, along with any other available evidence to decide whether to continue to pursue action after evaluating the ecological benefits (and potential for unintended consequences) with the economic, political, and social costs. Determine the fisheries management to be implemented. Determine whether management changes would constitute compensation or be required for other policy obligations. 4. Implementation: • The specific implementation approach will depend on the fishery management measure. It should adhere to standard regulatory and procedural processes followed when changing fishery management. • Establish and conduct monitoring programmes to assess the effectiveness of the management on seabirds and to ensure compliance. 5. Establish long-term adaptive management: • Continuously monitor the impacts of fisheries management (and other pressures) on fish stocks, seabirds, and the ecosystem. Make necessary adjustments based on the best available scientific data and stakeholder and international input.

	• Invest in research and innovation to develop new technologies and practices that enhance sustainability and reduce the environmental impact of fisheries. • Develop and implement a communication and outreach plan to help build buy-in for actions taken.
Monitoring summary For detail see: Research and monitoring recommendations	Several ecological components and interactions require continuous monitoring to assess the effectiveness of the action. Stock status (including changes in fish abundance): Forage fish populations can be monitored through different approaches, including quantifying the landings at fishing ports of each species, biological data on the size and age of the fish caught and ecological and biological data of fish at sea. Such data is collected through a variety of methods, although most data are currently collected specifically for fishery stock assessments, which will often not be directly relevant to prey abundance for seabirds (e.g. different age classes or season). Therefore, monitoring metrics that relate directly to fish availability for seabirds is crucial. Impacts of fisheries: A monitoring programme should be implemented to collect catch data through electronic monitoring (with cameras), fish landings, logbooks, on-board observers, and unsystematic surveys. Stock assessment models, such as surplus production models, virtual population analysis, and statistical catch-at-age models, can then be used to assess the status of exploited fish stocks. Monitoring compliance with the measures will be key. Changes in seabird demography: Monitoring seabirds to assess the impact of fisheries management should involve various demographic and foraging studies, including regular productivity observations, body condition assessments, capture-recapture survival rate studies, diet sampling, and tracking studies. Monitoring other variables: All other variables affecting seabirds and forage fish populations (e.g. environmental parameters, effects of HPAI, impacts of offshore windfarms) will need monitoring (e.g. advanced monitoring equipment integrated to traditional sampling gear to collect environmental information). Statistical analyses to understand management impact on seabirds: To better understand the relationship between the quality and stock of forage fish and how this translates to seabird breeding success and survival, statistical analyses, such as ecosystem and demographic models (e.g. Before-After-Control-Impact), are crucial.
Key considerations For detail see: Key considerations, potential barriers,	**Policy and legal**: Depending on the fishery, changes in management may impact EU-registered vessels, any closure or regulation of these vessels could then have implications for relations with EU countries. Therefore, it must be ensured that proposed management is consistent with existing laws, regulations, and international agreements governing fisheries management. **Undesired ecological effects**: Management measures risk displacing forage fisheries to other areas, or on to other species (within and outwith

and potential solutions	Scottish Waters). The implementation of an integrated approach to management is crucial to reduce this risk. **Social**: Negative social impacts on those involved in affected fisheries through reduced employment and income-earning opportunities. **Opposition and lack of compliance**: Opposition, particularly from the fishing industry, could lead to lack of compliance and difficulties in implementing fisheries management changes. **Lag effect**: Any benefit to seabird populations as a result of changes in fisheries management will generally take years to be detectable and may be hard to distinguish from changes in other pressures and natural variability. **Reduction of collection of scientific data**: Much of fish population monitoring is conducted on fishing vessels or from catch/landings data. Changes in fisheries management without replacing monitoring could decrease the biological data collected.
List of potential forage fisheries management	• Adopting effective set-aside policies for forage fish that account for predator needs and areas closed to fishing, thus reducing Total Allowable Catch (TAC). • Imposition of limits on time at sea. • Full/regional fishery closure. • Partial closures of e.g. key areas for forage fish and/or foraging seabirds. • Implementation of closures during critical biological periods (e.g. spawning, seabird breeding season) or in alternating years. • Fishing gear restrictions. • Implementation of fish size and age restrictions. *Note this is a list of potential alternative management approaches rather than specific recommendations.
Conclusion	Forage fisheries management, particularly closures, can enhance ecosystem resilience, indirectly benefitting seabirds. A recommended approach is to employ a combination of management strategies to increase the ecosystem health while aligning with economic and political responsibilities. This approach may also benefit from the implementation of additional supporting measures, such as fish habitat management and protection, to further improve forage fish populations. While this approach holds potential as a compensatory measure, there is a need for further research to reduce uncertainty. Overall, reducing or removing industrial fishing of forage fish species would remove one potential threat to seabirds, though quantifying any population benefit to seabird populations is challenging. As such, confidence in using it as compensation is limited, and more information is needed. Even with a reduction in fishing pressure, climate change is a key pressure on forage fish stocks which further reduces our ability to predict future changes and its efficacy in the long-term.

7.2.2 Background

Sandeel, Herring, and Sprat are important forage fish in Scottish waters, playing a crucial role in the marine ecosystem by representing a large component of the diet of seabirds, marine mammals, and predatory fish. Fluctuations in the abundance (i.e. population size) and availability (i.e. individuals that can be caught by predators) of forage fish can have profound effects on the entire marine food web, influencing both 'top-down' (regulation of lower trophic levels) and 'bottom-up' (regulation on marine predators) dynamics (Engelhard et al., 2013). Consequently, they play a vital role in maintaining the health and balance of the ecosystem, and fluctuations in their populations can have significant ecological impacts.

Many piscivorous seabird species rely on specific forage fish for their breeding success and population dynamics (Cury et al., 2011; Tasker and Sydeman, 2023). However, due to the concurrent targeting of these forage fish by fisheries, a scenario of potential direct competition arises, where fisheries activities have the potential to reduce prey availability to seabirds. Consequently, the sustainable management, protection, and abundance of forage fish populations is critical for the conservation of seabird populations. However, the relationship between fish abundance and seabird demography is not a linear one and establishing a clear causal relationship between forage fisheries and seabirds is challenging (Figure 28).

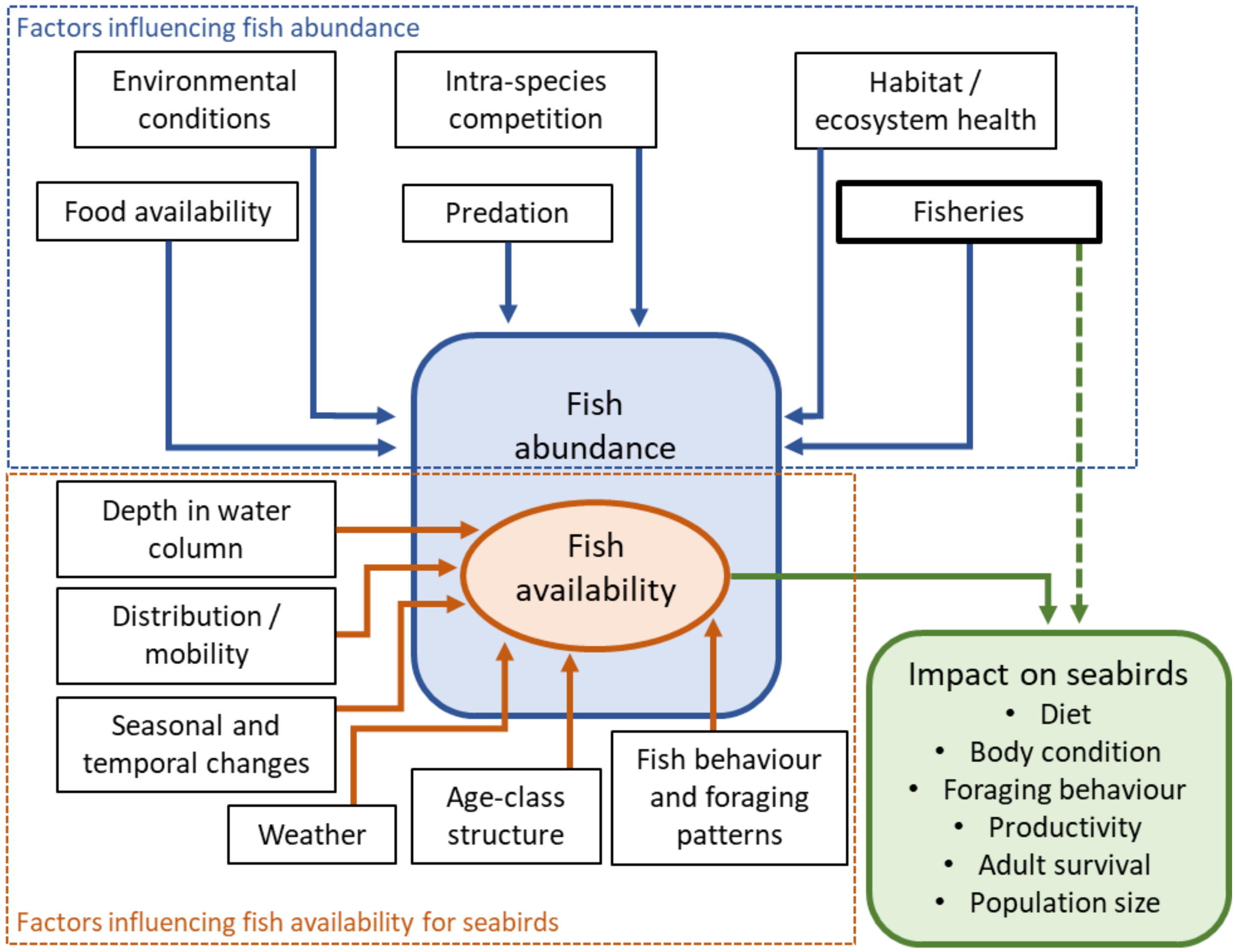

Figure 28. Conceptual framework of how fisheries impact seabirds. Factors influencing fish abundance are shown in blue (top square), while factors influencing fish availability for seabirds are shown in orange (bottom left square). The effect of fish availability on seabird demography is represented by a solid green line, and the indirect effect of fisheries on seabird demography is represented by a dashed green line.

Figure 28 illustrates the complex relationship between forage fish abundance, forage fish availability, fisheries, and seabird demography. As seen within the top blue box, the abundance of fish in the water, i.e. population size, is regulated not only by fisheries but also by a range of variables including predation, intra-specific competition, and environmental conditions. Seabirds exhibit diverse foraging strategies. Surface feeding seabirds, such as Kittiwake, can only forage on fish very close to the surface whereas other species such as Guillemot, Razorbill and Puffin can dive to considerable depths. Guillemot can potentially also extract fish from the sediment on the seafloor. Depending on the forage fish, seabirds may only take certain age classes of fish (e.g. older age classes of Herring are generally too large for most species), and often these are different to the age classes primarily targeted by fisheries. For example, most seabirds primarily take the 0-group Sandeel (Wanless et al., 2018), those that are less than a year old, while the fishery targets catches 1+ group Sandeel (Daunt et al., 2008), those that are at least one year. These differences mean that prey availability is not only defined by each seabird species-specific behaviours and fish abundance; but other factors such as fish location within the water column, seasonal and temporal fluctuations (e.g. Sandeel remain hidden in the sand during the night in summer).

While fisheries can significantly influence the total fish abundance within a designated area, the impact of fisheries on fish availability for seabirds is less straightforward. Quantifying the effect of a given fisheries management on seabird demography is therefore extremely challenging, marked by a high degree of uncertainty. Furthermore, lag effects between seabird demographic parameters and environmental conditions further compounds the intricacy and uncertainty of this effect.

7.2.2.1 Forage fish in Scotland

Sandeels (*Ammodytes* sp., predominantly *A. marinus*) are the most abundant species group of forage fish in the North Sea and are an important food source to UK seabirds, particularly Kittiwake and Puffin, during the breeding season (Furness and Tasker, 2000; Lewis et al., 2001b; Searle et al., 2023a). There is a seasonal shift in the availability of 0-group and 1+ group Sandeel, which corresponds to a shift from 1+ group Sandeel predominating in seabird diet early in the breeding season then 0-group later (Lewis et al., 2001b). Additionally there has been a long term dietary shift away from Sandeel as a whole and towards more 0-group than 1+ group Sandeel (Wanless et al., 2018).

Lesser Sandeel (*A. marinus*) are the main target for the largest single species fishery in the North Sea. In west Scotland, they have historically been primarily targeted for their oil and use as animal feed and fertiliser, but currently, no fishery is active nor are stock assessments undertaken. Sandeels have a unique life cycle, relying heavily on suitable sandy substrates. Sandeels lay eggs on sandy substrates in winter, hatch between February and April, and form diurnal pelagic feeding schools between May and June, during which time they bury themselves into the sand at night. They spend winters buried in the sand, emerging briefly for spawning in December and January. This life cycle means that Sandeel have high habitat specificity and are mostly resident, rarely travelling over 30 km from spawning areas. Despite management, most Sandeel stocks have suffered significant declines due to a combination of overfishing and climate change impacts. For more detailed information on their ecology, biology, and status within Scotland, refer to Scottish Government (2023d) and Marine Scotland (2023), and references within.

Atlantic Herring (*Clupea harengus*) populations rely on benthic habitats for reproduction. In Scotland, Herring reproduce in autumn or spring. Autumn-spawning Herring spawn near offshore banks in the North Sea and to the west of the Hebrides. Spring-spawning Herring, on the other hand, spawn in shallower nearshore areas along the west coast. Herring form dense shoals that migrate between feeding, spawning and wintering grounds, following similar patterns each year. They feed close to the surface at night and remain in deeper water during the day. Juveniles often shoal close inshore, while adults are found more offshore. Fishing for Herring in the North Sea and west of Scotland was banned by the Government in the late 1970s, to allow stocks to recover from collapse. Fishing in the North Sea resumed in 1983 after the stock recovered. After spending their first few years in coastal nurseries, two-year-old Herring move offshore into deeper waters, eventually joining the adult population in the feeding and spawning migrations to the western areas of the North Sea. In Scottish waters, two Herring stocks are assessed by the International Council for the Exploration of the Sea (ICES): the North Sea Autumn Spawning stock, fished in the northeast, and the West of Scotland autumn spawning stock, fished to the west of the Hebrides. The Clyde Herring stock is managed separately since it is only present in UK territorial waters. For further information refer to Frost and Diele (2022), Scottish Government (2022a) and Scottish Herring (2023), and references within.

Less is known about the European Sprat (*Sprattus Sprattus*). Throughout most of the year they are found at any depth in the water column, spread out over a wide area in local coastal waters, in relatively small shoals, grazing on zooplankton, and are too scattered to be economically targeted by large trawlers. In September and October, they begin to move inshore and assemble into large aggregations in preparation for spawning. All known spawning areas for Sprat are inshore. On the west coast of Scotland, juveniles tend to migrate into sea lochs in July and August. Migration tends to be towards inshore waters during winter though older fish may remain offshore. Sprat shoals move to surface waters at dusk. For further detailed information see ICES (2022) and Froese and Pauly (2023).

Table 43 describes the current understanding of the Scottish stocks and current fisheries management for each forage fish species. Overall, the status and knowledge base for most of the forage fish stocks around Scotland is lacking, especially in the west coast. Monitoring information is important to inform the sustainable management of the fish stocks. Note that the Total Allowable Catch (TAC) is advised by the International Council for the Exploration of the Sea (ICES) and may not necessarily represent the actual catch. The ICES-delimited subareas for management of Sandeel and Herring stocks in British waters and adjacent seas are shown in Figure 29A and Figure 29B, respectively.

The extent to which current ICES fisheries management advice for forage fish considers wider ecosystem considerations, especially of predator-prey interactions, was subject of a recent request to ICES from the EU and UK[8]. The corresponding advice was recently issued by ICES (2023a). While the headline summary noted that current ICES advice for forage fish (e.g. (ICES, 2023c; b)) does consider ecosystem effects, with these considered via natural predation and qualitative ecosystem considerations, the detailed advice makes clear that ICES advice alone does not ensure there is sufficient biomass of forage fish for marine predators (including seabirds). With relevance to seabirds, the advice noted that advice is at the stock level, so does not consider individual foraging grounds (relevant to breeding seabirds with a restricted foraging range). It went on to note that there is a significant role for national regulations with respect to whether fisheries management is supporting ecosystem functions.

[8] The Sixth meeting of the Specialised Committee on Fisheries on 27 June 2023 issued a joint request of the Parties to ICES to “provide further information on how ecosystem considerations, particularly predator-prey interactions and the rebuilding of sensitive higher trophic level species, and other ecosystems-based fisheries management aspects, are factored into to the provision of the single stock advice for forage fish species”.

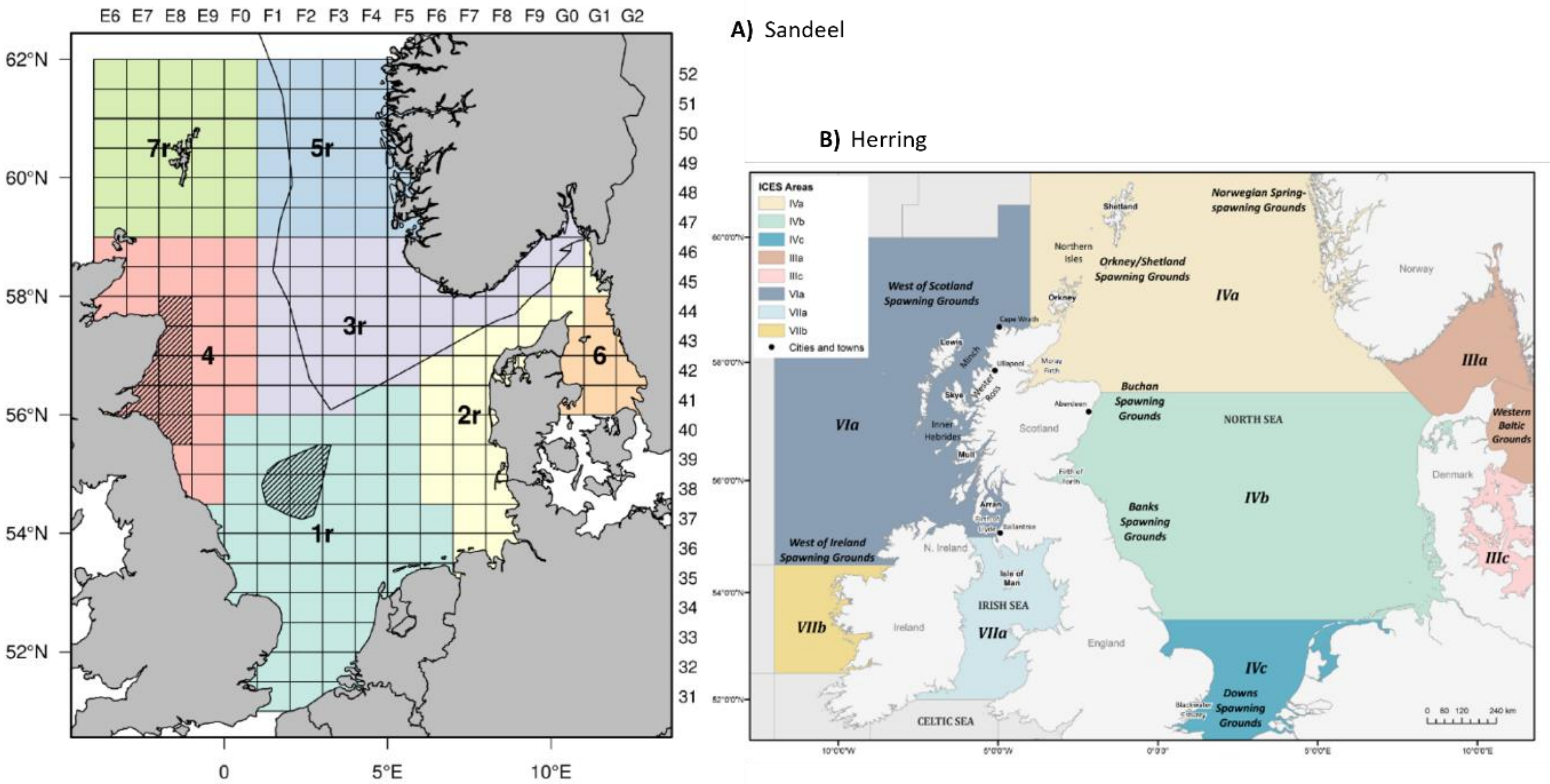

Figure 29. ICES-delimited subareas for management of (A) Sandeel and (B) Herring stocks in British waters and adjacent seas. Reproduced from: (ICES, 2023e). The Wee Bankie closure in Sandeel Area 4 and the Dogger Bank closure in Sandeel Area 1 are shown with hatched markings. The border of the Norwegian Exclusive Economic Zone is shown with black lines. B) Reproduced from: Frost and Diele (2022).

Table 43. Stocks and fisheries management of Sandeel, Herring, and Sprat in Scotland. Includes assessment of those fisheries where there is potential for seabirds to benefit from changes in fisheries management (NB this is potential only and would require further investigation to understand the likelihood of any benefit).

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
Sandeel	**Lifespan:** Relatively short-lived (up to 9 years). **Habitat:** Highly reliant upon the availability of suitable sandy substrates, which have a patchy distribution. **Behaviour:** They burrow in the sand at night during summer and throughout winter. During seabird breeding season, Sandeels form pelagic feeding schools during	Sandeel area 4 (SA4): northern and central North Sea, corresponding to east coast of Scotland (Figure 29A) – note some of SA4 is in the English North Sea EEZ.	Owing to the relatively low productivity of Sandeel in SA4 the maximum fishing mortality is much lower than that for other North Sea Sandeel stocks. Recruitment in 2014, 2016, 2017, 2019, 2021 and 2022 was above the geometric mean for the period 2012-2021, while the remaining years after 2010 were below. Fishing mortality has been low since 2005, apart from 2018 and 2021.	The Scottish Government consulted on a full closure of Scottish waters to industrial Sandeel fishing in 2023. The fishery is highly seasonal (active April – July). A Sandeel closure has been in place off the East Coast of Scotland since 2000 covering approximately 21,000 km^2 (Figure 29A). However, this closure has not been fully accounted for in SA4 catch limits in the	Yes	Scottish Government (2023). Sandeel fishing: consultation. ICES (2023d)

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
	the day and remain hidden in the sand at night. Seabirds now primarily target young of the year (i.e. 0-group) Sandeel with later age classes (1+ group) becoming less common in seabird diet over several decades (Wanless et al., 2018). **Movements:** Mostly resident, rarely travelling >30 km from spawning sites. Evidence of very little to no exchange between Sandeel aggregations separated by distances > 28 km, even if these			remaining areas open to fishing. Since 2021 Sandeel quota has not been allocated to UK vessels. Fishing vessels targeting Sandeel are mostly Danish. Sandeels are Priority Marine Features (PMFs) and are a protected feature in three Nature Conservation Marine Protected Areas (MPA) and several further MPAs aim to conserve Sandeel habitat. However, these sites do not yet have management measures in place.		

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
	aggregations were connected by continuous suitable habitat. **Threats:** Strongly affected by warming seas – influencing the timing and availability of copepod prey. At risk of trophic mismatches.			TAC advised annually by ICES.		
		West coast of Scotland	Data lacking.	No active fishery. Sandeels present within several Marine Protected Areas.	No	[Scottish Government (2023). Sandeel fishing: consultation.]
		Sandeel area 7r: northern North Sea and Shetland (Figure 29A)	Data lacking for recent years. Sandeel stock around Shetland collapsed in the early 2000s and is thought to be particularly vulnerable to fishing pressure (Wright, 2006).	No active fishery (last catch was in 2002). Sandeels present within several Marine Protected Areas. TAC advised annually by ICES. Most recent advice was for zero catches in each of the years 2023 and 2024. However, has been unable to be assessed due to lack of data. 'ICES cannot assess the stock exploitation	No	ICES (2023c)

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
				status relative to Maximum Sustainable Yield (MSY) and precautionary approach (PA) reference points because information to define reference points is not available.		
Herring	**Lifespan:** Long-lived (up to 25 years) and start to reproduce at 2 to 3 years. **Habitat:** Juveniles often shoal close inshore, while adults are found more offshore. **Behaviour:** They surface at night to feed and remain in	All areas of Scottish Waters		Pelagic vessels operating in Scottish Waters are expected to be required to have a REM system on-board in the near future once the Scottish Government has legislated for this (Scottish Government, 2023c).		
		IVa: northeast Scotland and IVb: eastern Scotland, both	North Sea Herring was assessed as a stock at risk of suffering reduced reproductive capacity for the years	TAC set by ICES each season. The quota allocation in Scotland is based on the Fixed	Yes	Scottish Herring (2023). Herring Fisheries. ICES (2023b)

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
	deeper waters during the day. **Movements:** Spawning season changes according to location: autumn-spawning occurs near offshore banks in the North Sea and to the west of the Hebrides and spring-spawning in shallower	part of North Sea stock	2009 and 2010. Since 2011, North Sea Herring has been assessed as being at full reproductive capacity and being harvested sustainably below the rate for Maximum Sustainable Yield (i.e. the harvest level achieving the highest long-term yields).	Quota Allocation (FQA) system. ICES advises that no activities on spawning habitats should be allowed unless the effects of these activities have been assessed and shown not to be detrimental.		MMO (2020)
	nearshore areas along the west coast. Spring-spawned Herring tend to live longer, reach a larger maximum size and produce fewer, heavier eggs that hatch into larger larvae when	VIa: West Coast	Data lacking. Stock never recovered from collapse 50 years ago.	Managed exclusively as an autumn-spawning stock. In 2023 ICES advised a small catch for the first time in several years (following a period with no advised catch).	Yes, depending on future catch advice (until recently no catch).	Scottish Herring (2023). Herring Fisheries. Frost and Diele (2022)
	compared to autumn-spawned fish that	Firth of Clyde Herring stock,	Data lacking.	It is the sole responsibility of the	Yes	DEFRA (2022). Herring in the

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
	hatch during less-favourable environmental conditions and slowly progress through developmental stages over the winter months. Herring forms dense shoals that migrate between feeding, spawning and wintering grounds, following similar patterns each year. Spawning requires specific substrates, preferably gravel beds free from silt.	managed solely by the UK	Current knowledge of the stock is uncertain, and insufficient to be able to quantify a scientific basis for a TAC. The Herring fishery in the Clyde has declined from its peak in the 1960s, with catches typically less than 500 tonnes over the last 20 years and only 180 tonnes landed in 2021. Scientific surveys suggest that the Herring population currently found in the Clyde is heavily dominated by young age classes (1- and 2-year old Herring).	UK to assess and set fishing levels for the Clyde Herring stock (due to being wholly within UK territorial waters). Seasonal ban on Herring fishing to protect fish from disturbance during spawning (from 1 January to 30 April). A ban on fishing with mobile or active gear in the Firth of Clyde between 00:00 Saturday morning and 24:00 Sunday night Vessels are required to provide acoustic and GPS data (where they have the facility		Firth of Clyde - setting the TAC for 2022 consultation.

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
			These fish are below the minimum landing size in place for this area.	to do so) and provide a haul by haul log of catches and time fishing associated with each haul. Vessels are required to provide a 15 kg sample of the Herring taken during each trip for analysis by Scottish Government scientists to determine age, length, weight/length and maturity.		
Sprat	**Lifespan:** Short lived (<7 years). **Behaviour:** They come to surface waters at night to feed and remain in deeper water during the day.	North Sea (sub-area IV)	The status is uncertain, but there are indications for an increase over most of the time-series.	TAC and Maximum Sustainable Yield (MSY) advised by ICES.	Yes	ICES (2022)
		West Coast	Data lacking. The information available is insufficient to	For stocks without information on abundance or exploitation rate, ICES	Yes	[Marine Conservation Society (2023). Sprat.]()

Forage fish	Key ecological factors	Region/stocks	Health status of stock	Current management	Is it worth exploring fishery management for the benefit of seabirds?	Relevant references/key information sources
	Movements: Migrations tends to be towards inshore waters during winter though older fish may remain offshore. Multiple batch spawners (between January and July).		evaluate stock trends and exploitation.	considers that a precautionary reduction of catches should be implemented where there is no additional information clearly indicating that the current level of exploitation is appropriate.		

7.2.3 Steps for implementation

The overall implementation of these conservation actions would need to be undertaken by government. The proponent could participate in steps 1 and 5.1.

1. **Collation of baseline information on forage fish, fisheries, and seabirds:**

To determine whether changes in fisheries management to benefit seabirds is appropriate for a given location, there must first be good baseline knowledge of the dynamics between forage fish, fisheries, and seabirds. A thorough scientific assessment, either through collation of existing information (e.g. ICES reports) or through new data collection, must be conducted to determine the following information:

   1.1. Knowledge on the ecology and biomass of forage fish and the role and the impact of fisheries on these species.
   - Forage fish data: population structure, seasonal and regional variations in prey distributions, life cycle, population size, and reproduction rates.
   - Fisheries data: catch levels, fishery type, and bycatch.
   - Analyses and predictions of the impact of fisheries on forage fish stocks, while accounting for other factors affecting these stocks (see Figure 28).
   - Assessments of the potential impacts of different fisheries management options and environmental conditions (oceanographic patterns, temperature, etc) on stocks.

   1.2. Understanding of the relationship between forage fish stocks and seabirds.
   - Seabird diet: proportion of each age/group/species of forage fish consumed by each species and regional, seasonal, and temporal variation on the diets.
   - Seabird foraging range and behaviour.
   - Analyses of stock size variation and their effects on seabird demography (survival, productivity), and predictions on how environmental changes and fishery pressures will impact them.

   1.3. Understanding of the relationship between fisheries and seabirds.
   - Assessments of the potential impacts of different fisheries managements on forage fish stocks and availability for seabirds, and, how this translates to impacts on seabird demography.

2. **Conduct formal and informal consultations:**

   2.1. Conduct both formal and informal consultation with key stakeholders, including fishing communities, international/EU fishing organisations (e.g. ICES), conservation organisations, and local authorities, to gather input and discuss the implications of potential management measures.

   2.2. Governments could develop and put in place a public consultation to explore one or various management measures aimed at protecting forage fish stocks. The primary objective of the consultation will be to assess the feasibility of implementing different measures, evaluate their economic impacts, and consider public opinion. Examples of relevant recent public consultations are: 1) setting of the TAC for Herring in the Firth of Clyde (Scottish Government, 2023a) and the Scottish Government consultation on the closure of Sandeel fisheries within Scottish waters (Scottish Government, 2023d). Note that these consultations aim to improve fish stock to generate broader environmental and ecosystem benefits rather than solely focussing on seabird protection.

3. **Decision on whether to proceed with conservation action (changes in fisheries management):**
    3.1. Evaluate and incorporate feedback from the consultations, along with any other available evidence. Consult with ICES for additional insight and expertise.
    3.2. Government should then decide whether to continue to pursue action after weighing up the ecological benefits with the economic, political, and social costs. This will also include identifying whether fisheries management changes could constitute compensation or be required for other policy obligations.
    3.3. Determine the fisheries management to be implemented.
4. **Implementation:**
    4.1. The specific implementation approach will depend on the fishery management measure. All should adhere to standard regulatory and procedural processes followed when changing fishery management.
        - Examples of potential considerations include defining geographic boundaries and duration of closures, implementing changes to fishing permits, licenses, or catch limits, and how any management relates to any other area-based conservation management (e.g. Marine Protected Areas (MPAs)).
    4.2. Identify and clearly communicate the reasons, objectives, and anticipated outcomes of the proposed fisheries management.
    4.3. Establish and conduct monitoring programmes.
        - Monitor compliance (see 'Other – Compliance' within the Key considerations section): ensure enforcement mechanisms to guarantee compliance with regulations.
        - Monitor to check effectiveness of the fisheries management on seabird demography (see monitoring).
5. **Establish long-term adaptive management:**
    5.1. Continuously monitor the impacts of fisheries management on fish stocks, seabirds, and the ecosystem, and make necessary adjustments based on the best available scientific data and stakeholder and international input. Note that studies to monitor the effects of such management interventions will generally take many years/decades to provide clear conclusions and could limit the potential for adaptive management.
    5.2. Invest in research and innovation to develop new technologies and practices that enhance sustainability and reduce the environmental impact of fisheries.
    5.3. Develop and implement a communication and outreach plan to help build buy-in for actions taken.

7.2.4 Ecological effects of implementing action

There is extensive evidence that show that changes in forage fish abundance, availability, and quality affect the breeding success and survival of seabirds through impacts on foraging efficiency, diet, chick provisioning and parental care to varying extents (Oro and Furness, 2002; Cury et al., 2011; Carroll et al., 2017). There is also evidence that commercial fisheries can deplete forage fish stocks and, as direct competitors, represent an important threat to seabirds (Frederiksen et al., 2004; Jennings et al., 2012; Cook et al., 2014; Carroll et al., 2017; Lindegren et al., 2017; Dias et al., 2019).

The ability of seabirds to prey on forage fish depends on both the absolute numbers of the fish (abundance/stock) and the availability of the fish to seabirds (Figure 28). During the breeding season, seabirds are constrained in both the distance from nest sites that they can forage and the depth in the water column that they can reach, with both foraging range and dive depth varying greatly among species. Additionally, some species have predominantly or exclusively fish diets and differ considerably in their responses to reductions in food abundance compared to seabirds with more generalist diets (e.g. large gull species). Therefore, prey changes and management of forage fish fisheries will have different effects on each seabird species and the ecological context (e.g. presence of other marine predators). The most vulnerable species are, therefore, likely to benefit from measures that allow stocks of forage fish to recover from depletion caused by fishing on those stocks.

As the abundance and quality of Sandeel decreases, there has been marked community level changes in seabird diet composition, especially on auks and Kittiwake over the last three decades towards a higher consumption of Sprat and Herring (Wanless et al., 2018). Therefore, any fisheries management that could secure the stability and/or increase of Sandeel, Herring and Sprat stocks have the potential to benefit seabirds in terms of productivity and survival. Below, a more detailed review on ecological impacts per species is summarised.

7.2.4.1 Kittiwake

Sandeels serve as the primary food source for Kittiwake in the UK during the breeding season. However, Kittiwake also consume Sprat and Herring, particularly in years when Sandeels are less available or of lower quality. Kittiwake are surface feeders, making them particularly susceptible to changes in the vertical distribution and abundance of their prey. Given the ecological characteristics of Sandeels, they are only available to Kittiwake for part of their annual cycle, and their availability depends, to a certain extent, on external factors such as upwelling or predatory fish making Sandeels available. Within Scotland, Kittiwake are the seabird species most vulnerable to the depletion of their food sources by fisheries, especially Sandeel (Furness and Tasker, 2000; Heath et al., 2017). Several studies have demonstrated population-level effects, including decreases in survival and breeding success due to a reduction in Sandeel abundance (Frederiksen et al., 2004; Daunt et al., 2008; Carroll et al., 2017). In Orkney and Shetland, Kittiwake breeding success, and breeding numbers, decreased dramatically after the collapse of the Shetland Sandeel stock (Furness and Tasker, 2000; Wright, 2006).

As a result, increasing the stock of forage fish species through total fishery closures or other fisheries management measures, especially improving the abundance and quality of 0-group Sandeels, has the potential to enhance breeding success and overall survival of Kittiwake, or at least to prevent further declines. However, a recent study by Searle et al. (2023a) examining the long-term seabird demographic effects of the Wee Bankie Sandeel closure shows that while the closure has prevented further declines, and in some colonies led to increases in Kittiwake breeding success, it has not led to a full recovery to pre-fishery levels, despite twenty years of potential recovery time. During this same period there were significant declines in zooplankton (i.e. prey for Sandeel) biomass in the region associated with longer term environmental change (Olin et al., 2022) and 'scientific fisheries', which may, in part, explain the lack of a strong recovery in Sandeel. Therefore, the evidence that further Sandeel fishery closures or other fisheries management, will deliver significant population level benefits to Kittiwake is unclear and is expected to highly depend on the ecological context.

7.2.4.2 Puffin

Puffin heavily rely on the focal forage fish, especially 0-group Sandeel. The breeding success of Puffin has been shown to correlate with availability of forage fish (Martin, 1989). In Shetland, during years of low Sandeel abundance, breeding success was low, increasing in years with moderate Sandeel abundance (Furness and Tasker, 2000). Similarly, Fayet et al. (2021) suggests that the poor productivity at north-eastern Atlantic populations is driven by breeding adults being forced to forage far from the colony, presumably because of low prey availability near colonies. Therefore, Puffin would benefit from managements aimed at increasing the stock of forage fish, especially those in proximity to breeding colonies. However, it is worth noting that the Wee Bankie closure did not result in an increase in breeding success. In fact, there was a significant decline in breeding success following the fishery closure (Searle et al., 2023a).

7.2.4.3 Razorbill and Guillemot

Razorbill and Guillemot both exhibit pursuit diving behaviour, but there are distinct differences between them. Razorbill tend to make shallower dives, forage more on Sandeel and less on Sprat, and provision chicks with several smaller fish compared to Guillemot, which provision single fish to chicks (i.e. multi- vs. single prey loaders). Razorbill may be less dependent on fish and able to consume more zooplankton (Mitchell et al., 2004). While both auk species are susceptible to food shortages, Razorbill may be more vulnerable to reduced Sandeel abundance than Guillemot. This is due to the latter's capacity to access Sandeel within the sand, providing an additional foraging advantage. Nonetheless, both Razorbills and Guillemots are notably more resilient than Kittiwake in the face of food scarcity (Furness and Tasker, 2000). Österblom et al. (2006) found that Sprat quality was a stronger determinant of Guillemot fledgling weight when compared to Sprat abundance. For Guillemot in the North Sea during winter, Sandeel form part of their diet (Sonntag and Hüppop, 2005), presumably foraged though benthic dives to extract burrowed Sandeel. Management measures securing forage fish stocks and fish quality are likely to increase breeding success and adult survival of auks.

7.2.4.4 Gannet

Gannet exhibit a high degree of flexibility in their foraging ranges (Woodward et al., 2019) and diet (in terms of prey species and sizes). Consequently, they are less susceptible to changes in abundance and distribution of individual forage fish species, being able to switch to other forage fish species or prey with no impact on their breeding success (Martin, 1989). However, Guillemette et al. (2018) demonstrated that the breeding success of Gannet begins to decline at approximately 8% of the maximum prey abundance. Similarly, Hamer et al. (2007) suggest that while adults have managed to maintain high reproductive success during years of low prey availability, they may struggle to do so in future years if providing sufficient food for chicks entails further increases in trip duration and/or foraging effort. Both studies demonstrate that even Gannet, a species considered to have low vulnerability to changes in forage fish abundance and distribution, may experience reduced breeding success and adult survival when certain conditions are reached, particularly a reduction of high-energy prey such as Mackerel. This vulnerability may be further exacerbated by factors like the ongoing HPAI outbreak.

7.2.4.5 Large gulls

Large gulls are generalist predators and opportunistic feeders, capable of exploiting a wider range of prey compared to most seabirds, including foraging on both marine and terrestrial habitats. Impacts stemming from the availability of forage fish during the breeding season can be mitigated by shifting to other available prey options (Furness and Tasker, 2000), and as such, there is low confidence that fisheries management will increase breeding success and/or survival of these species (Furness, 2021). Nevertheless, gulls also rely on larger fish species, such as Haddock and Whiting, which, in turn, feed on forage fish. As a result, there is a possibility that gulls benefit indirectly through increases in other prey species.

7.2.4.6 Benefits to other species and the wider ecosystem

Other seabird species with high foraging costs, limited diving ability (i.e., surface feeders) and restricted dietary flexibility, such as terns, Arctic Skua, Red-throated Diver and European Shag, are also likely to benefit in a similar way to the focal seabird species from any increases in forage fish resulting from changes to fisheries management; as has been shown for Common Tern and Sprat (Jennings et al., 2012).

Fisheries management focussed on increasing the biomass of forage fish is likely to yield ecosystem benefits by enhancing ecosystem resilience and reducing the risk of forage fish stock collapse, though may be unlikely to lead to full recovery unless the environmental conditions are suitable (e.g. Essington et al. (2015); (Lindegren et al., 2017)). These benefits extend to increasing the populations of other marine foragers, such as marine mammals (e.g. Harbour Porpoises) and other fish species (Heath et al., 2017), as well as of threatened and vulnerable species that rely on prey fish as a food source. Closures and/or implementation of sustainable fishing practices could lead to reduced mortality by decreasing bycatch of species like Whiting, Mackerel and other seabirds. The extent to which these benefits are realised will depend on factors such as the size of the spatial closure, whether industrial fishing activity is reduced or merely displaced, the time required for stocks to recover, and external factors such as the continued negative impacts of climate change.

7.2.4.7 Time-lags for population level responses

Population-level responses to fisheries management will manifest over the medium and long-term, making it increasingly challenging to disentangle the effects of the management from other variables. There is substantial uncertainty around the period over when benefits to seabirds from changes in managements would be measurable. This uncertainty is tied to the temporal gap between cause and effect, which is influenced by the life cycle of both forage fish and seabirds (age of sexual maturity ~4 to 6 years), combined with the uncertainty associated with the timing of any recovery in forage fish biomass alongside predicted impacts to survival from other pressures, including the operation of wind farms.

The impacts of climate change and other factors introduce additional complexities and uncertainties. These impacts are inherently difficult to predict and consequently, contribute to a reduction in certainty surrounding the expected outcomes of these management measures.

7.2.5 Research and monitoring recommendations

Given the complexity involved in determining the direct effects of fisheries management on seabird demography, several ecological components require monitoring to assess the effectiveness of the action. As changes in fisheries management for conservation purposes are ecosystem-based management approaches, effects will be observed over the long term and need to be understood in the context of any wider ecological changes. Therefore, continuous monitoring is necessary while the action is ongoing. Following Figure 28, several variables should be monitored.

7.2.5.1 Changes in fish abundance and impacts of fisheries

Before and during ongoing management, it is crucial to implement a data collection programme to monitor changes in forage fish abundance and fisheries.

Forage fish populations can be monitored through various methods including statistics on the quantities of each species landed at fishing ports, biological data on the size and age of the fish caught, and ecological and biological data of fish at sea. Such data can be obtained through a variety of techniques such as research trawls (controlled effort destructive sampling), surveys using imaging systems on robotic and autonomous underwater vehicles, hydroacoustic technology, proxies for abundance (e.g. catch per unit of effort), and electronic fish tags and genetic analysis, to understand habitat use, and fish movements.

Where there is not a full closure, the total fish removed from the stock by fisheries should also be monitored. A monitoring programme should be implemented to collect catch data and make this information available for analysis. Monitoring can take various forms, including monitoring of fish landings, logbooks (records from commercial fishers of their location, gear, and catch), electronic monitoring (with cameras), observers (scientists or trained individuals on fishery vessels observing fishing operations to collect data on catch levels, discards and bycatch), and unsystematic surveys (interviews and surveys to fishers).

Stock assessment models, such as surplus production models, virtual population analysis, and statistical catch-at-age models, can then be used to assess the status of exploited fish stocks (Fogarty and Siskey, 2019). These assessments help estimate critical stock characteristics such as biomass, spawning stock biomass (total weight of the reproductively mature individuals in the stock) and maximum sustainable yields (the largest average catch that can be continuously taken from a stock under existing environmental conditions). Currently, Marine Directorate scientists gather data on stocks in the North Sea and the west of Scotland annually. This information is then combined with data from other European nations that fish in these waters and is used by ICES to estimate the current state of the stock and predict possible future changes.

Most data on forage fish populations are collected for fisheries management purposes and, as such, will not necessarily provide detailed information on forage fish availability to seabirds. Therefore, enhanced monitoring that includes data collection aimed at understanding changes in prey availability to seabirds would be important to better link changes in fishery management to seabird foraging. This should include data collection during key periods (e.g. chick-rearing periods for seabirds). New technologies are making this more possible, e.g. by using remote surface and underwater monitoring techniques.

7.2.5.2 Changes in seabird demography and foraging ecology

To assess the impact of fisheries management on seabirds, monitoring should encompass a range of seabird demographic and foraging studies. This includes regular productivity observations, body condition assessments, capture-recapture survival rate studies. Additionally, bird tracking would enhance the understanding of foraging range and behaviour, while diet analysis through observations and sample collection will provide insights into forage fish consumption and dietary variations across species, regions, seasons, and years.

7.2.5.3 Other variables

As illustrated in Figure 28, fish abundance is regulated by several factors, all of which need monitoring. For example, advanced monitoring equipment integrated to traditional sampling gear can collect environmental information. Existing sampling data can also be used (or enhanced), e.g. continuous plankton recorder and Scottish Coastal Observatory. This information can then be used to undertake models to predict the impact of various climate change scenarios on fish stocks. Additionally, it will be essential to conduct simultaneous monitoring of other variables that may affect seabirds, including HPAI and the potential effects of offshore wind farms.

7.2.5.4 Statistical analyses to understand management impact on seabirds

To better understand the relationship between the quality and stock of forage fish and how this translates to seabird breeding success and survival, statistical analyses are crucial. Ecosystem and demographic models can be employed for this purpose. For instance, the use of Before-After-Control-Impact models is a valuable approach in evaluating the impact of management strategies on seabird populations. These models compare demographic data collected before and after the implementation of management measures, provided a baseline dataset exists. This approach enables researchers to isolate the direct effects of management on seabirds while accounting for other environmental variables.

Examples of valuable studies to be replicated include: Heath and Speirs (2011) and Searle et al. (2023a). Heath et al. (2017) highlight essential research priorities that should be addressed. Some ongoing studies may address some knowledge gaps (e.g. the OWEC project PrePARED and the EcoWind projects Pelagio and EcoWings).

7.2.6 Key considerations, potential barriers, and potential solutions

Key considerations	Potential issues	Potential solutions
Policy/political	International relations when changes in fisheries management affect non-UK vessels operating in Scottish Waters (e.g. most vessels targeting Sandeel in UK waters are Danish). Domestic political considerations if fisheries management reduces fishing opportunities to UK vessels. Scottish Government and UK Government managing Sandeel under different regimes e.g. one for wider conservation (for contributing towards Good Environmental Status) and the other as a compensatory measure.	If the management involves shared waters or species, collaborate with other countries and international bodies to, where possible, follow a coordinated approach. This could include regional agreements for common approaches to forage fish fisheries management across borders. Updated ICES approach to advising on forage fish TACs to account for their ecosystem role and emerging threats from climate change and impacts of renewable energy developments on fishing opportunities. Coordination between the Scottish and UK Governments to align forage fish management under a common regime.
Legal	Ensure that the proposed management is consistent with existing laws, regulations, and international agreements governing fisheries management.	Clear justification should be provided prior to implementing action to demonstrate how decisions are aligned with legislation (fisheries, environment, energy etc.) and avoid legal repercussions.
Financial	Costs of implementing measure: • Direct costs to the fishing industry from reduced access to fishing grounds. • Direct costs from any increased compliance monitoring through fisheries patrol vessels and inspections or review of REM footage. • Direct familiarisation costs to the vessels. • Indirect costs to the fishing industry associated	Undertake appropriate Business Regulatory Impact Assessments to identify risks and minimise these. Map the future trends of these fisheries and identify a just transition out of the fleet. Funding would need to be secured pre-implementation to ensure that the full scheme can be implemented as planned.

Key considerations	Potential issues	Potential solutions
	with displacement to other fishing grounds. • Indirect costs to the fish processers and fishmeal importers associated.	
Ecological	Management measures risk displacing forage fisheries to other areas (both within and outwith Scottish Waters), or on to other species. Therefore, previously unaffected species and ecosystems could be negatively impacted. This risk has the potential to be harmful if stocks, where data is limited, are overexploited. For instance, if a Sandeel fishery closure is implemented in part of UK waters only, then it could result in increased fishing in the remaining open areas. Similarly, the approval of a Sandeel closure could lead to more fisheries exerting increased pressure on Sandeel outside the Scottish/UK EEZ if TACs are not reduced to account for closed areas. Much of fisheries and general at-sea research is currently reliant on data collected by fishing vessels. A decrease in fishery activity could decrease the biological data collected at sea.	Implement an integrated approach to management. ICES point on better accounting for ecological role and areas closed to fishing, and better coordination with other countries as well as strict control/compliance and monitoring/enforcement. In cases where complete closure is not possible, or political agreement cannot be reached, alternative prey fisheries management strategies should be explored. Provide and secure funding to ensure the ongoing collection of scientific data.
Resources (non-financial)	Lack of available seabird and fish research capacity to undertake the detailed monitoring required to monitor ecosystem changes following changes in fisheries management.	Ensure adequate long-term funding arrangements to allow sufficient resource allocation and building up of research capacity. Use new technologies to automate aspects of monitoring (at seabird colonies and of forage fish at sea) and data processing.

Key considerations	Potential issues	Potential solutions
Practical and logistical	No additional practical and/or logistical issues beyond those already discussed were identified.	NA
Other – Social	The UK and EU fish processing sectors could be impacted. For example, of the Sandeel caught by non-UK vessels in Scottish waters in 2016-2020, just 1.1% was landed into Scottish ports. Negative social impacts for individuals involved in the impacted fisheries, leading to reduced employment opportunities. In 2022, Herring was the second most common fish species landed by Scottish vessels and third highest by value. Profit will depend on changes in allowed catches and could be affected (negatively or positively).	Implement financial compensation schemes for impacted fishery operators that are proportionate to the losses incurred and develop transition plans to support alternative economic opportunities. Engage with stakeholders and communicate clearly with them.
Other – Compliance	There is a risk of potential lack of compliance, which could undermine the ecological efficacy of the action.	Ensure strong enforcement mechanisms to support compliance with regulations. Implement monitoring and surveillance programs to deter illegal fishing practices and ensure compliance.
Other – Additionality considerations	This issue mainly applies to any Sandeel fishery closure. The existing commitments and rationale for closure have not been focussed on closure as a compensatory measure. This can introduce legal uncertainty if closure is subsequently tied to compensation. Similar issues may exist for changes to fisheries management for other forage fish, although the degree of uncertainty in these cases is greater.	Ensure coordinated policy approaches between marine conservation, fisheries management, and strategic compensation/marine restoration.

Key considerations	Potential issues	Potential solutions
Other – lag effects	Any benefit from fisheries management will be perceived in many years and will be hard to discern from other pressures, including natural variability. This could reduce the potential for robust adaptive management and implementation of additional compensatory measures were benefits from fisheries management are less than anticipated.	Develop research programmes to increase scientific understanding through data collection and development of advanced ecosystem models. Establish effective monitoring programmes from the outset.

7.2.7 Species-specific aspects of implementation

Because this is a fisheries management measure, there are no seabird species-specific aspects regarding its implementation, other than the associated monitoring efforts. All seabird species are likely to benefit from fisheries management measures aimed at increasing forage fish abundance, especially Sandeel, as these are highly attached to particular sand banks and have limited dispersal and movements.

7.2.8 Overall conclusion

Forage fish play a vital role in marine ecosystems, supporting various predators, including seabirds, marine mammals, and larger commercially valuable fish. These fish face multiple pressures, such as fishing, habitat modification, climate change impacts on food resources, and natural predation. Therefore, fisheries management, including closures, though practically feasible, may be best viewed as ecosystem-based measures for wider conservation benefits, so may be less suitable options for compensation focussed on specific feature species impacted by additional pressure from offshore wind (aka. like-for-like compensation). Even with detailed monitoring, it may not be possible to confidently determine the impact of fisheries management on seabird demography, which could compromise the ability to confidently quantify any benefits of changes in fishery management to seabird populations.

Where full fishery closures are not feasible, alternative fisheries management options to improve the sustainability of the fishery such as adjusting fishery quotas (e.g. set-aside policies for forage fish that account for predator needs and areas closed to fishing), imposing limits on time at sea, implementing closures during critical periods (e.g. seabird foraging periods and fish spawning), and restrictions on fishing gear, should be considered.

When designing any changes in fisheries management, particularly as a compensatory measure, then this must be developed in an integrated way. This will require an inter-disciplinary approach between scientists with expertise in benthic processes (e.g. to account for impacts of offshore wind development on fish habitat), plankton and fish ecology, seabird ecology, and wider marine ecosystem changes (from climate change). Of particular importance when seeking to predict future changes is in understanding directional changes in ecosystems, e.g. changes in the plankton communities that support forage fish, to be able to adequately account for both bottom-up (e.g. plankton abundance) and top-down (e.g. natural predation and fisheries) processes. The additional effects (opportunities and risks) from renewable energy development on oceanographic processes and forage fish will also need to be considered. Coordination between different Government departments and directorates will also be critical.

7.3 Practical feasibility: End of the Gannet harvest at Sula Sgeir

7.3.1 Summary

Table 44. Summary of practical feasibility for end of the Gannet harvest at Sula Sgeir. Further detail is provided following the table.

	End of the Gannet harvest at Sula Sgeir
Description	Cessation of the annual harvest of near full-grown Northern Gannet chicks ('guga') at Sula Sgeir.
Uncertainty	There is uncertainty on the wider population level effects beyond the Sula Sgeir population due to limited information on interchange between neighbouring colonies (metapopulation dynamics). While the target species is Gannet, there may be effects on other species, both positive and negative. Positive from reduced disturbance (e.g. petrels) and negative if Gannet expansion displaces other breeding bird (e.g. Fulmar). The overall feasibility is dependent on gaining community support for the action, the likelihood of this is not known. The recent significant impacts of HPAI on Gannet populations mean that the population level responses to the harvest locally and at wider spatial scales may change.
Species benefitting For detail see: Ecological effects of implementing action	Gannet: Productivity would increase with consequent expected increase in population growth rate at Sula Sgeir, with likely small benefits also to nearby colonies. Other species: Limited benefit to other species. Northern Fulmar, Leach's Petrel and European Storm Petrel may benefit from reduced disturbance increasing, productivity marginally, if at all. Majority of other seabird species have completed breeding at time of harvest (late August/early September) and therefore would not benefit.
Scale and degree of population benefit	Impact on Gannet: **Scale**: Local. **SPAs**: North Rona and Sula Sgeir. **Degree of benefit**: Ranging from medium to high (in a medium term) and low in the long-term. • Increase in population size until site reaches carrying capacity. Note that population size has been increasing in spite of the harvest. If current environmental conditions persist, and the harvest were to end, the site's carrying capacity would be expected to be reached more rapidly than with the harvest persisting. **Scale**: Regional (NW Scotland). **SPAs**: St Kilda; Sule Skerry and Sule Stack. **Degree of benefit**: will range from low to medium. • Increase of levels of natal dispersal from Sula Sgeir to nearby colonies • Increase of population size, mostly on neighbouring colonies **Scale**: National (Scotland). **SPAs**: Fair Isle; Noss; Hermaness, Saxa Vord and Valla Field; Forth Islands; Ailsa Craig. **Degree of benefit**: low

	• Minimal impact on population size due to metapopulation processes **Scale**: Biogeographic (Northeast Atlantic). **Degree of benefit**: very low • Minimal impact on population sizes at distant colonies
Sequence of steps to implement For detail see: Steps for implementation	1. Pre-decision to proceed: • Undertake a consultation with members of the Ness community to discuss proposals for ending of harvest. Engage in negotiations aimed at achieving a mutually beneficial agreement, including proposals for compensating the community. 2. Decision on whether to proceed: • Proponent and Scottish Government to decide whether to continue to pursue measure after weighing up the ecological benefits with the financial costs and social impacts. 3. Implementation of action: • A legal agreement to be drafted and signed between the proponent and the Ness community. Agreement to be shared with relevant authorities (likely to include NatureScot and Scottish Government). • Put in place any compensation package agreed with the community. 4. Post-implementation of action: • Undertake Gannet population monitoring. • Adaptive Management. Proponent to schedule meetings with members and representatives of the Ness community to show progress and reassess compensation packages, if needed.
Monitoring summary For detail see: Research and monitoring recommendations	Utilise the model proposed by Jeglinski et al. (2023) to gain a deeper understanding into how Gannet from the Sula Sgeir colony are linked through metapopulation dynamics to regional and global colonies driven by density-dependence processes and natal dispersal between colonies. Perform surveys to conduct population counts of Sula Sgeir and neighbouring colonies to monitor population growth and size and evaluate the population response from discontinuing the harvest. Use of counts to undertake Before-After-Control-Impact (BACI) models to evaluate the impact of harvests on seabird populations by comparing data collected before and after ending the harvest, provided a baseline exists (i.e. surveys undertaken during harvest years).
Key considerations	**Community support**: The measure would be difficult to implement without achieving community support, which would likely require agreement on some level of financial compensation.

For detail see: Key considerations, potential barriers, and potential solutions	**Lack of compliance**: Community opposition could lead to lack of compliance if licensing of the harvest were curtailed without community consent. **Political support**: Ultimately, it is a political decision to decide whether the conservation benefits outweigh the cultural heritage considerations. **Ecological benefits**: Benefits beyond Sula Sgeir are highly uncertain, with positive benefits expected for nearby colonies, though the size of such benefits is unclear. **Permanent loss of cultural heritage**: The Gannet harvest has been a long-lasting tradition dating back several centuries. As such, it holds significant cultural value for the Ness community. If the harvest were to stop completely, there is a possibility that this practice could not resume due to loss of traditional knowledge. **Effectiveness of conservation action**: The future harvest rates and the long-term continuity of the harvest are uncertain. However, it could be expected that harvest rates decline over time, as they have over the past century. Consequently, the long-term benefits of the action are subject to increased uncertainty. **Impact on community goodwill**: Ending the harvest without community support could undermine existing community goodwill and trust that took years to develop, this is essential to other ongoing and future conservation schemes.
Other potential alternatives to conservation action	Reduced harvest intensity could partially mitigate the cultural heritage impacts of a full end to the harvest and increase the likelihood of community consent. This may, however, reduce the scale of the ecological benefits, depending on the level of harvest reduction. Harvest intensity could be reduced by either reducing the number of chicks allocated per harvest (currently ca. 2,000 chicks/year) and/or by reducing the harvest frequency (currently annual but could be reduced to e.g. biennial/triennial). Given that the exemption permitting the guga harvest is included in legislation, NatureScot cannot remove the quota as a compensatory measure for a development. Therefore, this alternative would need to be supported by the community.
Conclusion	Discontinuing the controlled harvest is expected to accelerate the population growth rate of the Sula Sgeir colony and, to a lesser extent, that of neighbouring colonies. Ending the harvest would impact on local community cultural heritage and traditions that have existed for centuries so could lead to community opposition with associated political risks in pursuing the action. Therefore, the success and implementation of this action relies on the response and engagement of the local community. Planning for the implementation of this action, including associated monitoring, would need to account for HPAI, both in terms of how this impacts the Gannet population, and how it impacts the harvest practice.

7.3.2 Background

Sula Sgeir is a small, uninhabited rocky islet located 18 km west of North Rona (59°5’43.44" N, - 6°9’ 22.6188"W), in Northwest Scotland. To date, the Sula Sgeir Gannet population is subject to a licensed annual harvest of 2,000 full-grown chicks, approximately 17% of the colony’s annual chick production (Wanless et al., 2015). This quota is set by the Scottish Government, with advice from NatureScot, and is revised and approved on a yearly basis. The record of the number of harvested full-grown chicks in recent years is shown in Table 45 and, since 2011, has ranged between 1,723 and 2,000, excluding years where harvest did not occur.

The harvest is restricted to accessible areas and occurs over a two-week period between late August and early September, towards the end of the breeding season. During this period, most Gannet chicks have reached an advanced stage of development, making them less susceptible to incidental additional mortality caused by the harvest (i.e. mortality to additional chicks beyond those harvested due to disturbance). Nonetheless, the risk of premature fledging or the inability to return to the nests after the disturbance remains and has not been quantified. Similarly, there is limited evidence regarding the broader impacts of this practice on the overall bird and fauna community within the site (e.g. impacts resulting from disturbance caused during catching, culling, and bird preparation, and due to general human presence).

Table 45. Gannet chicks harvested at Sula Sgeir between 2011 and 2023. Data from NatureScot (reported by Berwick Bank (2023a)).

Year	Number of harvested Gannet chicks
2011	2000
2012	0 (reason unknown)
2013	2000
2014	1723
2015	2000
2016	2000
2017	1900
2018	1791
2019	1987
2020	0 (due to COVID-19)
2021	1900
2022	0 (due to HPAI H5N1)
2023	0 (due to HPAI H5N1)

Of note, in years when Government advice has been issued due to human health concerns (such as in years 2022 and 2023 due to HPAI), the community itself has taken the decision not to proceed with the harvest.

7.3.3 Steps for implementation

1. **Pre-decision to proceed:**
   1.1. Undertake a consultation with members of the Ness community to discuss proposals for ending the harvest.
      - The consultation could be targeted to the whole community, to key people of the community, or could be exclusive to those who will be directly affected by the ending of the harvest.

   1.2. Initiate negotiations aimed at achieving a mutually beneficial agreement. Given the loss of cultural heritage to the community, the proponent should consider providing compensation through:
      - Provision of some kind of community asset (e.g. community centre) or providing improvement to existing community assets (e.g. improvements to harbour infrastructure, improving school facilities, etc). The specific compensation arrangement would require discussion with the community. This would likely require some ongoing commitment for the maintenance of such assets. Alternatively, the proponent could pay into a community benefit fund[9] to be administered by the community, either on a one-off or annual basis.
      - Financially support alternative opportunities that could support other Gaelic community traditions (e.g. promoting and preserving traditional Gaelic arts, music, and language through cultural programmes and events, supporting local Gaelic festivals and exhibitions, providing resources for educational programmes aimed at passing down other traditions to younger generations), thus partially offsetting the loss of cultural heritage from ending the Gannet harvest. Note that each cultural activity has its own value and significance and, therefore, cannot be directly substituted.
      - Engage in negotiation and consider a compromise. If discontinuing the harvest is likely to lead to conflict, it may be more effective to consider alternative options such as reducing the harvest quota or adjusting the frequency of the harvest. These alternatives will need community agreement.

2. **Decision on whether to proceed:**
   2.1. Proponent, along with the Scottish Government, should decide whether to continue to pursue action after weighing up the ecological benefits with the financial costs and social impacts.

   2.2. If the decision is to permanently stop the harvest, then consider changing the Statutory Order within the Protection of Birds Act that allows this exemption.

3. **Implementation:**
   3.1. A legal agreement would be drafted and signed between the proponent and the Ness community. This would include a summary of the action to be taken (i.e. no further harvesting and thus no licence renewals) together with any conditions agreed (e.g. a compensation scheme for the community financed by the

[9] This could be modelled on schemes implemented by wind farm developers for impacted communities, see Local Energy Scotland and Shetland Community Benefit Fund for an example of such a fund.

proponent). The agreement (or summary of) should then be shared with relevant authorities (likely to include NatureScot and Scottish Government).

3.2. Put in place any compensation package agreed with the community (step 1.2).

4. Post-implementation:

4.1. Undertake Gannet population monitoring (see monitoring section).

4.2. Proponent to schedule regular meetings with members from the Ness community to:

- Re-evaluate and modify compensation packages, as necessary.
- Present updates on the impact of the harvest cessation on the Gannet population, including findings from ongoing monitoring efforts.

4.3. If stopping the harvest is not yielding positive ecological results, consider alternative compensation options.

7.3.4 Ecological effects of implementing action

7.3.4.1 Gannet

As discussed in detail in WP1, harvesting eggs and/or chicks of any species undoubtedly affects seabird populations. Therefore, ending the annual harvest would increase the annual productivity by ~2,000 chicks per year and would most likely increase the population growth rate and population size of certain Gannet colonies, especially at Sula Sgeir itself but also to some extent surrounding colonies.

Trinder (2016) estimated that the harvest has reduced the Sula Sgeir population growth rate below the level that would be predicted in the absence of the harvest. The author estimated that if the harvest were to end completely, the median annual population growth rate would increase from ~1.023 (i.e. an annual population increase of 2.3% per year) to ~1.035 and to ~1.029 if the harvest quota were reduced to 1,000 chicks. Similarly, results from Wanless et al. (2005b) show that the population growth rate at Sula Sgeir from 1969 to 2004 was significantly lower compared to those from other UK Gannet colonies when accounting for population size, suggesting that an end to the harvest would lead to a population increase.

The annual harvest might also be impacting neighbouring populations that are linked through immigration and emigration, such as those from St Kilda and Sule Stack, Sula Skerry and Flannan Isles. Trinder (2016) estimated that to maintain the current population growth rate, the Sula Sgeir population requires ~270 breeding age recruits each year, likely sourced from colonies in Northwest Scotland. Consequently, the Sula Sgeir population could act as a sink for emigrant Gannet from other colonies, and discontinuing the harvest might lead to increased population growth in those colonies as well. However, it is important to consider density-dependence processes. There is a negative relationship between colony growth rate and colony size, and as such, as the population increases and breeding spaces become limited, the population growth is expected to decrease. Such a relationship between colony size and population growth rates has been demonstrated for Gannet in Britain and Ireland

(Lewis et al., 2001a), though the level of density dependence varies depending on environmental conditions (Davies et al., 2013).

Given the increasing population trends observed in the Sula Sgeir Gannet population, along with most other Scottish populations (Figure 30; information prior to the 2021/2022 HPAI outbreak), the harvest itself seems to exert a limited impact on the overall population size and has been considered to be a sustainable practice. Although discontinuing the licensed harvest would undoubtedly increase the productivity and accelerate the population growth rate of the Sula Sgeir colony as well as, to a lesser extent, those of neighbouring populations, its impact at the UK scale is likely minimal. Furthermore, should younger generations within the Ness community decide to cease or reduce their harvesting activities over time on their own accord, the overall degree of benefit derived from this action diminishes accordingly.

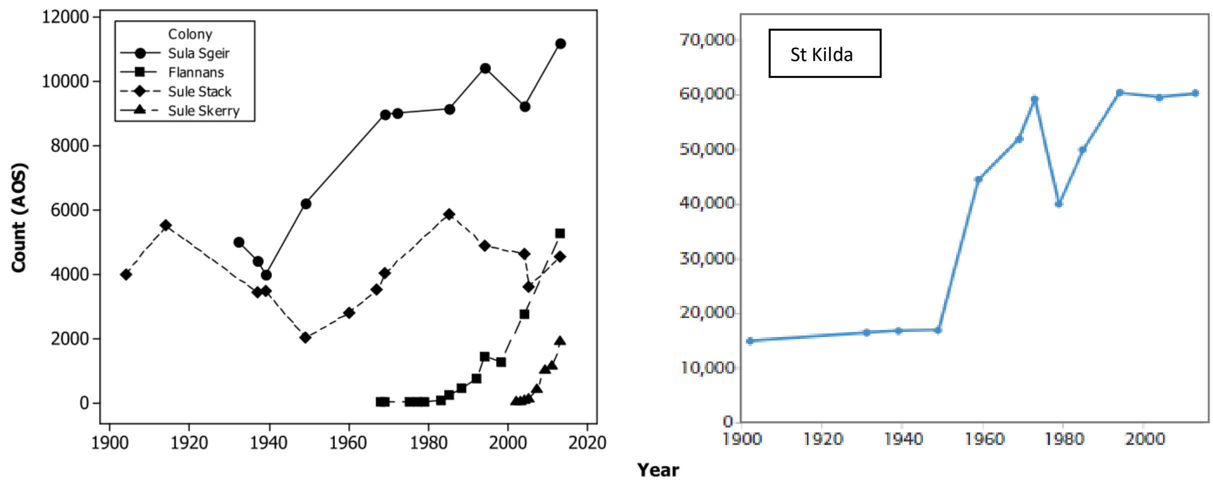

Figure 30. Number of Apparently Occupied Sites (AOS) through time at the Sula Sgeir and neighbouring colonies. A) Reproduced from: Wanless et al. (2015). B) Reproduced from: Murray et al. (2014). Note that this data excludes the years affected by the ongoing HPAI outbreak, which has been occurring since 2021.

7.3.4.2 Other species

Ending the harvest might provide limited benefits to other species present on the islet. The Northern Fulmar, Leach's Petrel and European Storm Petrel are the only other seabird species remaining at the site during the time of the harvest. As these species are also at late breeding stages, a reduction in disturbance could potentially lead to a slight increase in productivity. Most of the other seabird species have completed breeding at time of harvest (late August/early September) and therefore would not benefit. There is potential for negative impacts on some species were competition for nesting space to increase.

7.3.4.3 Time-lags for population level responses

For Gannet, the effects of this action will become evident within a short to medium timeframe. An increase in annual productivity will be seen effective immediately, as full-grown chicks will no longer be harvested. Survival and population growth, on the other hand, will become apparent as unharvested chicks reach sexual maturity, typically at around five years. As the colonies approach their carrying capacity and reach a 'saturation' point where nesting sites are no longer available, the rate of population growth will decline. For other species, the time lag for population level benefits will be longer.

7.3.5 Research and monitoring recommendations

7.3.5.1 Pre-implementation of action

Jeglinski et al. (2023) recently developed a model to understand the metapopulation dynamics and role of density dependent processes in Gannet colonies across the Northeast Atlantic, utilising over a century of census data, including data from Sula Sgeir. The study demonstrated that there were complex regional and broader metapopulation dynamics, including regional and local density-dependent processes, regulating population sizes. The study focussed on the development of a metapopulation model and its general findings with respect to population dynamics in Gannet. As such, it did not, in detail, discuss what the modelling revealed about the strength of different population processes operating for individual colonies or regions. Further development of this model, for instance by incorporating data on actual harvest levels (the current study only considers the presence/absence of harvests), would be a good first approach to understand how individuals from the Sula Sgeir colony are linked to regional and global colonies driven by density-dependence processes and natal dispersal.

Below we provide monitoring recommendations should this action be implemented. Nevertheless, we would advise that such monitoring plans are refined by further development of the model proposed by Jeglinski et al. (2023). Specifically, we suggest conducting a sensitivity analysis to identify which empirical data would best reduce uncertainty in model outputs, thus enhancing our understanding of the effect of changes to harvest practices at Sula Sgeir.

7.3.5.2 Post-implementation of action

Conducting population counts within the Sula Sgeir colony, as well as neighbouring colonies, is a good approach for monitoring population growth and size and assessing the effect of discontinuing the harvest on these colonies. Due to the challenges arising from researching large and remote gannetries, such as those along the NW coast, aerial surveys have emerged as the most common technique for the census of Gannet. This method involves capturing high-resolution photographs from an aircraft and subsequently counting the Apparently Occupied Sites (AOS) (see Wanless et al. (2015) for detailed aerial survey based count methods). However, Sula Sgeir's uneven terrain poses a challenge for population counts. Given its topography, counts based on aerial surveys are likely to be associated with significant errors. Depending on the expected change in the rate of population increase following the ending of the harvest, smaller population changes may not be detectable with this survey method. Furthermore, to gather more comprehensive data, such as quantifying the number of fledged chicks, juveniles, and immatures across the entire islet or in a representative sample, alternative methods like land, boat, and drone surveys could be more effective, either individually or in combination. These alternative surveys, however, may potentially cause additional disturbances, so the methods used would need careful consideration.

National Gannet surveys are undertaken separately to the main national seabird colony survey programmes (e.g. the recent Seabirds Count or Seabird 2000), and have typically been carried out at ca. ten-year intervals over the past few decades. To effectively monitor Sula Sgeir and ideally nearby colonies, implementing a programme of more frequent surveys during the initial period before and following cessation of the harvest at Sula Sgeir would be appropriate. Conducting the initial surveys, especially within the next few years, is highly important for establishing a robust baseline given likely population level changes from HPAI impacts. The survey frequency should be informed by a sensitivity analysis (see above) to determine what frequency of surveys would be most appropriate, however we would anticipate that relatively frequent surveys would be most useful (e.g. every third year or even annual for the first several years). More frequent surveys will provide thorough detail on both changes in population size and population growth rates over time, while longer survey intervals would only provide coarse data on changes in the rates of population change. Reporting requirements should correspond to the agreed data collection frequency. The initial reporting would focus on documenting the data collection process and, after the first few years, detailed analyses at agreed intervals would be required.

Before-After-Control-Impact (BACI) models are another valuable tool for evaluating the impact of harvests on seabird populations by comparing data collected before and after ending the harvest, provided a baseline exists (i.e. surveys undertaken during harvest years). This approach allows researchers to discern the direct effects of the harvest on seabirds while controlling for other environmental variables.

To enable effective comparisons across colonies, surveys should be conducted during similar time periods. Such comparisons are essential for understanding changes in population sizes and metapopulation processes, such as immigration and emigration rates. Whenever possible, comparisons of population trends and growth rates with those of other Scottish colonies will help understand whether the Sula Sgeir population is exhibiting similar behaviours when accounting for population size and potential impacts of climate change and/or HPAI. While fully disentangling mortality rates caused by climate change, HPAI and harvest can be challenging, the impact of the harvest can be quantified by contrasting the Sula Sgeir population rate with those from neighbouring colonies, where climate change and HPAI are expected to have similar effects. With the recent development of a metapopulation model for Gannet (Jeglinski et al., 2023), and potential for remote monitoring, the effects of these different pressures on individual Gannet colonies should be more possible to disentangle than was formerly the case using single colony closed population models.

Long-term ringing and resighting studies are also an important method of estimating annual survival rates to improve population models. This method involves the systematic ringing and subsequent recapture or resighting of individuals over several years. Annual survival estimates can be calculated using statistical models like the Cormack-Jolly-Seber (CJS) model. Nevertheless, implementing a long-term ringing-resighting scheme on Sula Sgeir may not be possible or advisable, given its challenging terrain and logistical limitations, so effort may be best allocated to more frequent population surveys.

7.3.6 Relevant SPA and SSSI Site Conservation and Management Advice

Sula Sgeir has protection both as an SPA and SSSI (as part of the North Rona and Sula Sgeir SPA/SSSI). The SSSI site management statement notes that the Gannet harvest is a "traditional right that has been exercised by Ness people for at least several hundred years" (SNH, 2010). Under SSSI site management objectives it is noted that the current harvest intensity (2,000 chicks per year) does not appear to be leading to population decline and it is concluded to, therefore, be compatible with maintaining the population in favourable condition (though notes that were the population to subsequently decline then the quota would be reassessed). Full Conservation and Management Advice has not yet been published for the SPA, however, Conservation Objectives are available. The Conservation Objectives are relatively generic (i.e. in common with other seabird breeding colony SPA sites) including e.g. maintaining, in the long term, the 'Population of the species as a viable component of the site'. As such, the SPA Conservation Objectives do not specifically consider the Gannet harvest.

7.3.7 Key considerations, potential barriers, and potential solutions

Key considerations	Potential issues	Potential solutions
Policy/political	Political decision to decide whether the conservation benefits outweigh the social and cultural heritage considerations. Balancing national and local interests and associated policies.	Gaining community agreement would reduce political risks. Also see the alternative solutions proposed at the beginning of the section.
Legal	As the harvest is a licensed activity, it is, in theory, possible to stop issuing new licences. However, it is not clear that the licensing authority (NatureScot) has the competence to stop issuing licences on grounds of compensation. Government intervention will be required. The traditional right to harvest has been granted to the Ness community for hundreds of years and may limit potential to remove this right without community consent.	Review the legal framework underpinning the licensing regime. Community engagement and agreement of compensation. See also the alternative solutions proposed at the beginning of the section.

Key considerations	Potential issues	Potential solutions
Financial	Financial costs associated with ending the harvest encompass various components: • Gannet monitoring • Community compensation	Funding would need to be secured pre-implementation to ensure that the full scheme would be implemented as planned.
Ecological	An increase in the Gannet population could reduce the available nesting space for other more vulnerable species, like Fulmar. Risk that compensation proves less effective than expected.	Detailed monitoring plans should be developed and agreed pre-implementation, these should include agreed success criteria to evaluate whether the compensation is delivering as predicted. These would then inform any adaptive management required.
Resources (non-financial)	Implementing the measure itself would require limited resources. Associated activity would require expertise and staffing (for monitoring and community engagement activities). Depending on the monitoring programme decided on, specialist digital aerial survey services may be required.	The (non-financial) resource requirements are relatively limited so should not be a significant barrier. Local community members could be employed for monitoring and engagement building on existing expertise. Digital aerial surveys would be carried out infrequently (likely <1 survey/year) so survey capacity and costs should not be a significant barrier.
Practical and logistical	Organising regular meetings can entail practical and logistical challenges. Working at Sula Sgeir and neighbouring colonies is challenging. Many logistical problems may arise that, if not considered, could potentially compromise the integrity of the scientific research and could yield inconclusive and erroneous results.	Successful meetings demand careful planning, effective communication strategies (including providing alternative communication channels), and ongoing efforts to create an inclusive and collaborative atmosphere within the community. Best practice approaches for community engagement should be followed. Plan fieldwork well in advance to minimise unexpected logistical problems that may arise. During the planning phase, consider establishing communication with researchers who have previously conducted work at these sites, or similar sites, to gain valuable insight into

Key considerations	Potential issues	Potential solutions
		potential issues and ensure preparedness to address them effectively.
Other – Cultural	The harvest represents a longstanding tradition that dates back to at least the 16th century (Beatty, 1992). As such, it holds significant cultural value for the Ness community, encompassing not only the practice of the harvest itself, but also the culinary tradition of eating the salted Gannet dish. It is possible that stopping the harvest, even for a limited time period (e.g. 15 years) would lead to permanent loss of traditional knowledge, leading to it being impossible to resume the harvest in the same way in the future, even if it were subsequently deemed to be desirable to so. Possibility that younger generations decide to discontinue or reduce the harvest by their own accords, in which case the benefit of the measure will be less impactful.	See the alternative solutions proposed at the beginning of the section.
Other – Community goodwill	Enforcing the end of the harvest without the support from the community could impact ongoing local conservation schemes (e.g. payments for managing land for Corncrake on crofts and sustaining the Loch Stiapabhat Nature Reserve and Observatory) as well as potential future conservation	Community engagement to ensure community support prior to implementing action is crucial.

Key considerations	Potential issues	Potential solutions
	initiatives. This could undermine previous conservation efforts and community trust that took years to establish.	
Other – Health and safety	The logistical challenges of monitoring and traveling to Sula Sgeir could raise significant health and safety concerns. Researchers could get injured while conducting surveys and/or installing cameras.	Conduct a comprehensive risk assessment before commencing fieldwork, ensuring thorough consideration of potential issues. Develop contingency plans for suspending fieldwork and addressing emergencies in the event of unforeseen circumstances. Field risks could be mitigated by relying more on remote monitoring (camera systems) and/or digital aerial surveys.
Other – Compliance	Any legal agreements and arrangements made around ending the harvest would need monitoring and compliance arrangements to assure that agreements are followed through.	Compensation plan should include associated monitoring and compliance arrangements.
Other – HPAI	Continuing or further outbreaks of HPAI could reduce the effective benefit of ending the harvest (as the harvest may not have taken place anyway, as in 2022 and 2023, due to human and/or animal health concerns), i.e. there would be less additional benefit if harvest frequency and rates were reduced anyway due to HPAI concerns. Further outbreaks of HPAI (or other diseases) leading to significant Gannet mortality would reduce the potential to attribute population responses to ending the harvest.	More frequent monitoring will better allow for HPAI impacts to be accounted for when analysing population level responses.

7.3.8 Species-specific aspects of implementation

Ending the harvest is solely focussed on Gannet, therefore, this section does not apply for this action.

7.3.9 Overall conclusion

Discontinuing the controlled harvest is expected to accelerate the population growth rate of the Sula Sgeir colony and, to a lesser extent, that of neighbouring colonies. The impact at the UK scale is likely to be minimal due to the distance and small levels of population exchange between Sula Sgeir and more distant colonies, however, the metapopulation process is complex and remains unclear. Though practically feasible and likely to provide ecological benefits, this action has several risks. Ending the harvest would impact on local community cultural heritage and traditions that have existed for centuries so could lead to community opposition with associated political risks in pursuing the action. Therefore, the success and implementation of this action relies on the response and engagement of the local community.

There is a lack of evidence regarding the broader impacts of this practice on the overall bird and fauna community within the site so we may have underestimated the benefit of implementing this action to other species. Planning for the implementation of this action, including associated monitoring, would need to account for HPAI, both in terms of how this impacts the Gannet population, and how it impacts the harvest practice (given that no harvest occurred during 2022 nor 2023 due to HPAI).

7.4 Practical feasibility: Mammalian predator eradication and/or management

7.4.1 Summary

This section focusses on predator eradication, mostly focussed on rodents and on islands, and predator control or exclusion which focusses on larger mammals and at mainland colonies and islands. The focal seabird species identified for this conservation action are auks (Common Guillemot, Puffin, Razorbill) and large gulls.

There has been substantial work done in the UK in recent years on predator eradication on islands and associated biosecurity, in this account we provide a high-level summary of key information relevant for using this conservation action as a strategic compensatory measure. We also provide signposting to key sources for further information.

Table 46. Summary of practical feasibility for mammalian predator eradication, control, or exclusion. Further detail is provided following the table.

	Predator eradication (islands)	Predator control or exclusion (mainland colonies and islands)
Description	The removal of a mammalian land predator/s from an island for permanent reduction in predation. Requires ongoing biosecurity (including emergency incursion response plan) to avoid predators re-establishing subsequently.	Reducing predation to low levels by either excluding predators (e.g. exclusionary fencing on mainland sites) or by reducing predator density to low levels (usually for island sites) by ongoing predator control (e.g. trapping/poisoning).
Uncertainty	There is good confidence that predator eradication can lead to significant population level responses for seabird populations, however the feasibility of eradication is predator- and site-specific. The potential gains for individual species from eradication at any given site cannot be predicted with confidence; uncertainty is greatest where species are absent from a site as species will not necessarily re-establish post-eradication.	Requires ongoing long-term action to maintain effectiveness (e.g. maintaining predator exclusion fencing or predator control). If this was not possible to maintain (e.g. due to break in funding) then predation pressure could rapidly increase.
Species benefitting For detail see: Ecological effects of implementing	Predator eradication is a site-based measure with broad benefits to species vulnerable to mammalian predators. The species of benefit will vary by site but, in general, burrow and ground nesting seabird species will benefit most. Cliff nesting species	Predator control will benefit the same species as for predator eradication, though the level of benefits may be lower due to some predation continuing.

	Predator eradication (islands)	Predator control or exclusion (mainland colonies and islands)
management interventions	will rarely benefit significantly, though may in some circumstances (depending on types of predators present and the topography of the site). The key effects from mammalian predator eradications are reduced predation and increased productivity, together these can also lead to higher recruitment rates. Focal species: Guillemot are expected to have limited benefit for most sites, though may benefit at some sites depending on the topography and type of predator present (e.g. more vulnerable to Black Rat than Brown Rat). Razorbill may have moderate benefit for some sites where nesting in more accessible locations (e.g. boulder fields or scree). Puffin are highly vulnerable to mammalian land predators, so expected to benefit significantly. As ground nesting species, large gulls have potential for significant benefits. Other seabird species: The burrow/cavity nesting species, Manx Shearwater and European Storm Petrel, are the species likely to benefit most. Ground nesting species like terns and waders are also likely to benefit significantly where there is suitable nesting habitat for these species. Other cliff nesting species, like Kittiwake, are unlikely to benefit significantly.	Predator exclusion fencing is most likely to benefit large gulls (amongst the focal seabird species). Other ground nesting species, such as terns could also benefit (depending on site and existing predation pressure). The key effects of control and exclusion are the same as for eradication; reduced predation rates leading to increased productivity, and potential for higher recruitment rates.
Predators that may respond to management	Predator eradication can, in principle, be used for all species of mammalian land predators but the technical difficulty of eradication and the appropriateness of eradication will	Predator control (i.e. reducing population density of predators) can be applied to a wide range of mammalian land predators. It will generally only be suitable for

<table>
<tr><th></th><th>Predator eradication (islands)</th><th>Predator control or exclusion (mainland colonies and islands)</th></tr>
<tr><td>in Scotland/UK

For detail see: Predator-specific aspects</td><td>vary by species and site, particularly depending on the area, topography, and size of any resident human population. To date, most eradication attempts in the UK have focussed on rodents, especially Brown Rat and Black Rat, so success is more likely for these species given existing methods and experience.</td><td>islands, though may be suitable for non-native predators present on mainland areas (e.g. the Mink Control Project in northern Scotland).

Predator management via exclusionary fencing is most appropriate for medium-sized mammalian predators, such as Fox</td></tr>
<tr><td>Scale and degree of population benefit</td><td colspan="2">Impact on all species:
Scale: Local. Degree of benefit: Will range from no effect to strong effect, dependent on the vulnerability of the seabird species to the predator eradicated/controlled. Initial responses could be rapid with:
Decrease in predation and disturbance rates
Increase in productivity rates
Increase in adult survival rates (for some species and predator combinations only)
At a medium to long term, potential for:
Increase in population size
Distribution expansion, with range within an existing colony increasing, or re-establishment of previously locally extinct species.
Scale: Wider. Degree of benefit: Will range from no effect to moderate effect, dependent on the seabird species and predator eradicated. In the medium to long term, potential for:
Increase in levels of natal dispersal from target colony to other colonies in the same region.</td></tr>
<tr><td>Sequence of steps to implement

For detail see: Steps for implementation</td><td>1. Pre-implementation of action:
Long-list sites: Identify potential sites and the species likely to benefit for each site.
Determine coordination and delivery approach.
For long-listed sites undertake detailed site-specific feasibility study, including baseline studies.
Short-list sites: Prioritise sites based on results from site-specific feasibility studies.</td><td>For predator control, where on islands this will follow the same sequence as for predator eradication with some differences (detailed in: Steps for implementation).

For predator exclusion (using fencing), the initial pre-implementation steps will be similar, as will monitoring. However, the types of sites and nature of intervention (i.e. installing fencing) are quite</td></tr>
</table>

	Predator eradication (islands)	Predator control or exclusion (mainland colonies and islands)
	2. Implementation of action: • Produce detailed eradication design and biosecurity plans. • Initiate pre-eradication monitoring, eradication scheme, and biosecurity with preventative measures along key incursion pathways. 3. Post-implementation of action: • Biosecurity – maintain, review, and update biosecurity plans regularly with these reviewed annually. • Undertake monitoring and routine surveillance to confirm eradication of predator, to monitor for seabird population level responses to eradication, and to be able to rapidly respond to re-incursion.	different. The specific steps required are described in recent guidance (see references in Steps for implementation).
Monitoring summary For detail see: Research and monitoring recommendations	A crucial first step is to identify suitable sites for predator eradication, control, or exclusion. This requires understanding of the predator status of sites (e.g. offshore islands for predator eradication), what seabirds currently breed at a site and the presence of suitable occupied and unoccupied nesting habitat. Initially this can be explored through desk-based studies based on existing data. Once candidate sites have been long listed, then more detailed studies, including site visits are required to assess site-specific feasibility. Once sites have been chosen for predator eradication, control, or exclusion then monitoring should commence, first to establish baseline (abundance of predators, current levels of predation, seabird population counts, and demographic rates), then to monitor how these change during and post-implementation of the conservation intervention.	
Key considerations For detail see: Key considerations, potential barriers, and	**Policy and legal**: Predator eradication and control, when used for strategic compensation, could cut across a wider strategic approach to seabird colony restoration if the objectives differ (e.g. different target seabird species). Coordinating with wider island restoration initiatives would help mitigate this. Predator exclusion, control, or eradication could be considered a required site management for protected sites, so there is legal uncertainty around additionality.	

	Predator eradication (islands)	Predator control or exclusion (mainland colonies and islands)
potential solutions	The most widely used class of control (second generation anticoagulant rodenticides) for rodents in eradication projects will no longer be available to use in open areas from 2025, this poses a significant risk to viability of future eradication/control projects should suitable alternatives not be found (or exemptions made). **Financial (short- and long-term)**: The costs of eradication attempts are significant and could increase where initial eradication/control is unsuccessful. Long-term funding is required to maintain biosecurity, and for control/exclusion for ongoing action/maintenance. **Ecological**: Eradication and control can have negative impacts on non-target species, e.g. from secondary poisoning, direct poisoning from taking of bait, and getting caught in traps. Failure to eradicate all invasive mammalian species at a site could lead to unintended consequences with increased predation by the remaining invasive mammal/s and/or increased herbivory impacting vegetation. Where relying on pesticide, there is a risk of existing resistance or this developing overtime with long-term use. This will reduce the viability of control versus eradication approaches. Risk of developing resistance can be partly mitigated by switching pesticides used. **Practical, logistical, and social**: All schemes (particularly eradication) will only be successful with support from resident communities, those using sites, and land managers. As such, this is critical to gain before going ahead with a scheme at any site. Island eradications are a highly specialised activity, requiring expertise in pesticide use, rope access, etc. depending on the site and scheme. If implemented at scale, in the short-term there would likely be a shortage of specialised personnel and contractors. A strategic programme may help mitigate this. **Public perception**: Opposition by animal rights groups could increase difficulty of implementing management.	
Conclusion	Predator eradication has significant potential as a strategic compensatory measure. Several successful island eradications have been completed in the UK demonstrating its practical feasibility. However, it requires significant preparation and resources to implement effectively. It would benefit from a strategic approach that would allow for a programme of seabird island colony restoration targeting the sites where benefits would be greatest. However, as compensation there are some issues that need to be considered. Key issues	Predator control, especially when used on islands, has the same general benefits as eradication. In some cases, it may be more appropriate than eradication where full eradication is practically infeasible or where reestablishment is very likely (e.g. islands separated by short sea distances from the mainland). However, in the long-term it is likely to be more costly due to the level of long-term commitment required. It has most potential as part of a coordinated island

	Predator eradication (islands)	Predator control or exclusion (mainland colonies and islands)
	include the status of the conservation action with respect to additionality (which may differ depending on the level of site protection), and the scale of compensation possible to deliver for the species most at risk from offshore wind developments, as these species are generally not those most benefitting from predator eradications. Eradication must be combined with ongoing biosecurity, to secure predator free status in the long-term.	restoration programme with control considered for sites where eradication is less appropriate. Predator exclusion is an effective and practical conservation action for ground-nesting seabirds, especially on mainland sites. It is a smaller scale action than predator eradication, but locally benefits can be significant. It has some potential as a strategic compensatory measure but will generally be most appropriate for smaller scale initiatives (e.g. project-specific compensation).

7.4.2 Background

This action includes different approaches to eliminating or minimising predation by mammalian predators at seabird colonies. The types of management intervention considered are:

- Eradication: Aims to fully remove a predator from an island for permanent reduction in predation (assuming no re-invasion).
- Predator control: In contrast to eradication, control seeks to reduce predation to low levels by reducing predator density (usually for island sites), typically through ongoing predator control (e.g. trapping/poisoning).
- Predator exclusion: Reduced predation by excluding predators from nesting sites, usually by use of predator exclusion fencing around the nesting habitat for ground-nesting species on mainland sites.
- Biosecurity: This has three key components, minimising the risk of (re-)invasion by predators (e.g. rats being carried by boats), regular monitoring (e.g. monthly) for early detection of incursion, and a rapid incursion response to allow prompt and efficient removal before predator establishes, thus avoiding a more costly full-scale eradication attempt. Here, this is considered as an integrative measure to secure the benefits following eradication and/or control measures. Biosecurity can also operate as a stand-alone conservation action to secure existing predator-free status for island seabird colonies, however we do not consider this in detail here[10].

[10] The steer from the project steering group was to include biosecurity as an integrated measures with predator removal or reduction measures rather than as a standalone measure (in terms of strategic compensation).

Practical feasibility: Mammalian predator eradication/management

In WP1, we concluded that there was strong evidence supporting predator eradication as an effective conservation tool for island breeding seabird populations. However, the size of benefit and the appropriateness of predator eradication is influenced by many factors (*inter alia* type predator present, nesting strategy of target seabird species, distance to mainland/other islands). This review found that eradication schemes were generally most successful for small mammals (e.g. rodent species such as Brown Rat) while control could be more appropriate for medium mammals (e.g. American Mink). Effective schemes for eradication and control of invasive species is an ongoing and complex process that demands continuous monitoring, preventive measures, and sustained resource investment (Holmes et al., 2023).

Predator eradication or control and associated biosecurity are non-targeted site-based measures which typically benefit multiple bird and non-bird species for a given site. Eradications take considerable planning and will not always be practically feasible for a given location or may be unsuccessful. Eradications typically take several years, once the planning phase is included, requiring significant funding (millions £s per site) and ongoing biosecurity. As such, if using as a compensatory measure there are benefits to strategic delivery, which could deliver a programme of eradication and associated biosecurity across multiple sites. While control approaches are most suitable for sites where it is impossible to fully remove (e.g. mainland sites) or reduce re-invasion probability to low levels (e.g. island sites separated from mainland by small sea distances). In the short-term control measures will often be cheaper to implement than full eradication, but the long-term costs will typically be higher than eradication (and associated long-term biosecurity).

The history of eradications of invasive mammalian predators on islands in the UK is summarised by Thomas et al. (2017a). The key focus of island eradication schemes on seabird breeding islands has been for removal of Brown Rat and, to a lesser extent, other species (e.g. Black Rat and Stoat). The key seabird species that have been the target beneficiary species are burrow-nesting seabirds (i.e. Manx Shearwater, European Storm Petrel, and Atlantic Puffin). Thomas et al. (2017a) identified that there had been at least 12 eradication attempts for rodents on islands in the UK between the 1960s and 2017, with many successful though not all (and some sites required multiple attempts). Predator exclusion through anti-predator fencing is a standard measure for protection from predation for ground-nesting species (especially waders, terns, and gulls) on mainland sites (White and Hirons, 2019; Babcock and Booth, 2020). Its benefit has been demonstrated for terns (Babcock and Booth, 2020) and gulls (Dalrymple, 2023). The method has been used especially for wader species, including in Scotland[11].

[11] See e.g. Crook of Baldoon reserve, in South-west Scotland, an RSPB reserve, where this conservation action has recently been used to protect nesting waders (and other species including Black-headed Gull). The fencing is funded by the Scottish Marine Environmental Enhancement Fund (SMEEF).

7.4.3 Steps for implementation

The following steps focus primarily on predator eradication on islands; the steps for predator control and predator exclusion fencing will be similar, with key differences noted at the end of the section.

1. **Pre-implementation:**
   1.1. Long-list sites: Identify potential sites and the species likely to benefit for each site.
   - Undertake a desk-based study to identify suitable island sites for predator eradication or control and use a scoring approach to prioritise amongst these (for detail see Pre-implementation monitoring: predator control or eradication on islands).
   - For predator exclusion, a more targeted long-listing approach would be appropriate. This would focus on mainland and some island sites where predation by medium-sized mammals (especially Fox) have been identified as a threat to ground nesting species (principally terns and gulls).

   1.2. Determine coordination and delivery approach.
   - There are various options for how a strategic island eradication programme could be coordinated and delivered. It could potentially build on existing initiatives (e.g. the Seabird Island Biosecurity Programme (SIBP), the Scottish Biodiversity Strategy and Delivery Plan, Biosecurity for Scotland's Seabird Islands) and minimally would at least need to coordinate with these initiatives. However, most existing initiatives are focussed on biosecurity rather than eradication.

   1.3. For long-listed sites, undertake a detailed feasibility study (predator eradication).
   - Below are set out key factors to consider when assessing the feasibility of predator eradication for long-listed sites. A detailed guide on undertaking site-specific feasibility studies (focussed on eradication of rodents but broadly relevant to all mammalian predator eradications) is available in Section 3 of the UK Rodent Eradication Best Practice Toolkit (Thomas et al., 2017b). Table 1 therein sets out seven key criteria to consider which are focussed on practical aspects:
     - Technical feasibility – the logistical feasibility of trapping, catching, or killing all of the target species at a site;
     - Sustainability – whether the risk of re-invasion can be reduced to an acceptable level;
     - Socially acceptable – there is full support from landowners and managers, the local community, and other island users;
     - Politically and legally acceptable – that all required permits and consents can be obtained (e.g. for use of second generation anticoagulant rodenticides);
     - Environmentally acceptable – any impacts on the environment can be reduced to a low and acceptable level;
     - Capacity – that all required resources (including trained personnel, and equipment) can be sourced within the project timeframes;

  - Affordable – that the total project costs in the long-term (i.e. including both the initial eradication and ongoing biosecurity) with contingency (for e.g. if the eradication takes longer than anticipated/re-invasion occurs) can be funded.
- There must also be an assessment of whether a proposed eradication is likely to lead to the desired outcome (i.e. recovery/increase in the target beneficiary seabird species).
  - Gain a good understanding of the potential for the seabird species of interest to benefit from eradication of predators at the target site/s. This should include understanding the vulnerability of the seabird species to predation by the mammalian predator/s present, including any site-specific factors (e.g. accessibility to the predators of occupied and unoccupied potential nesting habitat). To assess the potential scale of benefit, a detailed habitat survey should be conducted, using this to map and quantify the extent of currently occupied and unoccupied habitat. The current population status of the seabird species and any historical knowledge on this (especially where there are data from pre-invasion) are important context. For a significant population level response to a successful eradication attempt, the population must not be significantly limited by other factors (e.g. food availability), therefore having a good understanding of the species ecology is important.
  - Undertake predator surveys at the site (see Research and monitoring recommendations), and any nearby areas (e.g. neighbouring islands) from where re-invasion could occur. Using these surveys to confirm the presence of predators and potentially the presence of previously unrecorded predator species at a site.
  - Eradication feasibility: For an eradication programme to be followed it must be realistically possible to remove the whole population of the invasive predator, if this is not possible then eradication is not appropriate (in such cases predator control may be a more appropriate alternative). A key consideration will be whether there are multiple invasive mammalian predators or a single predator species. Where multiple predator species are present it will often be advisable to eradicate multiple species at the same time to avoid the risk of the remaining predator/s producing greater impacts post-eradication of a competitor predator (i.e. predatory release/ or reduced interference competition).
  - Biosecurity feasibility: This must be undertaken pre-decision to undertake an eradication attempt at a site. While the acceptable level of risk of predator re-establishment will vary (e.g. in proportion to the size of potential benefit and resources available to commit in event of predator incursion), it is crucial to ensure that this risk can be reduced to an acceptable level. The pathways by which invasive mammals could return to an island should be determined, including by vessels (e.g. recreational

vessels, cargo ships, and ferries) and via predators swimming considering predator specific swimming abilities (e.g. based on models of predator distribution, for Brown Rat see Tabak et al. (2015)).

1.4. Short-list sites: Prioritise sites based on results from feasibility study.
- Produce short-list of sites, initially removing those not deemed to be feasible then re-prioritising using updated information gained from the above preparatory work. Where the feasibility of eradication is assessed to be low, but the benefit of reduced predation assessed to be significant then it may be appropriate to have an alternative objective of predator control (i.e. seeking to minimise the abundance of the predator).

2. Implementation of management intervention:

2.1. For selected site/s produce detailed eradication design and biosecurity plans (see Annex 4: Biosecurity and Incursion Response in Thomas et al. (2017b)), assemble resources required for eradication (staff and equipment), and obtain all permits and licences required.

2.2. Initiate pre-eradication monitoring (see Research and monitoring recommendations).

2.3. Initiate eradication scheme.

2.4. Initiate biosecurity. This will include producing detailed biosecurity plans which should be developed and implemented working with the land manager/s and community. Ongoing surveillance for mammalian predators should be established, including training personnel and potentially training a specialised biosecurity dog. The users of a site (e.g. any inhabitant community and local businesses) should be trained in biosecurity to understand how they can minimise the risk of introducing mammalian predators. An emergency response plan must be developed so that this can be deployed in the event of the mammalian predator returning, or when a high risk of this occurring is identified (e.g. a ship wreck). Preventative measures should be established along key incursion pathways. For full details of planning biosecurity, see Annex 4 of Thomas et al. (2017b) which provides a guide to planning and mounting an incursion response (this is developed for rodents, so while broadly relevant to other invasive mammals there will be additional considerations to those included).

3. Post-implementation:

3.1. Undertake ongoing monitoring to confirm absence of eradicated predator (see Post-eradication monitoring).

3.2. Maintain ongoing biosecurity with routine surveillance. Review and update biosecurity plans annually and ensure that equipment is maintained and replaced as required both for monitoring and of incursion equipment stored at any associated rapid response hub. This will be most sustainable if part of a wider regional or national programme (e.g. building on the current Biosecurity for Scotland's Seabird Islands project).

3.3. Monitor seabird response (by e.g. population counts and productivity monitoring) post eradication (see Post-eradication monitoring).

7.4.3.1 For predator control and predator exclusion:

The steps to take for predator control on islands will follow the same principles as above which is primarily focussed on predator eradication. A key difference for predator control is that there is a less clear distinction between the implementation and post-implementation phases, as control of predators must continue indefinitely. However, control would typically start with a higher effort period to reduce predator abundance, then subsequently lower the effort to maintain the low predator abundance.

Predator exclusion is generally a lower scale initiative, this would still require similar preparation in terms of understanding which sites may most benefit and in establishing the likely level of ecological benefit. Once these sites have been identified, the action would likely be most effectively managed on a site-by-site basis (i.e. rather than as part of a wider strategic programme). Guidance on establishing predator exclusion fencing is available, which would need to be considered if implementing (White and Hirons, 2019; Babcock and Booth, 2020). Guidance is included on the preparatory work required to decide whether a predator exclusion fence may be appropriate for a site, on the design of the fencing, and on planning for their installation (White and Hirons, 2019). This should be considered in conjunction with guidance written specifically on predator exclusion fencing for ground-nesting seabirds, which is available for tern species (Babcock and Booth, 2020), and case-studies, such as (Dalrymple, 2023) which reports on the use of predator exclusion fencing for the benefit of ground-nesting gulls (Herring Gull, Lesser Black-backed Gull, and Great Black-backed Gull) in North-west England.

7.4.4 Ecological effects of implementing management interventions

Mammalian predators impact seabirds by predating on eggs or chicks and in some cases adult birds; therefore, management to reduce predation can lead to increased productivity and survival. These predators most impact species nesting on more accessible terrain, thus ground and burrow nesters are most sensitive to predation. Species that nest among boulders or on low-lying accessible rocky shores (e.g. Razorbill at some sites) can also be sensitive. Species that primarily breed on steep rocky cliffs will rarely have significant benefit (including Common Guillemot and Kittiwake). In WP1, we produced an overview of the evidence for different seabird species benefitting from control or eradication of various mammalian predator species. Below we draw on that review and some additional sources to summarise the ecological effects of these measures for the focal seabird species and briefly other seabird species.

7.4.4.1 Ground-nesting colonial species

Large gulls (including Herring Gull, Lesser Black-backed Gull, and Great Black-backed Gull): As ground nesting species often breeding on mainland coastal sites (including adjacent to/or on more accessible parts of coastal cliffs) these species are vulnerable to mammalian land predators. On island sites these species should generally benefit from mammalian predator eradication and/or control. On mainland sites, depending on the topography and terrain, predator exclusion fencing may be suitable, which has been shown to reduce predation by Foxes increasing productivity in all three large gull species for a breeding site in England (Dalrymple, 2023).

Terns are vulnerable to predation by ground predators, so can benefit from any measures to reduce ground predators including eradication (for island nesting sites) and predator exclusion fencing (reviewed in Babcock and Booth (2020).

7.4.4.2 Auks

Guillemot and Razorbill: Both species nest on rocky cliffs, however Guillemot are largely confined to steep rocky cliffs but do nest among boulders or on flat open ground in some areas (e.g. on tops of sea stacks), while Razorbill generally nest in slightly more accessible areas including scree around the top of cliffs and boulder-fields. As such both species are relatively protected at most sites to predation by most mammalian ground predators. However, Razorbill will typically be more vulnerable than Guillemot, so stand to potentially benefit from island eradications at some sites.

Puffin, as a burrow nesting species, are highly vulnerable to ground predators, particularly rodents. On Lundy Island in the Bristol Channel both Brown Rat and Black Rat were eradicated in the early 2000s, subsequently Puffin returned to breed on the island (Lock, 2006) with 1335 Puffin reported breeding in 2023 (InsideEcology, 2023). However, at Ailsa Craig in the Firth of Clyde, where an eradication programme was completed in the earlier 1990s, Puffin only slowly established with 186 individuals recorded in 2015 (Thomas et al., 2017a). While at Cardigan island, Ceredigion in Wales, where eradication occurred in the 1960s, Puffin have never re-established (Thomas et al., 2017a). This demonstrates the significant potential for Puffin to benefit from eradication of mammalian predators but the scale or such benefit is likely to be highly site-specific.

7.4.4.3 Other species

The most cited species for benefits from island predator eradications are burrow nesting seabirds, including Manx Shearwater and European Storm Petrel. In addition to seabirds, wader species are often the focal beneficial species for predator eradication or control programmes. As a broad site-based measure it is expected that for many sites where implemented additional species will benefit beyond the target species, however which species and to what extent will be highly site-specific. There may also be wider ecosystem benefits.

7.4.4.4 Time-lags for population level responses

In the case where predation targets seabird chicks and the applied management successfully reduces disturbance and chick predation rates, an immediate increase in annual productivity can be anticipated. If predation targets adults and the management successfully reduces adult predation rates, an increase in adult survival rates is expected within a short period. Population recovery will be dependent on the wider ecological context, including whether there is a source of new recruits (relying on the health of the species across the wider region), and availability of prey. Reestablishment is most uncertain, and it can take decades for a species to return once absent, if at all.

7.4.5 Research and monitoring recommendations

7.4.5.1 Pre-implementation monitoring: predator control or eradication on islands

Produce long-list of candidate sites for predator eradication/control using desk-based study. Several previous studies have sought to identify and prioritise islands for predator eradication in the UK (Ratcliffe et al., 2009; Stanbury et al., 2017; Mitchell et al., 2018) which can be used as a starting point.

The study of Stanbury et al. (2017) is the most complete and comprehensive study covering nearly all offshore islands in the UK and considering the presence of mammalian predators and the potential conservation benefits of removing these. For taking a strategic approach to the selection of sites for predator eradication (or control), a useful approach would be to build on the original analysis and associated islands database included as supplementary material within the study. Key components to update or revise could include: 1) updating population numbers (Seabird 2000 was used for the original study) using the Seabirds Count census results (published November 2023) and the recent additional colony counts undertaken during 2023 in response to the HPAI outbreaks. 2) including information on site protections (SPA/SSSI and associated qualifying features), useful around understanding current site management context (relevant e.g. to additionality issues). 3) potential to refine the prioritisation criteria and formulas used (see next point).

Develop and agree prioritisation criteria. For strategic compensation, it may be relevant to produce separate prioritisations for key species and/or develop an aggregate score including multiple species. Stanbury et al. (2017) and Ratcliffe et al. (2009) developed similar prioritisation scoring approaches which could be further developed for the purpose of strategic compensation.

Produce initial long-list of candidate sites based on desk-based assessment of feasibility, level of benefit (including to the target species) prioritised according to the agreed prioritisation criteria.

7.4.5.2 Pre-eradication monitoring

For the seabird species of interest, suitable indicators should be identified (see section 5.4 in Thomas et al. (2017b)). Baseline data should be collected pre-eradication to provide a point of comparison. For demographic rates (e.g. productivity and annual survival rates), that can display high inter-annual variability, data should ideally be collected for multiple years pre-eradication. For most sites there will currently be recent population counts available following the Seabirds Count census, however as this data gets older (or where significant changes are anticipated – e.g. for species or sites impacted by the HPAI outbreak) repeating colony counts to establish a firm baseline will be required.

The abundance and distribution of the target predators should be established pre-eradication to provide a baseline against which progress can be tracked for the adopted predator management action. The general approach here will be as for post-eradication predator monitoring.

7.4.5.3 Post-eradication monitoring

Undertake ongoing monitoring to confirm the absence of the eradicated predators including surveillance focussed especially on high-risk areas (e.g. vicinity of settlements and entry points). The methods used will vary depending on the predators being monitored for. Methods for rodent detection are set out by Thomas et al. (2017b) (see Annex 3 therein), with many of these methods suitable for multiple predator species. Standard practice is to undertake an intensive monitoring check two years post-eradication to confirm the absence of predators, this would include monitoring throughout a site including in inaccessible areas (e.g. where rope access is required). Monitoring for the presence of predators then becomes part of the routine surveillance as part of the biosecurity plan.

Monitor the target seabird species. This should include regular population counts to track the changes in population over time post-eradication. Depending on site accessibility, practicality, and species ecology the intervals between population counts would vary (e.g. species that are slower to establish/recruit to a site could be monitored at reduced frequency). For larger sites where whole colony counts are impractical to undertake frequently a stratified sampling/indicator area approach could be taken. Monitoring could also include measuring key demographic rates expected to change post-eradication (e.g. adult survival and productivity) using standard approaches depending on the species of focus.

7.4.5.4 Predator control and predator exclusion monitoring

For predator control the monitoring requirements will be largely the same as for predator eradication. As predators are not eliminated, but rather maintained at low densities, the monitoring for predators will have a different purpose, but the same monitoring methods could be used. For predator control, monitoring would be used to assess the abundance of predators and reactively adjust control methods (e.g. trapping) to avoid predator populations increasing.

For predator exclusion the monitoring approach for the target benefitting species (i.e. the seabird species) would take the same general approach. There will also be some specific requirements around checking that the exclusion fencing is intact and fully functioning (and repairing/adjusting as required), thus monitoring of the fencing would be integrated with maintenance (see chapter 10 in: White and Hirons (2019)).

7.4.6 Relevant SPA-specific information

7.4.6.1 Biosecurity

For the UK Marine Strategy Assessment 2018 (Mitchell et al., 2018) it was assessed that most island SPAs with seabird features lacked adequate biosecurity measures (only 20% assessed to be sufficient). However, following the Biosecurity for Life project and other initiatives it is expected that when re-assed (due in 2024), over 90% of SPAs will be deemed to have adequate biosecurity. The Biosecurity for LIFE project was a 5-year, EU LIFE funded initiative, started in 2018 to put robust and sustainable biosecurity measures in place for 42 island SPAs across the UK with breeding seabirds as designated feature species. This was a partnership project, which with respect to Scotland, included RSPB and the National Trust for Scotland. Its main outputs are:

- **Biosecurity plans**: working with island land managers and communities to develop and implement biosecurity plans.
- **Biosecurity surveillance**: supporting biosecurity surveillance for invasive predators by training personnel, deploying surveillance equipment, and training a specialised biosecurity dog (to detect invasive Brown Rats).
- **Rapid response hubs**: developing a network of regional hubs equipped to rapidly respond in the event of an incursion on any of the 42 island SPAs.
- **Industry training**: providing training to marine industries and businesses on how to undertake and implement effective biosecurity when operating in areas of risk.

In Scotland, Biosecurity for LIFE has been continued by the Biosecurity for Scotland's Seabird Islands project funded by the Scottish Government's Nature Restoration Fund up until 2026. Rapid response hubs with associated volunteer networks have been established in four locations (Edinburgh, Stornoway, Orkney and Shetland) providing coverage for all of Scotland.

7.4.6.2 Sites for predator eradication

Stanbury et al. (2017) produced an assessment for all identified UK islands (including crown dependencies) on the presence of invasive mammals and reptiles together with the presence of species of conservation interest. This was a desk-based review, so relied on various sources, so for any given site the information should be ground-truthed. They ranked islands based on the feasibility of eradication and the level of conservation benefit (this was not restricted to seabird species). Many of the top islands identified are SPAs for breeding seabirds located in Scotland (see Table 3 therein). This is a useful starting point for considering sites that could benefit, but some of the information used is now out-of-date (e.g. on seabird abundance) and the prioritisation approach used was not designed with strategic compensation in mind (see Pre-implementation monitoring: predator control or eradication on islands).

7.4.6.3 Information on specific locations (selected cases only)

Rum SPA: There is concern about the potential impacts of Brown Rat on the Manx Shearwater population on Rum. The current management plan for Rum SPA, which is a National Nature Reserve managed by NatureScot, includes a project under objective NH4.3 to: "Undertake surveillance of impacts and activity of brown rats where they come in contact with priority species and habitats" (NatureScot, 2023h). Previous studies on Rum have suggested that Brown Rat are impacting Shearwaters but the level of impact may be low due to the location of the Shearwater colonies (inland on higher altitude parts of the island) (Lambert et al., 2015). Also present on Rum are Wood Mice, which a recent study suggests may be impacting the Shearwaters (Lambert et al., 2021). For Rum there is a need to better understand the impacts of both the Brown Rat and Wood Mice on the Manx Shearwater and the interactions between these two mammals to inform any potential future control or eradication programme.

Shiant Isles SPA: The Shiant Islands Seabird Recovery Project, started in late 2014, successfully removed Black Rat with the island declared rat free in March 2018 (Main et al., 2019).

Handa SPA: In the late 1990s, Brown Rat were eradicated from Handa Island (Stoneman and Zonfrillo, 2005). This led to an initial recovery in seabird populations. However, subsequently Brown Rat re-established, potentially naturally from the mainland (which is ca. 300 m distant). Berwick Bank (2023b) examined the feasibility of re-eradicating rat from the site.

Canna and Sanday SPA: Between 2005 and 2006 Brown Rats were eradicated from Canna and Sanday which are two neighbouring islands that connect at low tide. This has led to a recovering in many of the seabirds nesting on the islands, including Puffin breeding on the main islands again (previously being restricted to offshore stacks), however some other species did not show obvious benefits including Common Guillemot and Kittiwake (Luxmoore et al., 2019).

Orkney Islands: Stoats established on the Orkney Islands relatively recently, being first recorded in 2010, since then becoming widespread on Mainland Orkney and connected islands and were considered a threat to the bird life (especially of ground nesting species) (Fraser et al., 2015). There is currently an eradication scheme ongoing through the Orkney Native Wildlife Project, though at the time of writing this had identified a significant funding shortfall, so its continuation is not guaranteed.

Further locations are mentioned in relation to specific mammalian predators below (see Predator-specific aspects).

7.4.7 Key considerations, potential barriers, and potential solutions

Key considerations	Potential issues	Potential solutions
Policy	Predator eradication and control, when used for strategic compensation, could cut across a wider strategic approach to seabird colony restoration if the objectives differ (e.g. different target seabird species).	Develop a wider strategic programme of seabird colony restoration (see also Other – Additionality below), instead of a separate strategic compensation programme for predator eradication/control. With this approach, parts of the programme could be apportioned to compensation and others to wider conservation objectives.
Legal	Additionality issues (see below). Second generation anticoagulant rodenticides (SGARs) will no longer be available for use in open areas from 1st January 2025 (Think Wildlife). These are currently the preferred poisons for rodents in eradication and control schemes.	There are currently no proven alternative techniques available for eradication. There is one alternative for control. Alternatives are being explored but it will take time to build confidence in their efficacy for eradication purposes (and potentially to bring them to market in the UK). If suitable

Key considerations	Potential issues	Potential solutions
		alternatives are not found, this will pose a significant risk to the viability of rodent eradication schemes unless exemptions are made for island restoration.
Financial	All the predator management options (eradication, control, and exclusion) require long-term funding (see Other – long-term viability below). Eradication projects are generally the costliest in the short term with significant costs from staffing required and associated logistics (e.g. travel and accommodation), Costs of eradication failing or requiring increased effort. If an eradication attempt fails and it is decided to go ahead with eradication a second time the costs will be significant. Likewise, if eradication takes longer than expected then costs will increase. This risk means that there is a high risk of exceeding pre-determined budgets.	When developing a proposed management intervention, a detailed budgeting plan should be developed to ensure that the full costs are considered at the start so that full funding is secured. Undertake detailed site-specific feasibility planning to reduce risks of failure and allow more accurate costing of eradication attempt. A strategic programme of eradication could help distribute risk compared to a single eradication attempt undertaken by one or a few funders, who would then have to bear the costs if that attempt failed.
Ecological	Good baseline data is needed to appropriately prioritise sites (see also **Pre-implementation monitoring: predator control or eradication on islands**) The rate and size of recovery post eradication (especially were relying on re-establishing/establishing absent species) can only be predicted with high uncertainty. Seabird populations may not recover, or their recovery may be weaker than anticipated, if factors other than predation by invasive	Include early consideration of baseline data collection when making predator eradication plans. A strategic programme of eradications targeting multiple sites will decrease the risks from one/a few sites delivering smaller than anticipated population gains. Funding for research studies to refine the modelling of population gains post-eradication informed by monitoring data for past eradications can improve population models.

Key considerations	Potential issues	Potential solutions
	mammalian predators are limiting productivity, e.g. food availability, or neighbouring colonies acts as population sinks.	Studies to better understand any other factors limiting population growth (e.g. food availability) will provide important context.
	Negative impacts on non-target species from secondary poisoning (i.e. ingesting poison by consuming animals previously poisoned) or direct poisoning from taking of bait.	Where recovery or natural recolonisation is unlikely, or found to be slow post eradication, then the feasibility for reintroduction should be considered (Spatz et al., 2023b). Undertake detailed risk assessments considering other species present at a site and their ecology and how best to avoid impacting them. Follow best practice recommendations (see Annex 5 in Thomas et al. (2017b))
	Failure to eradicate all invasive mammalian species (in some cases including predators and herbivores) at a site could lead to unintended consequences with increased predation by the remaining invasive mammal/s and/or increased herbivory impacting vegetation (see e.g. Bergstrom et al. (2009)).	Undertake detailed site-specific feasibility study. Plan eradication at site to target all key invasive mammals identified.
	Where pesticides are used (in eradication/control projects this would most commonly be anticoagulants for rodents) there is a risk of existing resistance and/or introducing resistance through longer term use.	Risk of existing resistance is low for small offshore islands (e.g. no known mutations for anticoagulant resistance were found in Brown Rat on Rum, see Lambert et al. (2021)), unless there is a history of pesticide use. Follow best practice for reducing risk of resistance developing, e.g. by switching rodenticides (see Annex 5 of Thomas et al. (2017b)) and avoiding their long-term use – which is likely to reduce the viability of control schemes (as opposed to eradication) where these are reliant on pesticide Pascal et al. (2008).

Key considerations	Potential issues	Potential solutions
Resources	Lack of available specialised personnel to undertake eradications. Depending on the sites this will often require a combination of eradication and biosecurity expertise plus specialist support services (e.g. rope access expertise).	Strategic programme of eradication and biosecurity could help build up specialist capacity by providing long-term employment/or ongoing opportunities for specialised contractors. Coordinated delivery of eradication attempts to reduce risk of resource bottlenecks.
Practical and logistical	Inadequate site-specific feasibility studies and operational planning conducted could lead to high risk of failure, either of eradication/control or of subsequent biosecurity, risking unsuccessful eradication or subsequent re-invasion. The use of second-generation anticoagulant rodenticides is highly regulated and requires expert handling.	Undertake detailed feasibility study. Follow best practice guidance (see Annex 5 in Thomas et al. (2017b)) ensuring risks are considered and mitigated for.
Other – long-term viability	Eradication is only effective in the long-term with biosecurity, including capacity to respond to incursions. While control and exclusion require ongoing action to maintain their effectiveness. This leads to a risk that the measure is not effective in the long-term.	When planning for a predator management measure its long-term viability must be considered with measures put in place to secure this (e.g. long-term funding agreement).
Other – Social	Eradication and ensuing biosecurity both require wide support from resident communities (where present) and from those visiting/using a site (e.g. boat operators and recreation visitors). Without this, there is a high risk of failure, as both the effectiveness of the eradication programme and biosecurity measures may be compromised.	Ensure that sites are only short-listed once community support has been established. It must be recognised that while some sites will be ecologically suitable for eradications if community support cannot be gained then these sites may be ruled out as not practically feasible. Include funding for ongoing community engagement and

Key considerations	Potential issues	Potential solutions
		education, including post-eradication to support biosecurity. Note that the time required to develop good community engagement and build their support should not be underestimated. For example, an eradication on St. Agnes and Gugh (Isles of Scilly) took more than 10 years of preparatory work (Stanbury et al., 2017).
Other – Additionality	Eradication and predator control could be a required site management to fulfil conservation objectives for protected sites, especially for SPA colonies (e.g. Biosecurity for Scotland's Seabird Islands). This is likely to be less of an issue for non-SPA colonies.	Undertake legal review to confirm position with respect to additionality. A wider strategic programme of island eradication (with biosecurity) could be undertaken for a variety of objectives (e.g. wider nature restoration, biodiversity net gain, and protected site management) with parts of the programme apportioned to compensation.
Other – Ethical	The lethal removal of animals or the use of any management that has the potential to reduce the presence, productivity and survival of an animal may be ethically contentious.	Ensure that management is effective and that it is meeting the desired objectives (i.e. proving beneficial towards seabirds).
Other – Public perception	Some organisations and animal rights groups may object to lethal control and removal of predators, especially for certain species (e.g. domestic or feral cats).	Undertake early stakeholder engagement, as part of detailed site-specific feasibility study and biosecurity plan. Include a public education campaign to raise awareness on the reasons for predator removal. In some cases, it may be appropriate to live trap and relocate animals (as is being done for Hedgehog on Uist as part of Uist Wader Research).
Other – Health and safety	There is a risk in handling poisons (see Practical and logistical above). The handling and disposal/removal of live or dead animals can pose	Conduct a comprehensive risk assessment before commencing programme, including developing handling and disposal/removal

Key considerations	Potential issues	Potential solutions
	environmental health and risks to those handling.	protocols with any mitigation identified followed.
	For predator eradication, and to a lesser extent control, access will be required to the full area, in sites with complex topography this may require specialist assess (e.g. using rope access).	Where relevant, include rope access expertise and training when planning work on sites which require specialist access.

7.4.8 Predator-specific aspects of implementation

For offshore islands in the UK (and its Crown Dependencies), the known or suspected predator status is reviewed in Stanbury et al. (2017). This was completed based on published and reported information and included some simplifying assumptions (e.g. assuming certain invasive species were present on islands with larger resident human populations) rather than field visits and the status may have changed since that study was completed. Therefore, this information should be confirmed when considering potential sites for eradications. On the mainland there are both native (e.g. Fox) and non-native (e.g. Mink) mammalian predators present with the approaches used for control or management of these consequently differing (e.g. exclusion versus control). Below we provide some background on predator management each focal predator species.

7.4.8.1 Rodents

Rodents, including rats and mice species, are the most widespread invasive non-native species present on UK islands and have been the main targets of island eradication schemes in the UK for the benefit of seabirds (Thomas et al., 2017a) and globally (Howald et al., 2007), with rats considered the predators most threating seabird species worldwide (Dias et al., 2019). Therefore, there is extensive experience of eradicating rodents with best practice methods developed (see Thomas et al. (2017b)).

Brown Rat (also known as Norwegian Rat) are the most common target of mammalian predator eradication schemes for benefit of seabirds in the UK (Thomas et al., 2017a). They are present on many islands around the UK including SPA sites (e.g. Rum, see Relevant SPA-specific information above).

Black Rat, where present, have potential to be a greater threat to seabirds (in terms of the range of species impacted) than Brown Rat due to their greater agility, potentially being able to access some cliff nesting habitat. On UK islands they have a highly restricted distribution. They were present previously on Lundy and the Shiant Islands but have been successfully eradicated from those sites. For seabird breeding island sites in Scotland, they are now only understood to be present on Inchcolm (Firth of Forth) where their presence is confirmed[12].

Mice species are considered threats to seabirds globally, particularly to albatross, petrel, and shearwater species (Spatz et al., 2023a). Mice have not been the focus of eradications in the UK[13], however their impacts may have been previously underestimated with recent studies demonstrating potential for impacts on St Kilda (Bicknell et al., 2009; Bicknell et al., 2020) and Rum (Lambert et al., 2021). It will not always be appropriate or desirable to remove these species where long established (e.g. on St Kilda there is the endemic St Kilda Field Mouse, *Apodemus sylvaticus hirtensis*, thought to have been introduced by the Vikings centuries ago) but the presence of mice and how this could affect the success or otherwise of removal of other species should be considered (see e.g. Lambert et al. (2021)).

7.4.8.2 Medium-sized mammals

American Mink is a medium sized mammal which, though more easily detectable than rodent species, have strong swimming abilities meaning that they can cross relatively wide expanses of water (>2 km), given the difficulty in preventing reestablishment, control measures rather than full eradication are often used. Two large scale mink control or eradication projects have been conducted in Scotland in recent years, the Hebridean Mink Project and the Mink Control Project. The Hebridean Mink Project aimed to reduce Mink numbers to low numbers (and locally eradicate) amongst the Outer Hebrides running from 2001 in a phased project, with by 2018 only a few (low single figures) individuals caught that year. The Mink Control Project targets Mink on the Scottish mainland across northern Scotland, this has been running from 2018 trapping Mink across a wide area. This is a long-term project, part of the wider The Scottish Invasive Species Initiative, which is currently funded for 2023-2026 by a grant from the Scottish Government's Nature Restoration Fund and in-kind funding by project partners and volunteers.

Fox are a native predator, however they can negatively impact ground nesting birds on mainland sites, particularly waders, terns, and gulls. Predator exclusion fencing has been used to exclude Foxes from nesting areas for gulls and terns (Babcock and Booth, 2020; Dalrymple, 2023).

Stoats are present on the Orkney Islands and subject to an eradication programme (see Information on specific locations (selected cases only)).

Other mammalian predator species are present on some islands in Scotland (see Stanbury et al. (2017)) including feral cats and hedgehog. The latter species is subject of a removal programme on the Uists, primarily for the benefit of wader species.

[12] Recently confirmed (2022) by a field study to support an assessment of the feasibility of eradication of Black Rat from Inchcolm Island. Berwick Bank Wind Farm (2023). Additional Information - Addendum to the Derogation Case - Berwick Bank Offshore Wind Farm - Firth of Forth. Section 6 - Incholm Feasibility Study.

[13] RSPB are currently undertaking a review and analysis on the evidence around the impacts of mice on seabirds globally and in the UK (funded by RSPB and Natural England's Action for Birds in England programme) which is due to report in 2024.

Non-invasive native mammals can also predate on seabirds, for example Otter have been recorded predating on Black Guillemot and European Storm Petrel (Bolton et al., 2017; Johnston et al., 2020). To fully understand predation impacts it is important to consider both invasive and non-invasive predators, however it would rarely ever be appropriate to control native non-invasive predators.

7.4.9 Key references

This account has given a high-level summary of key issues to consider when developing a mammalian predator eradication, control, or exclusion programme for the purposes of strategic compensation. As well as the references cited within the text, we recommend considering the resources summarised in Table 47, which provide greater detail on various aspects of this action.

Table 47. Key resources for further information on mammalian predator eradication or control and associated biosecurity.

Citation	Webpage	Description
Stanbury et al. (2017)	Standbury et al. paper link	A useful starting point for prioritising sites to consider for eradication. For all islands in the UK and Crown Dependencies the state of knowledge (as of 2017) on presence/absence of mammalian predators in summarised. Accompanying the paper are supplementary material containing site by site assessment information. It should be noted that this was completed as an initial guide and that subsequent detailed site-specific feasibility studies should still be undertaken.
Ratcliffe et al. (2009)	Ratcliffe et al. paper link	Takes a similar approach to Stanbury et al. (2017) but focussed on petrel species. The scoring approach used for prioritisation of sites could be adapted to consider additional species/species groups.
Mitchell et al. (2018)	Mitchell et al. Invasive mammals web link	Assessment undertaken against the invasive mammal indicator of the UK Marine Strategy. Includes a useful summary of the state of knowledge (as in 2018*) on the presence of invasive mammalian predators on key seabird colonies across the UK, the risk of invasion, and on whether biosecurity measures were in place. *NB since this assessment the number of sites with biosecurity measures in place has increased substantially, largely owing to the

Citation	Webpage	Description
		Biosecurity for Life project. Therefore, details for specific sites should be confirmed.
Thomas et al. (2017a)	Thomas et al. paper link	Provides an overview of past mammalian predator eradication attempts conducted across the UK (up to 2017).
Thomas et al. (2017b)	Thomas et al. UK Rodent Eradication Best Practice Toolkit	Provides a comprehensive set of resources for planning and undertaking rodent predator eradications in the UK, including biosecurity. While developed for rodents much of the material is also relevant for other invasive mammalian predators.
Biosecurity for Life resources	Biosecurity for Life online resources	Various resources covering all aspects of biosecurity for both prevention of (re-)invasion and incursion response. Also includes some resources on eradications (e.g. the above UK Rodent Eradication Best Practice Toolkit)
Predator Free 2050	Predator Free 2050 New Zealand Depart of Conservation project website Predator Free 2050 dedicated project website	Some potential learning from predator eradication in New Zealand which are experienced with eradication of many of the same predators we are dealing with in the UK. They have an ambitious eradication and biosecurity programme. This includes research and development of new eradication techniques, that may in time make eradications more feasible for the most challenging sites in the UK.
IUCN (2017). Island invasives: scaling up to meet the challenge. Proceedings of the international conference on island invasives 2017	IUCN (2017). Island invasives conference proceedings papers	A conference proceeding including papers on a wide range of international (including UK) island eradications. Most of these studies were presented at the Third Island Invasives Conference, held in Dundee in July 2017.
Scottish Invasive Species Initiative	Scottish Invasive Species Initiative project website	The Scottish Invasive Species Initiative is an 8-year partnership project which works with local organisations and volunteers to control invasive non-native species along riversides in Northern Scotland. Though not specifically focussed on seabirds or islands, aspects of this

Citation	Webpage	Description
		project are relevant to consider (e.g. control of mink).
Babcock and Booth (2020)	Babcock and Booth Anti-predator fencing manual	Best practice guide for anti-predator fencing for terns. Relevant also to other ground nesting species.
White and Hirons (2019)	White and Hirons – predator exclusion fencing methods.[14]	Provides a detailed guide on predator exclusion fencing methods. Generally most appropriate for terns, gulls, and waders, though its suitability is site-specific.

7.4.10 Overall conclusion

Predator eradication on islands would benefit from strategic delivery through a coordinated programme and as such has potential as strategic compensation. Strategic delivery would better allow for sites for eradication to be prioritised appropriately. Predator eradication is only a viable measure where biosecurity can be put in place in the long term to secure predator-free status. Predator control may be a suitable alternative in some circumstances, where eradication is not realistic, or where there is a high probability of re-establishment (e.g. islands close to mainland/other islands where predators are present). However, predator control can be financially prohibitive in the long term due to the need for ongoing control (though eradication also has ongoing costs associated with biosecurity).

Predator exclusion, particularly on mainland sites will generally be most suitable as a site-specific measure for the benefit of ground nesting species, predominantly gulls and terns. The number of sites where this may be suitable for seabirds in Scotland is unclear but is likely to be limited. As such this measure has more promise for project-specific compensation rather than for strategic level delivery.

Key issues remaining include the status of the measure with respect to additionality, particularly for protected sites (SPAs and potentially also SSSIs), and its potential to deliver for the species most impacted by offshore wind (aka. like-for-like compensation) with cliff nesting species least likely to benefit. Given that the measure is broad-based (particularly predator eradication), with wider conservation benefits for sites where implemented, there may be potential to develop this measure as a wider strategic conservation programme, with benefits apportioned between compensation and wider biodiversity net gain or nature restoration targets, depending on the species benefitting for a given site.

[14] The original link was not working at the time of writing (November 2023), but the manual is available via the 'Wayback Machine' service from the Internet Archive (link provided in table).

7.5 Practical feasibility: Avian predator management

7.5.1 Summary

This conservation action, the management of avian predators (i.e. raptors, gulls, and crows), focusses on a set of different types of management interventions, each of which will be described separately. The management interventions are diversionary feeding (DF), removal techniques (REM), and deterrence (DET). The focal seabird species identified for this conservation action are auks and large gulls.

Table 48. Summary of practical feasibility for avian predator management. Further detail is provided following the table.

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
Description	The provision of alternative food to avian predators to reduce predation on seabird adults or chicks and to reduce overall disturbance. Note that DF, as opposed to supplementary feeding, does not seek to increase the density of the predator population (Kubasiewicz et al., 2016).	The targeted or non-targeted removal of predators' nests, eggs, chicks and/or breeding individuals via lethal or non-lethal means.	The use of deterrent objects, including physical and acoustic means, to deter birds from a site.
Uncertainty	Overall, the level of predation and/or disturbance associated with avian predators has not been well studied in Scotland for most seabird species, and management interventions have rarely been trialled for the benefit of seabirds, including the focal species. Consequently, there is a high degree of uncertainty regarding the potential benefits of this conservation action. If any, the effects of all management interventions are likely to be highly site- and context-specific.		
	DF has not been well studied for its potential benefits to seabird species and has been minimally tested in Scotland for most avian predators. Further research is required to determine which predators respond to DF and to	The targeted removal of individuals with high predation rates has been proven to be highly effective. What remains less understood is the timeframe, if any, for other individuals to fill the open	Although the use of deterrent objects has been explored as a strategy to deter birds in areas such as landfills, airports, and agricultural sites, their application at seabird colonies remains relatively unexplored.

	Diversionary feeding (DF)	**Removal (REM)**	**Deterrence (DET)**
	investigate its impact on seabird colonies.	predation niche, and the potential impact on the food chain and the ecosystem that this might have. Nest and chick removal also require further exploration.	Habituation and the long-term use of deterrent objects remains untested. The lack of evidence in WP1 and other sources makes it challenging to draw conclusions regarding the effectiveness of deterrent objects at seabird colonies. Further trials are required, involving various predator and seabird species and diverse combinations of deterrent methods.
Species benefitting For detail see: Ecological effects of implementing management interventions	In theory, if predators consume diversionary food and, as a result, seabird predation decreases, all seabirds are likely to benefit from increased productivity and in some cases also survival. Focal species: At sites where avian predation is significant and DF proves successful, then large gulls and auks may benefit by increased productivity and survival. Other seabird species: Ground-nesting colonial species like terns and waders are the most likely beneficiaries of DF. Should DF prove attractive to predators, it could potentially benefit other species	Focal species: Gulls are usually those species targeted for removal. However, gulls also show strong intra-species competition which suggests that, if individual gulls with higher predation rates are removed, then overall gull productivity may increase. Smaller gull species predated by larger gulls may also benefit. At sites where avian predation is significant and removal proves successful, auks may benefit from increases in productivity and survival. The targeted removal of gull nests and/or individuals may reduce	In theory, if predators are effectively deterred from an area, and, as a result, seabird predation and disturbance decrease; all seabirds are likely to benefit from increased productivity. To what extent, and whether there are differences in the effectiveness of the management between species, however, is not well understood (see knowledge gaps).

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
	vulnerable to avian predation, such as Black-legged Kittiwake and Fulmar. Predator species: As predator chicks are ensured a stable food supply during the DF period, it is anticipated that fledgling rates and productivity rates will remain stable, or even increase, even in years with limited food availability.	kleptoparasitism rates, particularly among Puffin (i.e. where food, usually fish, are taken by one bird from another bird), potentially improving the body condition of both adults and chicks and ultimately increasing productivity, and survival rates. Other seabird species: Other seabird species are also likely to benefit from the removal of avian predators.	
Predators that may respond to management in Scotland/UK	Target predator species and note on whether there is evidence available on DF: • White-tailed Eagle – DF is currently being tested on agricultural grounds in Argyll. Mixed results, as not every pair responded to DF (NatureScot, 2020). Eagles seem to respond to food dumps in the Cairngorms (see Cairngorms Connect project) • Golden Eagle – no clear evidence found/not trialled	Target predator species and note on whether there is evidence available on removal: • Gulls – multiple studies have successfully used removal techniques on gulls (Parr, 1993; Finney et al., 2001; Sanz-Aguilar et al., 2009) • Corvid – evidence of success (Parr, 1993) • White-tailed Eagle – nest removal currently being tested on agricultural	Target predator species and note on whether there is evidence available on deterrent means: • Gulls e.g. Herring Gull, Lesser Black-backed Gull, Great-Black backed Gull – use of bamboo canes at Arctic Tern colony, non-significant effect (Boothby et al., 2019). Use of different deterrent means at landfills provided mixed results but overall effective for short periods of time: distress calls, falconry, and combinations of

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
	• Eurasian Kestrel – successful; increased Little Tern productivity (Smart and Amar, 2018) • Peregrine Falcon – no clear evidence found • Gulls e.g. Black-headed Gull, Herring Gull – no clear evidence found, but given their generalist diet, DF likely to attract individuals • Great skua – no clear evidence • Corvids e.g. crows, magpies, jackdaws, and ravens – no clear evidence Non-seabird avian predators for which there is evidence of successful DF: • Hen Harriers – used for Red Grouse management (Redpath et al., 2001; Ludwig et al., 2018) • Common Buzzard and European Sparrowhawk – used for Pheasant management (Parrott, 2015) • Red Kites – used for Northern Lapwing conservation (Mason et al., 2021)	grounds in Argyll (NatureScot, 2020) • Golden Eagle – no clear evidence • Eurasian Kestrel – no clear evidence • Peregrine Falcon – no clear evidence • Great skua – no clear evidence	lethal and non-lethal use of ammunition were the most effective techniques for initially deterring birds from landfills (Baxter and Robinson, 2007; Cook et al., 2008; Soldatini et al., 2008). Use of laser hazing at a Roseate Tern colony, non-significant effects but requires further trials (Alfarwi, 2021) • Corvids e.g. crows, magpies, jackdaws, and ravens – use of different deterrent means at landfills provided mixed results (Baxter and Robinson, 2007) • White-tailed Eagle – no clear evidence found in Scotland/UK, potential to learn from trials elsewhere, e.g. trial of scarecrow at a Caspian Tern colony in Sweden (Lötberg et al., 2020) • Golden Eagle – no clear evidence found • Eurasian Kestrel – no clear evidence found • Peregrine Falcon – no clear evidence found

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
			• Great skua – no clear evidence found
Scale and degree of population benefit	Impact on all species: **Scale**: Local. **Degree of benefit**: Will range from no effect to medium effect, dependent on the effectiveness of the management intervention and whether predation occurs on chicks or adults. If an effect were to occur, it would manifest immediately and might potentially lead to a: • Decrease in predation and disturbance rates • Increase in body condition • Increase in productivity rates • Increase in adult survival rates At a short to medium term, potential for: • Distribution expansion • Increase in population size **Scale**: Wider. **Degree of benefit**: Will range from no effect to low effect, dependent on the effectiveness of management. At a medium to long term, potential for: • Increase in levels of natal dispersal from target colony to other colonies		
Sequence of steps to implement For detail see: Steps for implementation	1. Collation of baseline information and field studies including field trials: • Gather baseline knowledge regarding the ecology, breeding season, and general behaviour of both predator and seabird species. • Identify relevant predators and seabird colonies that could potentially benefit from avian predator management in Scotland. • If needed, design and conduct preliminary field trials to test methods and assess the efficacy of the different management interventions. 2. Decision on suitability as a compensatory measure and, if suitable, determining which management intervention to implement:		

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
	• Based on the information collated during step 1, determine the management intervention with the most potential for the specific species and site/s. 3. Detailed design of management intervention: • Undertake site visits to explore terrain and overall site and colony characteristics to identify whether the management could be implemented at the target site/s and towards those species. 4. Pre-implementation of management: • Obtain necessary permits for land use and species-related actions. • Offer training to personnel responsible for implementing management. • Install necessary infrastructure and secure material and equipment. • Identify specific individuals with higher predation rates and/or locate predator nests. • Consider other management-specific requirements. 5. Implementation of management: • Implement management. • Undertake prey and predator observations (see monitoring). 6. Post-implementation of management: • Evaluate and reflect on what worked and/or did not work to enhance efficacy in subsequent years. • Perform appropriate data analyses to measure effectiveness of management.		
Monitoring summary For detail see: Research and	Establishing a baseline understanding of the predator-prey dynamic before implementing any avian predator management is crucial. This involves identifying and quantifying the impact of predators, both in terms of predation and disturbance, on key species and colonies. Predation data can be obtained through utilising traditional field observation methods, existing literature, or dietary studies of key predators. Life history and survival data for the seabird prey species can also be obtained using traditional field observation methods or existing literature.		

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
monitoring recommendations	Subsequently, this information could be employed to calculate overall predation levels, which can then be used to conduct population viability analyses to model the population-level impacts of avian predators on seabirds. Once the population-level impacts of predation are understood, detailed biological data becomes crucial (e.g. population size, productivity rates, predation rates and predation behaviour of both prey and seabird) to assessing the impact of predation management. This information can be gathered through fieldwork in the years preceding the initiation of the management. For some management interventions it will be necessary to locate the nests or potential nesting sites of predators and, whenever possible, identify individual predators with higher predation rates prior to implementing the management. Monitoring should also take place while the management is ongoing. While there will be specific details to evaluate for each management intervention, the primary objective is to monitor predation attempts (the frequency of predator attacks) and success rates (the proportion of successful attempts) through in-situ observations at various points during the seabirds' breeding season. To understand the impact of the management intervention on the focal seabird prey species, monitoring should encompass aspects like productivity, behaviour, population counts, and predation rates and attempts. Surveys can be conducted in person, throughout the breeding season, and variables such as the number and growth stage of chicks should be monitored to calculate the annual productivity. Subsequently, employ statistical analyses to quantify the effects of the management intervention on predation rates and seabird productivity either by comparing years and/or sites with versus without management and, if applicable, differences between treatments. Observation should also focus on recording any unforeseen impacts on other wildlife, such as the presence and impacts of other non-target species.		
General key considerations For details see: Key considerations, potential issues,	**Good baseline knowledge of ecological factors**: for avian predator management to be successful, understanding the predator-seabird system is essential, as well as detailed knowledge on the ecology, behaviour, and breeding season of both seabird and predator species. **Legal and policy issues**: When considering all management interventions, it is essential to consider the conservation status of predators and their protection under UK laws and regulations. Compliance with these regulations is crucial to avoid legal repercussions and to determine the necessary permits for undertaking management/s. **Location**: For more inaccessible locations or difficult terrains certain avian predator management interventions may not be feasible to conduct.		

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
and potential solutions	**Ethical**: The lethal removal of animals or the use of any management that has the potential to reduce the presence, productivity and survival of an animal may spark ethical concerns. **Opposition**: Opposition by animal welfare groups could increase difficulty of implementing management.		
Specific key considerations For details see: Key considerations, potential issues, and potential solutions	**Undesired ecological effects**: Potential to attract or recruit new/more predators and other animals, increasing predator abundance and density and the risk of disease transmission. **Site-specific feasibility**: DF may not be practically feasible to conduct on uninhabited sites, remote islands, or remote mainland sites where DF cannot be properly sourced and/or kept fresh, or at sites where DF would cause strong disturbance impacts on both predators and seabirds.	**Undesired ecological effects**: The removal of larger dominant competitors can increase the presence of subordinate predators, precipitating unpredictable trophic cascades. The removal of individuals of the target predator species could lead to declines amongst their population. There is also a risk of removal techniques incidentally impacting non-target species. **Site-specific feasibility**: Certain lethal removal techniques should not be conducted at sites where humans are present or where predator nests are inaccessible.	**Undesired ecological effects**: The deterrent could potentially disturb not only the predator species but also the target breeding seabird population and other wildlife. **Site-specific feasibility**: Certain deterrent approaches may not be practically feasible to conduct at sites where the deterrent technique could cause strong disturbance impacts on other seabirds and wildlife or on uninhabited sites, remote islands, or remote mainland sites. **Habituation**: Predators could habituate to certain deterrents over time, reducing its overall efficacy. **Effectiveness**: A combination of different deterrent methods could result in an increase in effectiveness.
Knowledge gaps	DF has not been well studied for its potential benefits to seabird species and has been minimally tested in Scotland for most avian predators. Further research is required to determine which	The targeted removal of individuals with high predation rates has been proven to be highly effective. What remains less understood is the	Although the use of deterrent objects has been explored as a strategy to deter birds in areas such as landfills, airports, and agricultural sites, their

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
	predators respond to DF and to investigate its impact on seabird colonies.	timeframe, if any, for other individuals to fill the open predation niche, and the potential impact on the food chain and the ecosystem that this might have. Nest and chick removal also require further exploration.	application at seabird colonies remains relatively unexplored. Habituation and the long-term use of deterrent objects remains untested. The lack of evidence in WP1 and other sources makes it challenging to draw conclusions regarding the effectiveness of deterrent objects at seabird colonies. Further trials are required, involving various predator and seabird species and diverse combinations of deterrent methods.
Benefits of management intervention	DF proves particularly useful when both prey (i.e. seabirds) and predator species are of conservation concern, as it reduces the motivation for a predator to hunt natural prey without compromising the needs of either species (Smart and Amar, 2018). The management approach is highly adaptable and can be discontinued at any time. Its overall duration is short-term, conducted in weeks or, at most, months. The frequency and timing of DF efforts can be tailored to the management objectives.	Removing only specialised individuals is more efficient than larger scale culling for protecting species of conservation concern. If management proves successful in reducing the number of seabird-specialised predatory individuals, then this approach has the potential to offer short to medium term solutions.	This management is a non-lethal way of deterring individuals. Depending on the deterrent, it may be quick and easy to implement and with low costs.

	Diversionary feeding (DF)	Removal (REM)	Deterrence (DET)
Conclusion	Given the lack of specific evidence available for the use of predator management measures for the benefits of seabird populations in the UK or Scotland, if considering for strategic compensation, it is essential that further research and trials are first conducted to better understand which management approaches may be appropriate for a given context (*inter alia* predator species, seabird species impacted by predation, and the location). Combining multiple avian management approaches may yield more favourable outcomes. The effectiveness of the management approaches is likely to change over time. Therefore, it is essential to adapt the programme based on monitoring data, analyses of past results, and changes in environmental and location variables.		

7.5.2 Background

Avian predators can exert significant top-down effects on seabird populations (Perkins et al., 2018; Anker-Nilssen et al., 2023), either directly, by taking adults, eggs and chicks, or indirectly, through disturbance or other means such as kleptoparasitism, when an individual steals food or prey from other individuals (Finney et al., 2001; Sanz-Aguilar et al., 2009; Perkins et al., 2018). Among these predators, raptors, corvids, and large seabirds like gulls and skuas, have been observed preying on seabirds at Scottish colonies (Votier et al., 2004; Perkins et al., 2018; Langlois Lopez et al., 2023). In WP1, we explored the effect of various avian predator management interventions on seabirds and waterbirds to identify the specific predation reduction actions that had most potential as strategic compensation for benefitting auks and large gulls (the focal species).

The most commonly employed management interventions included: a) diversionary feeding, a non-lethal, temporary method aimed at providing predators with alternative prey items to divert them from predating on seabirds (DF), b) the targeted or non-targeted removal of predators' nests, eggs, chicks and/or breeding individuals (REM), and c) the use of deterrent objects, including physical and acoustic means (DET). It was clear throughout WP1, that the effectiveness of each management intervention is contingent upon multiple factors, such as the avian predator involved, the nesting ecology of the target seabird species, site-specific conditions, and the chosen management intervention. Additionally, the review in WP1 highlighted a notable scarcity of evidence concerning the applications of these management interventions on the focal species, and very little evidence testing such management in Scotland or the wider UK.

7.5.3 Steps for implementation

Each management intervention possesses inherent advantages and disadvantages that require careful consideration during the planning and implementation stages and should always be tailored to the specific seabird species, avian predator in question and overall context. Therefore, the implementation steps are here outlined at a high level only (and may not apply to all situations). Further detail on the monitoring related elements is discussed in the monitoring section.

1. **Collation of baseline information and field studies including field trials:**
    - 1.1. Review knowledge on impacts of avian predators on Scotland's seabird populations generally.
    - 1.2. Identify which predators have the most significant impact on which seabird species and at which breeding colonies.
    - 1.3. Identify which predator management intervention/s may be possible to apply in order to reduce impacts from predators and identify candidate field trial locations.
    - 1.4. Gather comprehensive ecological, breeding, and behavioural data from both predator and seabird species.
    - 1.5. For all management interventions, except potentially predator removal, it would not be possible to proceed directly to delivering as a compensatory measure, with research and trials first required (see monitoring section for specific recommendations).

- Design and conduct preliminary field trials to test methods and assess the efficacy of the different management interventions. Note that the duration of the trials may vary depending on the management intervention, potentially requiring several years to determine suitability in some cases.
    - **(DF)** Trials focussing on DF should conduct experiments to compare DF delivery methods (e.g. feeding on ground, feeding platforms, nest feeding) to determine the most effective approach.
    - **(DET)** Trials researching the impact of deterrence should aim to identify which deterrent mean or group of deterrent means would be most efficient for each specific predator while also noting their effects on the focal seabird species (i.e. avoiding disturbance).

2. Decision on suitability as a compensatory measure and, if suitable, determining which management intervention to implement:

2.1. Based on the information collated in step 1, determine the management intervention with the most potential for the specific species and site.

3. Detailed design of management:

3.1. Undertake site visits to explore terrain and overall site and colony characteristics to identify whether the management could be implemented at the site and towards those species.

- Determine the land ownership status by identifying whether sites are privately-owned, designated as a reserve, public land, etc.
- Use of maps or field visits to comprehend the terrain's characteristics.
- Gain detailed knowledge on the target avian predator, including its breeding ecology, behaviour, feeding habits, and diet preferences. **(DET)** For deterrence, also obtain information on previously used deterrent methods and whether these were efficient and to what degree.
- Research the breeding ecology of focal seabird species within the site, including information on laying, hatching, peak chick provisioning period, and fledgling dates.
- Understand the ecological dynamics between seabird and predator by gathering data on e.g. current predation rates, peak predation timing (in terms of date and time of day), behaviour, and seabird colony responses to the predator.
- Research the conservation status and relevant protections of target species.

3.2. Confirm the feasibility of implementing the management at the given location/s and target species.

4. Pre-implementation of management:

4.1. Prepare for management implementation.

- Obtain necessary permits for land use and species-related actions.
    - Where the target site is an SPA colony, then an HRA will be required.
- Offer training to personnel who will be responsible for implementing management.
- Install necessary infrastructure and secure required materials and equipment:

  - **(DF)** Erect feeding poles/stations (locations will be determined based on baseline knowledge), construct, mount and/or identify hides or observational points, install surveillance cameras and identify where and how food for diversionary feeding is going to be stored and disposed of.
  - **(DET)** If applicable, install deterrent objects.
- Identify individual predators with higher predation rates and/or locate predator nests/pairs.
  - Conduct searches to locate predator nests near or around the seabird colonies by monitoring displays, nest-building, prey transportation, and food-passing interactions behaviours.
  - The identification of individual predators with higher predation rates on seabirds could be done by conducting behavioural observations and quantifying successful predation rates and/or by inspecting the food items present in pellets located within/in the vicinity of the predators' nests.
- Management-specific considerations:
  - **(DF)** Identify when and what food type and quantities are going to be fed to predators. Secure the source and quality of diversionary food.
  - **(DF)** Decide whether all predators or just a subset of them should be targeted for DF.
  - **(DET)** The specific implementation approach will depend on the deterrent used. If necessary, install deterrent objects, such as speakers, canes, scarecrows, etc prior to the start of the seabird breeding season, so as to avoid unnecessary disturbance.

5. **Implementation of management:**

5.1. **(DF)** For detailed information on methods, see Redpath et al. (2001), Ludwig et al. (2018), Smart and Amar (2018) and Mason et al. (2021).

- If predators are breeding, provide DF from post-hatching until predator fledgelings have left area or until all seabirds have fledged. Note that the frequency of which the DF will be provided will depend on the predator's dietary requirements. For example, smaller items within DF may need replacing at least daily while larger items may likely be available for longer.
- If predators are not breeding, provide DF during the peak of seabirds' breeding season.
- Ensure that predators are feeding on diversionary food.
- Throughout the season, ensure that amount of food is accordant to brood sizes/ages and/or number of predator individuals using the DF.
- If applicable, dispose of uneaten food daily.

5.2. **(REM)** For examples of potential removal techniques see Finney et al. (2001) and Sanz-Aguilar et al. (2009).

- Search potential nests and constantly monitor predators throughout the seabirds' breeding season.

    - Destroy, remove and/or replace, eggs, chicks and/or adults, as required. Potential removal techniques are egg pricking and substitution, destruction of empty active nests, trapping, shooting or poisoning adults.
  - 5.3. **(DET)** Example of study using bamboo canes as a deterrence: Boothby et al. (2019)
    - Some deterrents will require active intervention, such as operating speakers, lasers, ensuring that canes are set correctly, etc. Others, once in place will not require any actions until removal, although regular checks will still be necessary.
  - 5.4. Undertake prey and predator observations to monitor the success of management, e.g. whether predator's rates reduce, and if prey productivity, survival, abundance and recruitment increase (see monitoring).

6. Post-implementation of management:

  - 6.1. Evaluate and reflect on what worked and/or did not work to enhance efficiency in subsequent years.
    - Note whether individuals got habituated to management (e.g. deterrent object) over time. If so, reassess management programme.
  - 6.2. Measure effectiveness of management.
    - Perform appropriate data analyses to understand the impacts of the management on the productivity of both prey and predator, as well as its effect on other wildlife.

7.5.4 Ecological effects of implementing management interventions

The management interventions considered have rarely been trialled at seabird colonies. Consequently, there is a high degree of uncertainty regarding the potential and degree of ecological benefits of this conservation action as a whole, especially on the focal species of this review. Any effects, if present, are likely to be highly site- and context-specific and we are, therefore, unable to provide detailed information in this section.

7.5.4.1 Ground-nesting colonial species

Ground-nesting colonial species, such as terns and waders, are the species for which there is strongest evidence for benefits from general avian predator management. Studies by Smart and Amar (2018) and Mason et al. (2021) demonstrated the efficacy of DF of raptors in reducing predation rates and doubling the productivity of Little Terns and Northern Lapwings, respectively. DF of certain raptors, such as Kestrels and Red Kites, can be a highly effective predation management tool that enhances productivity of ground-nesting colonial species that could consequently lead to increased population growth rates. As ground-nesters, large gull species may potentially benefit from DF through reduced nest predation, though the extent to which gull colonies could benefit in Scotland is unclear. Ground-nesters are also highly likely to benefit from predator removal and deterrent techniques. Deterrents like lasers and bamboo canes, are most likely to work for the protection of these species.

7.5.4.2 Auks

While no direct evidence of the use of the management interventions on focal species was found, if raptors were to prey on an auk colony and the management interventions were successful in reducing disturbance, predation and/or kleptoparasitism, avian predation management could immediately increase productivity and/or adult survival rates.

7.5.4.3 Other seabird species

Given that the benefit to seabirds strongly depends on the successful implementation and response (e.g. disturbance and predation rate reduction) of the avian predator management interventions, seabirds regulated by top-down effects from avian predators, such as Black-legged Kittiwake (Oro and Furness, 2002; Anker-Nilssen et al., 2023) and Northern Fulmar (Swann, 2002; Reid et al., 2023), should theoretically show some degree of benefit.

7.5.4.4 Predators

Target predators are likely to experience adverse effects from removal techniques, particularly those involving lethal methods, as well as from deterrent efforts. These management interventions have the potential to reduce their survival rates and population size, and/or force individuals to relocate to other sites. On the other hand, non-target predators may benefit from compensatory responses. Additionally, DF may attract other predator individuals, either from the same species or different ones, owing to the increased food availability and ease of access to it. While this benefit could lead to higher population density and improved survival rates, regulation may be necessary if it leads to an increase in seabird predation, which would undermine the purpose of the management.

7.5.4.5 Time-lags for population level responses

In the case where predation targets seabird chicks and the applied management successfully reduces disturbance and chick predation rates, an immediate increase in annual productivity can be anticipated. If predation targets adults and the management successfully reduces adult predation rates, an increase in adult survival rates is expected within a short period. Distribution expansion and population growth are expected in the short to medium term, depending on the continued success and implementation of the management. The extent of these effects, however, will depend on the effectiveness of the management intervention.

7.5.5 Research and monitoring recommendations

7.5.5.1 Baseline information required to decide which management intervention is suitable

Establishing a baseline understanding of the predator-prey dynamic before implementing any type of avian predator management is crucial. The initial step involves identifying and quantifying the impact of predators, both in terms of predation and disturbance, on key seabird species and colonies as well as understanding their life history and survival traits. In some cases, this information may also be available in existing literature. In most cases, however, this information would need to be collected through field studies, which can be obtained through traditional field observations, dietary studies, survival analysis and/or installing cameras at nests. Subsequently, this information could be employed to calculate overall predation levels, such as the number of predated adult Puffins per year or the number of predated Guillemot eggs and/or chicks per year. Predation levels life history and survival data can then be used to conduct population viability analyses, following a similar approach to Langlois Lopez et al. (2023), to model the population-level impacts of avian predators on seabirds.

Experimental trials will be essential for most management interventions. These trials serve a dual purpose: first, to measure the management's effectiveness in terms of predation reduction and seabird benefit, and second, to refine and test methods. The latter will involve determining correct quantities (e.g. the density of bamboo canes at nests or how many nests should be removed and which ones), the timing (i.e. when management is most effective), the frequency (i.e. how often a certain action needs to be conducted), and, in the case of deterrence, the time of predator response to deterrent and effectiveness of combining different approaches. All experiments should adhere to well-established experimental protocols; therefore, experiments should be well-designed, carefully controlled and appropriately analysed, with the aim of providing reliable and meaningful insights into the effectiveness of the management.

7.5.5.2 Ecological information required prior to implementing management intervention

Once the population-levels impacts are understood, and the decision has been made to proceed with the management intervention at a specific site, detailed biological data becomes crucial. This data encompasses population size, productivity rates, predation rates and predation behaviour of both predator and seabird. This information can be gathered through fieldwork in the years preceding the initiation of the management. This may involve regular observations from hides and/or vantage points throughout the breeding season, through cameras, or, if available, through existing long-term datasets. For certain management interventions it will be necessary to locate nests or potential nesting sites of predators and, whenever possible, identify individuals with higher predation rates prior to implementing the management. Colour-ringing individuals could facilitate the identification of specific individuals for this purpose. If available, it is important to obtain information on previously used management interventions at the site and their efficiency concerning both predators and seabirds, either by reviewing existing literature, reaching out to potential sites that might have implemented such actions, or conducting experiments before the official management implementation.

7.5.5.3 During implementation of the management interventions

Monitoring should take place while the management is ongoing. While there will be specific details to evaluate for each management interventions, the primary objective is to monitor predation attempts (the frequency of predator attacks) and success rates (the proportion of successful attempts) through in-situ observations at various points during the seabirds' breeding season, with particular focus during the peak of breeding or when chicks and adults are most vulnerable.

For diversionary feeding: Observations of the predator's food intake, provisioning rates, predation rates, and productivity are crucial aspects to understanding the effectiveness of the management. These observations should account for potential variations in diurnal hunting patterns and seasonality and can be conducted through direct observations (from hides or vantage points), cameras (either miniature cameras at nest or at feeding platform), by collecting and analysing regurgitated pellets, or by weighing the food that was not consumed. The key aspects at this stage are to confirm whether birds are indeed consuming the provided food and to quantify their intake of the focal seabird species. Some studies, for example, have dyed the diversionary food with a distinct colour to aid in distinguishing it from natural prey items during observations.

For removal: Conduct constant monitoring efforts around the seabird colony to gather evidence of predation. This includes monitoring direct predation rates, localising active nests and analysing the content of pellets found within nests. Additionally, monitor overall predator population trends to provide a clear understanding of the likely impact of removal on the predator population.

For deterrence: To detect habituation, the responsiveness of predators to the deterrent object should be monitored over time. Observations should quantify differences in reaction time, proportion of times individuals are deterred, intervals between predation attempts, and successful predation attempts.

Overall, to understand the impact of the management intervention on the focal seabird species monitoring should encompass aspects like productivity, behaviour, population counts, and predation rates and attempts. Surveys can be conducted in person, throughout the breeding season, and variables such as the number and growth stage of chicks should be monitored to calculate the annual productivity. Subsequently, employ statistical analyses to quantify the effects of the management intervention on predation rates and seabird productivity either by comparing years and/or sites with versus without management and, if applicable, differences between treatments. Observation should also focus on recording any unforeseen impacts on other wildlife, such as the presence of other non-target species and how these are impacted.

7.5.6 Key considerations, potential issues, and potential solutions

The parenthesis before each consideration indicates the management intervention it is applicable to: DF = diversionary feeding, REM = removal, and DET = deterrence. If not stated, then the point is applicable to all management interventions.

Key considerations	Potential issues	Potential solutions
Policy	The focal avian predators may also be threatened and of conservation concern. Therefore, it may require a political decision on balancing the conservation of one species over another. This is particularly the case for **REM**.	Ensure that the full conservation impacts both on the focal seabirds and predator species are fully understood and specifically considered before deciding whether to proceed with avian predator management.
Legal	Where habitats, species, and/or locations are under protection, some permits may be required. Permissions may include activities such as deploying deterrent objects, provisioning DF, constructing observation hides, installing nest cameras and/or feeding posts, and allowing for lethal removal.	Ensure that permissions are obtained before implementing the management and experimental trials. Conduct thorough research in advance to ascertain the legal and conservation status of target predators. Species under

Key considerations	Potential issues	Potential solutions
	The predators' conservation status and protection under the British laws and regulations should be considered for all management interventions as compliance with these regulations is essential to avoid legal repercussions. Certain managements, especially **REM**, could accidentally affect non-targeted legally protected species.	protection should not be handled or killed. Certain management interventions may be unfeasible and should be ruled out early on as unviable. Ensure that proper training is in place to promote a clear understanding of legal obligations and to minimise the likelihood of management accidents.
Financial	Financial costs associated with avian predator management could encompass various components: Costs of implementing management: • Training and employment/contractor costs • Permits • Infrastructure (hides, feedings posts) • Equipment (binoculars, cameras, speakers, canes, guns, food storage, poison) • Analytical services (for analysis of associated monitoring data) • Transport • **(DF)** Diversionary food	Funding would need to be secured pre-implementation to ensure that the full scheme can be implemented as planned. Overall costs may be lower when compared to most other potential compensatory measures. However, costs could still be significant given most of these measures would require a multi-year commitment and if carried out across multiple sites.
Ecological	All management interventions within this conservation action could create undesired ecological effects: **(DF)** Potential to attract or recruit new/more predators (mammalian and/or avian), increasing predator abundance and density and increasing the risk of disease transmission (e.g. HPAI). Note that an increase in predator abundance and density would only be an issue if this leads to an increase in predation of focal seabirds.	Constant monitoring to measure effectiveness of action and unwanted consequences. Adapt management as required. **(DF)** Implementing DF for a short period, especially during periods with peak predation rates (e.g. peak seabird breeding season or during predator chick rearing) and/or during alternating years to reduce dependence and habituation.

Key considerations	Potential issues	Potential solutions
	(DF) DF could lead to an increase in predator juvenile survival, and hence, population size, which could have unintended future impacts on the focal seabird species. **(DF)** DF could attract predators of the focal predator, which could, therefore, affect their survival rates. **(REM)** The removal of larger dominant competitors could increase the presence of subordinate predators, precipitating unpredictable trophic cascades. The shooting of gulls at breeding colonies may also eliminate potential recruits (young birds) and lead to disturbance. This could lead to population declines of the predators. **(REM)** Removal techniques may also impact non-target species through accidental shooting, poisoning or nest removal. **(DET)** Deterrents could potentially result in disturbance, not only to the predator species but also to seabirds and other wildlife. **(DET)** If a deterrent were found to have detrimental effects on the target predator, it could potentially influence their survival rates.	**(DF)** Targeting DF to specific individuals estimated to have higher predation rates. **(DF)** Ensure a supply of diversionary food is secured from appropriate sources and that the bait does not contain lead shot (or any other harmful substances). Plan for appropriate removal and disposal of unconsumed DF. **(REM)** Important to consider and monitor ecological community and ecosystem effects during management. **(REM)** Removal may only be practical where access to nest sites is possible, areas can be sealed from human disturbance temporarily and carcasses can be cleared up for disposal. **(REM)** Ensure that removal techniques are only accessible to targeted individuals/species. **(DET)** Change deterrent object, frequency and/or timing to improve effectiveness. If possible, trial different experimental settings.
Resources	**(DF)** Access to appropriate diversionary food and the personnel to be able to deliver it.	**(DF)** Prior to the start of the DF programme, identify who will provide DF, and when, how, and where it will be provided. Secure delivery dates.
Practical and logistical	There are certain terrains and/or colonies where certain avian predator	Experimental trials will provide a clearer understanding of the

Key considerations	Potential issues	Potential solutions
	managements may not be feasible. DF, for example, may not be practically feasible to conduct on uninhabited sites, remote islands, or remote mainland sites where DF cannot be properly sourced and/or kept fresh, or at sites where DF would cause strong disturbance impacts on both predators and seabirds. Agreement from landowners and site managers would be required to proceed with predator management. The location of focal nests and/or individuals could be identified once management has already started or could change from year to year.	optimal settings and land characteristics required for conducting each type of management. Plan management according to location and species. Before initiating project, detect and approach potential landowners and site managers to request permission to work on their land. When doing so, explain the project's goals and what it would entail as this may facilitate permission. Prior or during the programme, identify alternative locations to implement management.
	(DF) DF must be consistently provided, and should be adjusted according to the predator's needs (e.g. increase DF as predator chicks grow). If predators do not receive the necessary food quantities, they are likely to resort to predating seabirds. **(DF)** Ensure that the targeted individuals consume the provided DF, as other predators may also consume it, reducing the effectiveness of the action. **(DF)** Providing DF close to the nest or at most frequented site/s may not be possible if it is unsafe to do so, the landowner refuses access, the nest is inaccessible, or the target species is prone to disturbance.	**(DF)** Good knowledge of what, where, when and how to provide DF, how much food to provide, how to minimise the amount of food being taken by non-target species, and when to start and finish feeding. Use of the right type of diversionary food, in terms of size, quantities, and species will increase probability of success. Being consistent about timing and frequency of feeding. Aiming to provide around 100% of their requirements accounting for the number and age of offspring and adults. **(DF)** Monitor for unwanted predators/adverse effects on wildlife.
	(DET) Predators may habituate to the deterrent object, in which case it would reduce its effectiveness.	**(DET)** Monitor and quantify the degree of habituation and adjust accordingly. Using a combination of deterrent objects may reduce habituation and provide flexibility

Key considerations	Potential issues	Potential solutions
	(DET) Some deterrent objects may not be practically feasible to implement during certain environmental conditions, e.g. at night or during strong winds.	to select the most suitable one under specific conditions.
Other – Ethical	The lethal removal of animals or the use of any management that has the potential to reduce the presence, productivity and survival of an animal may be ethically contentious.	Ensure that management is effective and that it is meeting the desired objectives (e.g. proving beneficial towards seabirds). **(REM)** Targeted removal of only individual predators specialising in seabirds from a colony is more ethical than large-scale culling.
Other – Opposition	Some organisations and animal welfare groups may object to predator management methods, especially those that involve lethally controlling or provisioning of dead animals, potentially leading to interferences or suspension of the management.	Offering environmental education and engaging with locals can raise awareness and foster understanding of the management and its key objectives. If management were to be conducted within a reserve, consider adding a poster or sign explaining the ongoing management. Training and awareness among wardens or individuals responsible for undertaking the management is crucial to ensure they are well-prepared to respond effectively.
Other – Health and safety	The logistical challenges of monitoring, lethally controlling, providing diversionary food, etc. could raise health and safety concerns. People could get injured while conducting observations, installing cameras, during removal techniques, and/or providing diversionary food. **(DF)** The handling of raw, dead animals could expose workers to pathogens (e.g. salmonella, *E. coli*).	Conduct a comprehensive risk assessment before commencing programme, ensuring thorough consideration of potential issues and that identified mitigation is followed. **(DF**, **REM)** Put in place proper hygiene and safety protocols and safe handling and disposal procedures. Use of PPE and secure that workers are vaccinated and aware of risks. Develop

Key considerations	Potential issues	Potential solutions
		contingency plans for suspending diversionary feeding and addressing emergencies in the event of unforeseen circumstances.
Other – Habituation	**(DET)** Predators could habituate to certain deterrents over time, reducing its overall efficacy.	**(DET)** Change deterrent object, frequency and/or timing to improve effectiveness. A combination of different deterrent techniques could also result in an increase in effectiveness.

7.5.7 Species-specific aspects of implementation

Overall, how successful DF would be for the focal seabird species remains uncertain. However, targeting nests with DF is more likely to reduce raptor predation, as it minimises scavenging and non-target predator consumption. Deploying DF more broadly to target various predators decreases its effectiveness, as extensive scavenging by non-target predators and gulls at gull colonies could deplete the food source too rapidly to influence the target predators. This, however, would require field trials to confirm.

7.5.7.1 Large gulls

Including Herring Gull, Lesser Black-backed Gull, and Great Black-backed Gull. Note: gulls to benefit through predator management.

DF, REM and DET could benefit gulls in certain circumstances, but has not been proven. Results will depend on the response of the avian predators. Notably, gulls may be attracted by the DF which could prove beneficial in terms of food availability (though this could reflect an incorrect DF programme). REM should be conducted in locations where it would have minimal impact on the targeted gull species. Physical and acoustic DET are unlikely to be suitable, as gulls are likely to react to them. However, they may be effective if they do not provoke a response.

7.5.7.2 Puffin

DF requires a stable terrain and may prove difficult or impractical to implement close to burrows. Puffins, known for their sensitivity to disturbance, require DF to be conducted at a distance from the colony, which diminishes its effectiveness as gulls often engage in kleptoparasitism directly in front of burrows. Therefore, burrow-nesting auks are less likely to benefit from DF. Puffin could, however, benefit from REM and DET efforts, if performed away from the burrows and they do not respond negatively to them.

7.5.7.3 Guillemot and Razorbill

Guillemots and Razorbills are cliff-nesters within large colonies. This means that, for DF to prove successful, it would need to occur on the outskirts of the colony, potentially reducing its effectiveness depending on the predator's location. If effective, REM could decrease disturbance and predation rates at Guillemot and Razorbill colonies. DET objects could be easily placed at a stable terrain close to the colonies. However, it may be challenging to protect individuals from sea-based predation.

7.5.8 Overall conclusion

While all the management interventions (diversionary feeding, removal, and deterrence) included within this conservation action (avian predator management) show potential, further research and trials are necessary to determine their suitability for use as strategic compensation. Given the limited evidence and knowledge available on the topic, removal techniques appear to be the most ecologically effective, followed by diversionary feeding and deterrence. However, potential conflicts may arise during implementation, particularly if the predators themselves are birds of conservation concern (e.g. gulls, raptors), making predator removal inappropriate in many cases despite their ecological feasibility. Therefore, the practical feasibility of management interventions, especially those involving lethal measures for avian predators, requires careful consideration, rendering avian predator management particularly challenging as a strategic compensatory measure.

We have sought to outline the necessary steps that would be required to implement this conservation action as compensation, adding important information for each management intervention. However, given the significant level of uncertainty surrounding their efficacy and specific implementation, primarily due to the lack of specific research, these steps will require refinement as evidence is collected and field trials are conducted.

7.6 Practical feasibility: Reduction of disturbance (at colony)

7.6.1 Summary

During the breeding season, seabirds, especially those located and/or nesting in accessible locations, are exposed to human disturbance occurring from water, land, and air (through Unmanned Aerial Vehicles; hereafter UAVs). Therefore, management measures to reduce disturbance at seabird colonies should be tailored to the source. When applicable, each source is described separately within this document. The focal seabird species identified for this conservation action are auks and large gulls.

***Note**: This section focusses primarily on incidental disturbance resulting from recreational activities. There are other sources of potential disturbance in the vicinity of seabird colonies, including e.g. seaweed harvesting (Goodship and Furness, 2019), inshore fishing activity (e.g. creeling), agricultural activity adjacent to nesting sites, and scientific research activities.*

Table 49. Summary of practical feasibility for the reduction of disturbance (at colony). Further detail is provided following the table.

	Disturbance on land	Disturbance at sea	Disturbance by UAVs
Description	The reduction and management of human disturbance on land, mostly caused by visitors, within seabird colonies.	The reduction and management of human disturbance from sea, caused by marine vessels, near and around seabird colonies.	The reduction and management of disturbance by UAVs used for scientific and recreational purposes) above and near seabird colonies.
Uncertainty	While there is substantial evidence regarding the impact of human disturbance on seabird colonies, and despite many regulations and management measures already being in place, especially within Scottish reserves, the degree of the effect of these measures have not been thoroughly studied for most seabird species. This is particularly true in terms of how behavioural responses translate into changes in demographic parameters. Consequently, there is a certain degree of uncertainty regarding the potential benefits of this conservation action.		
Species benefitting For detail see: Ecological effects of implementing	Focal species: Auks are likely to benefit from the management and reduction of human disturbance due to stress and predation reduction and increased parental care, productivity, and survival. It could, potentially, also lead to colony	Focal species: Coastal cliff-nesters, such as Guillemot and Razorbill, are the species to most benefit from management measures to reduce disturbance originating from sea, as they are	Focal species: Given that UAVs (either for recreational or research purposes) are currently rarely used at active seabird breeding colonies, it is highly improbable that they are presently causing significant detrimental effects

	Disturbance on land	Disturbance at sea	Disturbance by UAVs
management interventions	expansion or recolonisation. Puffin may also benefit from a reduction in burrow trampling. Gulls, given their size and aggressive behaviour towards defending themselves from perceived threats, may experience fewer benefits from a reduction in human disturbance. Nevertheless, gulls show strong intra-species competition and commonly predate on their neighbours' nests. Therefore, any management that reduces any disturbance that leads to them leaving nests unattended, could reduce egg predation and thus, increase productivity. Other seabird species: Kittiwake, Black Guillemot, petrels, and small ground-nesting seabirds like terns are also highly likely to benefit from reduction in human disturbance on land.	the most exposed to it. The benefit, however, lies in the reduction of flushing behaviour and stress, which has the potential to lead to increased productivity, although the degree of it is uncertain. On the other hand, Puffin and large gulls are less likely to benefit significantly due to their lower proximity to the disturbance source. Other seabird species: Other cliff nesters (including Kittiwake), or any species nesting close to shore, are also likely to benefit from the reduction of disturbance from the sea.	on seabird demographic parameters. However, there is a possibility that the use of UAVs increases in the future. Nevertheless, UAV regulations are likely to reduce stress and flushing responses from Guillemot, Razorbill and gulls, but are unlikely to significantly increase their productivity and survival. As burrow nesters, Puffin are less likely to be impacted by UAVs and their management. Other species: Cliff nesters, such as Kittiwake, and ground nesters, such as terns, are also likely to benefit from UAV management measures to the same extent as the focal species.
Scale and degree of population benefit	Impact on all species: **Scale**: Local. **Degree of benefit**: Will range from no effect to medium effect, dependent on the effectiveness of the management and on responses of individuals due to differences in factors such as risk perception, body condition, social status, location of nests, colony size, etc. Note that most benefits will be from management measures targeting land-based disturbance. If a positive effect were to occur, it would manifest immediately and might potentially lead to a: • Decrease in stress and negative physiological changes (e.g. increased cardiac rhythm)		

	Disturbance on land	Disturbance at sea	Disturbance by UAVs
	• Decrease in energy expenditure in behaviour such as agitation, flight response, and flushing rates • Increase in parental care • Increase in body condition of both adults and chicks • Better energy allocation (e.g. more time spent feeding and caring for young instead of defending nest or being alert) • Decrease in predation rates • Reduction in nest destruction • Increase in productivity rates At a medium to long term, potential for: • Distribution expansion • Increase in adult survival • Increase in population size and colony density • Recolonisation **Scale**: Wider. **Degree of benefit**: Will range from no effect to low effect, dependent on the effectiveness of the management measure and colony structure. At a medium to long term, potential for: • Potential for increase in levels of natal dispersal from target colony to other colonies		
Sequence of steps to implement For detail see: Steps for implementation	1. Collation of baseline information on disturbance levels and their impact on seabirds, including field trials: • Review evidence on what type and to what degree human disturbance occurs at Scottish seabird colonies and identify at what locations human disturbance management measures are already in place. 2. Decision on feasibility of implementing management measures at given colonies and focal seabird species: • Based on the information collated in step 1, undertake site visits to explore the site and colony characteristics to determine the management measure with the most potential for each specific species and colony. For some management measures, research and trials first required. 3. Pre-implementation of management:		

	Disturbance on land	Disturbance at sea	Disturbance by UAVs
	• Review the Scottish Outdoor Access Code, the Scottish Marine Wildlife Watching Code, the Guide to Best Practice for Watching Marine Wildlife, and the Scottish Drone Regulations, to understand what can and cannot be done, and what should be already in place. • Obtain necessary permits for land use and vessel management measures. • Offer training to personnel who will be responsible for implementing any management measure. • Offer environmental education, workshops, meetings, or signage to inform residents and site users, particularly marine vessel owners, about the new management measures and the motives behind them. • Create designs and prototypes of paths and signs. 4. Implementation of management: • Implement management (e.g. install informative signs, hire warden and personnel, construct paths) • Undertake observations to monitor the success of the measures (see Research and monitoring recommendations). 5. Post-implementation of management: • Measure effectiveness of management measures in terms of human disturbance reduction and benefit to seabirds. • Assess whether additional measures or adjustments to existing ones are needed to enhance effectiveness.		
Monitoring summary For detail see: Research and monitoring recommendations	Establishing a baseline understanding of the effects from human disturbance on a site and determining the primary source of disturbance affecting seabirds are crucial for understanding the effectiveness of potential management measures. The initial step involves identifying and quantifying the impact of human disturbance on key seabird species, either through existing literature or field studies. The latter will require utilising traditional field observations to quantify changes in behaviour, parental care, productivity, physiological responses, and/or survival analysis with respect to human disturbance. This data can then be used to calculate overall human disturbance levels caused by different disturbance sources. The optimal approach, however, is to conduct experimental trials to quantify and refine the effectiveness of management measures in terms of reducing human disturbance and increasing the benefits to seabirds (e.g. determining the maximum distance a visitor can approach individuals without causing major effects). Monitoring should also take place while the management measures are in place. While there will be specific details to evaluate for each disturbance type and source, the primary objective is to monitor human disturbance (effectively,		

	Disturbance on land	Disturbance at sea	Disturbance by UAVs
	whether humans comply with the management measures), and to determine whether such compliance influences seabird's demography. To understand the impact of management measures on the focal seabird species, monitoring should encompass aspects like productivity, behavioural responses, and population counts. Due to the unclear and challenging nature of measuring the impact of human disturbance, which may manifest as physiological changes, and the influence of other threats on seabird demographics, detecting and quantifying the direct effects of reducing human disturbance is challenging. Nevertheless, surveys and counts should be conducted throughout the breeding season, with variables such as the number and growth stage of chicks monitored to estimate annual productivity. Subsequently, statistical analyses should be employed to quantify the effects of the management measures on seabird productivity and behaviour either by comparing years and/or sites with versus without measures. Note that management measures should be reassessed periodically.		
Key considerations For detail see: Key considerations, potential barriers, and potential solutions	**Legal and policy issues**: While Part 1 of the Land Reform (Scotland) Act 2003 grants all visitors statutory access rights to most land and inland water in Scotland, these rights are only active when exercised responsibly, including 'caring for the environment'. Consequently, enforcing some management measures aimed at reducing human disturbance at seabird colonies may not be politically feasible and may only act as guidance, especially when the impact on the seabird is hard to detect. This could potentially reduce their effectiveness. **Social**: Certain management measures, such as capping daily visitor numbers, may result in a decline in the total number of visitors at a site, which could negatively impact conservation efforts, education, local economy, and limit appreciation of wildlife. **Additionality**: Within Scotland, there are already a set of existing guidelines that provide recommendations for appropriate behaviour around wildlife to minimise human disturbance. Moreover, many of the proposed management measures are already implemented at many reserves in Scotland, including SPA colonies. Hence, most management measures are either already in place or should be. **Effectiveness of conservation action will be hard to quantify**: Changes in seabird behaviour caused by human disturbance can be difficult to detect and measure, especially when there are other variables that could be contributing to low productivity and survival. Therefore, monitoring the efficacy of the management measure can be extremely challenging, characterised by significant uncertainty.		
List of potential management	• Set minimum distances for approaching birds (buffer zones on land and at-sea)		

	Disturbance on land	Disturbance at sea	Disturbance by UAVs
measures to reduce human disturbance at and around colonies	• Reduce the number of visitors and group sizes • Restrict access • Provide paths • Use of signs to inform people of impacts of disturbance on breeding seabirds, including requiring dogs to be on leads • Wardening to provide information and ensure compliance with management measures, regulations, and/or guidance for visitors • Use of fences to delimit colonies and impede human access • Conduct educational programmes for personal watercraft owners • Habituate birds to visitors • Regulate use of UAVs; provide specifications of flight heights and minimum distances to birds and prohibit flights during certain days/weeks when birds may be more responsive to disturbance Considering that seabirds inhabit colonies only during the breeding season, this action would only be conducted during that period and may not be needed throughout the year. *Note this is a long list of potential management measures rather than specific recommendations.		
Conclusion	Different management measures would bring varying benefits to focal species. An important consideration in this conservation action is additionality given that existing guidelines already exist and are applied at many visitor sites, including at SPA colonies. Hence, most management measures are either already in place or should be. However, a recommended approach would involve employing a combination of management measures that, at times, complement each other, e.g. wardens can increase compliance by visitors, marine vessels and UAV operators with management measures, regulations and guidance, while the construction of paths may regulate the number of visitors in an area. Since the effect of human disturbance at colonies on seabird demographic parameters is unclear and challenging to quantify, there is considerable uncertainty about whether implementing this action would effectively mitigate the impacts of offshore windfarms. It is difficult to ascertain whether this conservation action would work effectively as a strategic compensatory measure.		

7.6.2 Background

Seabirds in colonies are highly vulnerable to human disturbance, which can originate from various sources including water, land, and air. This type of disturbance is mostly linked to tourism, recreation, photography, research, pedestrians, pets, and UAVs (for recreational and research purposes). The impact of the disturbance can vary in intensity and effect, contingent on colony-specific characteristics and individual differences, but can range from changes in behavioural responses and physiology to effects on demographic parameters and at a population level, including changes in population size and permanent colony abandonment (Carney and Sydeman, 1999; Blanc et al., 2006; Ellenberg et al., 2006).

In WP1, we explored the effects of various human disturbance management measures in and around seabird colonies, mostly for recreational purposes, to identify those with the most potential for strategic compensation for our focal species in Scotland. The most commonly tested management measures included visitor measures (e.g. set-back distances, cap number of visitors and use of signs), marine vessel measures (e.g. set-back distances and speed limits), and UAV regulations. Despite a limited number of studies identified throughout WP1, it was clear that measures to reduce disturbance had a beneficial impact on seabirds, but the degree of the benefit varied between studies and was, at times, unclear. Overall, the effectiveness of these management measures greatly depends on location characteristics, the extent of the impacts of the disturbance, and the type and quantity of visitors. It is important to note that many of these management measures are already implemented in Scotland, particularly in reserves and protected areas, but the efficacy of these measures is not commonly studied, published, or publicly available.

7.6.3 Steps for implementation

1. **Collation of baseline information on disturbance levels and their impact on seabirds including field trials:**
    1.1. Review evidence on what type and to what degree human disturbance occurs at Scottish seabird colonies.
    1.2. Identify at what locations human disturbance management measures are already in place. Existing management measures are likely to be in place for many SPAs or reserves.
2. **Decision on feasibility of implementing management measures at given colonies and focal seabird species:**
    2.1. Based on the information collated in step 1, undertake site visits to explore the site and colony characteristics to determine the management measure with the most potential for each specific species and colony.
        - Identify the source/s of human disturbance that have significant impacts on seabirds at each colony. Note seasonal changes.
        - Research the breeding ecology of focal seabird species within the site, including information on laying, hatching, peak chick provisioning period, and fledgling dates and how each parameter is affected by disturbance.

- Determine the land ownership status by identifying whether sites are privately-owned, designated as a reserve, public land, etc. Identify whether there are already management measures in place.

2.2. Confirm the feasibility of implementing management measures at the given location/s and target species.

2.3. For some management measures, such as fixed set-back distances, speed limits and UAV-related regulations, it would not be possible to proceed directly to delivering as compensation, with research and trials first required.

- Design and conduct preliminary field trials to test methods and assess the efficacy of the different proposed management measures. Note that the duration of the trials may vary depending on the measure.

3. Pre-implementation of management measure:

3.1. Review the Scottish Outdoor Access Code, the Scottish Marine Wildlife Watching Code, the Guide to Best Practice for Watching Marine Wildlife, and the Scottish Drone Regulations, to understand what can and cannot be done, and what should be already in place, noting that these documents provide guidance on access rights and responsibilities as a wildlife watcher and UAV operator and are not legally enforceable (except Drone Regulations).

3.2. Prepare for implementation of management measures.

- Obtain necessary permits for land use and vessel management measures.
    - Where the target site is an SPA colony, then an HRA may be required depending on the type of measure.
- Offer training to personnel who will be responsible for implementing any management measure (this is mainly focussed on wardens).
- Offer environmental education, workshops, meetings, or signage to inform residents and site users, particularly marine vessel owners, about the new management measures and the motives behind them.
- Create designs and prototypes of paths and signs.
- Secure familiarisation of each measures' best practice for reducing seabird disturbance (e.g. Edney et al. (2023) provides a set of best practices for using UAVs in seabird monitoring and research and NatureScot will soon publish a guidance for use of drones at seabird colonies).

4. Implementation of management measures:

4.1. Once the measure/s have been established, the next step is implementation, which will vary depending on their nature. Some examples include:

- Install informative signs to educate the public about the potential impact of human disturbance on seabirds, promote responsible behaviour, and clearly outline the newly implemented management measure.
- Hire a warden and/or personnel to monitor visitor numbers, increase compliance with new management measures and offer guidance and information to incoming visitors about the origin and importance of following measures.
- Construct pathways and or set up infrastructure to define designated visitor areas, clearly indicating areas that should be avoided.

   4.2. Undertake observations to monitor the success of the measures (see Research and monitoring recommendations).
   4.3. Given that most seabirds can be found at the colonies exclusively during the breeding season, some management measures would only need to be implemented during the seabird breeding season (though this will be species-specific).

5. **Post-implementation of management measures:**
   5.1. Measure effectiveness of management measures in terms of:
      - Human disturbance reduction: evaluate whether the new measures were followed effectively by visitors.
      - Benefit to seabirds: perform relevant data analyses to understand the impacts of the measures on the productivity of seabird species.

   5.2. Assess whether additional measures or adjustments to existing ones are needed to enhance effectiveness.

7.6.4 Ecological effects of implementing management interventions

7.6.4.1 Large gulls

Management measures aimed at reducing human disturbance have rarely been tested for the benefit of large gulls. Consequently, there is a considerable degree of uncertainty regarding the potential ecological benefits for these species. Due to their size and aggressive responses to perceived threats, large gulls may experience limited benefits from reduced human disturbance. Nevertheless, these species exhibit strong intra-species competition and frequently predate on neighbouring nests. Therefore, any management measures that effectively minimise disturbances that lead to gulls leaving their nests unattended could potentially reduce egg and/or chick predation, subsequently increasing productivity. While management measures relating to UAVs may reduce stress, attacks, and flushing responses, it is unlikely that they would significantly enhance productivity and survival.

7.6.4.2 Auks

Overall, cliff-nesting auks are likely to benefit from management measures and reduction of human disturbance due to stress and predation reduction, and increased parental care, productivity, and survival. It could, potentially, also lead to colony expansion or recolonisation if habitat is available, with effects likely to be strongest at the top of the cliffs. Coastal cliff-nesters, such as Guillemot and Razorbill, are the species expected to benefit most from measures to minimise disturbance originating from sea, as they are the most exposed to this type of disturbance.

Guillemot productivity is influenced both by physical nest characteristics (e.g. nest height, proximity to the sea, gradient of cliff slope, number of neighbours) and human disturbance. At St Abbs Head, for example, halving the number of visitors was predicted to result in an increase of nesting success from 70.1% to 87.2% (Beale and Monaghan, 2004). The benefit, however, lies in the reduction of flushing behaviour and stress, which has the potential to lead to increased productivity, although the degree of it is uncertain. Razorbill tend to occupy crevices in cliffs, so have more protection. As no studies have been conducted on testing such measures to reduce disturbance for Razorbill, their effectiveness on the species is highly uncertain.

7.6.4.3 Puffin

Puffin are less likely to be threatened by human disturbance through visitors, marine vessels, and UAVs. This is because during the day, they are typically away foraging at sea and at the colony are hidden within burrows, minimising proximity to marine vessels and reducing their impact. Additionally, UAVs are unlikely to cause significant disturbance to burrowing individuals. Puffin, however, may benefit from a reduction in burrow trampling, if visitors are indeed causing such an impact.

7.6.4.4 Other seabird species

There is strong evidence, particularly for Kittiwake and terns, supporting the potential benefits of reducing human disturbance (Beale and Monaghan, 2004; Medeiros et al., 2007; Vogrin, 2013; Bishop et al., 2022). Human presence has been strongly linked to poor nesting success in these species, with the impact attributed to factors such as people load and proximity to the nests. Kittiwake, for example, were found to be more sensitive to human disturbance than Guillemot at St Abbs Head, possibly due to their closer proximity to viewpoints (Beale and Monaghan, 2004). Similarly, petrels, cormorants, and Fulmar are highly affected by human disturbance at their colonies (Dias et al., 2019). Even with larger species such as Gannet, there is evidence that installing signs can increase reproductive success (Allbrook and Quinn, 2020).

7.6.4.5 Time-lags for population level responses

If management measures successfully reduce human disturbance at a colony, one can anticipate several immediate positive effects. These include an immediate reduction in stress and negative physiological responses, a decrease in nest destruction and predation rates resulting from human disturbance, and a more efficient allocation of energy expenditure. As a direct consequence, an improvement in overall body condition and parental care can be expected, potentially resulting in an immediate increase in annual productivity. In the short to long term, assuming no other threats are impeding progress, distribution expansion, an increase in adult survival rate, recolonisation, and population growth could be anticipated.

7.6.5 Research and monitoring recommendations

7.6.5.1 Pre-implementation of management intervention

Establishing a baseline understanding of the effects from human disturbance on a site and determining the primary source of disturbance affecting seabirds are crucial for understanding the effectiveness of potential management measures. The initial step involves identifying and quantifying the impact of human disturbance on key seabird species. In some cases, this information may be available in existing literature, especially from reserves where this has been monitored previously, or it could be inferred from literature on similar sites or those managed by similar organisations (e.g. RSPB, National Trust for Scotland).

In most cases, however, this information would need to be collected through field studies, utilising traditional field observations to quantify changes in behaviour, parental care, productivity, and/or survival analysis. Experiments monitoring physiology responses can also be conducted. Subsequently, this data can be used to calculate overall human disturbance levels caused by different sources. In some instances, inferring information from similar sites or by comparing plots with different degrees of disturbance may be employed. Alternatively, the optimal approach is to conduct experimental trials to quantify and refine the effectiveness of management measures in terms of reducing human disturbance and benefitting seabirds (e.g. determining the maximum distance a visitor can approach individuals without causing major effects).

7.6.5.2 Implementation of management intervention

Monitoring should take place while the management measures are in place. While there will be specific details to evaluate for each disturbance type and source, the primary objective is to monitor human disturbance (effectively, whether humans comply to management measures), and to determine whether such compliance influences seabird's demography. This requires in-situ observations at various points during the breeding season, with a particular focus during the peak of breeding or when chicks and adults are most vulnerable.

To understand the impact of management measures on the focal seabird species, monitoring should encompass aspects like productivity, behavioural responses, and population counts. Due to the unclear and challenging nature of measuring the impact of human disturbance, which may manifest as physiological changes, and the influence of other threats on seabird demographics, detecting and quantifying the direct effects of reducing human disturbance is challenging. Nevertheless, surveys and counts should be conducted throughout the breeding season, with variables such as the number and growth stage of chicks monitored to estimate annual productivity. Subsequently, statistical analyses should be employed to quantify the effects of the regulations or management measures on seabird productivity and behaviour either by comparing years and/or sites with versus without measures (or those less impacted by human disturbance) and, if applicable, assessing differences between treatments (see e.g. Watson et al. (2014)). Before-After-Control-Impact (BACI) models, for example, are a valuable tool for evaluating the impact of management on seabird populations by comparing data collected before and during management, provided a baseline exists.

Eventually, management measures should be reassessed periodically. For example, if a colony expands towards newly added paths, a decision should be made on whether the paths need to change after a few years or whether the action has already met its objectives, and no further management measures apart from those already there, are needed.

7.6.6 Key considerations, potential barriers, and potential solutions

Key considerations	Potential issues	Potential solutions
Policy/political	While Part 1 of the Land Reform (Scotland) Act 2003 grants everyone statutory access rights to most land and inland water in Scotland, these rights are only active when exercised responsibly, including 'caring for the environment'. Consequently, enforcing some management measures aimed at reducing human disturbance at seabird colonies may not be politically feasible and may only act as guidance, especially when the impact on the seabird is hard to detect. This could potentially reduce their effectiveness.	Employ a combination of management measures to enhance and complement their effectiveness. If needed and applicable, local authorities can formally exempt land from access rights for short periods. Local authorities and some other public bodies could introduce byelaws during the seabird breeding season at colonies.
Legal	Ensure that the proposed management aligns with existing laws and regulations. However, it is important to note that most management measures are guidance only, and not adhering to them may not result in legal repercussions unless the offences violate the Wildlife and Countryside Act 1981 and the Conservation Regulations 1994. Where habitats and/or sites are under protection, permits may be required for certain activities, such as constructing paths or building infrastructure.	Ensure good understanding of legal rights prior and during management implementation. Ensure that permissions are obtained before implementing and enforcing management measures.
Financial	Financial costs associated with human disturbance management measures could encompass various components: Costs of implementing management: • Training and employment/contractor costs (e.g. wardens) • Permits	Funding would need to be secured pre-implementation to ensure that the full scheme can be implemented as planned. Overall costs are likely to be relatively low compared to most other conservation actions.

Key considerations	Potential issues	Potential solutions
	• Infrastructure (paths, signage) • Equipment (binoculars, telescopes, cameras, radios)	
Ecological	An increase and expansion of the population of certain species (e.g. gulls) due to reduced human disturbance following implementation of management measures could increase predation on other species. Risk that compensation proves less effective than expected.	Develop and agree on detailed monitoring plans prior to implementation, including predefined success criteria to evaluate whether the compensation is delivering as predicted. These criteria would then inform any necessary adaptive management required.
Resources	Management measures requiring additional wardens and/or visitor liaison staff will require recruitment and training of staff.	Determine any additional wardening or staffing requirements early during planning to allow for appropriately timed recruitment and training.
Practical and logistical	In some colonies or sections of colonies, managing and monitoring disturbance may not be feasible. For example, wardening may not be practically feasible on uninhabited or remote sites, or in certain parts of cliffs or caves where monitoring and managing marine vessels could be challenging. At certain sites, agreement and cooperation from landowners and site managers would be required to proceed with disturbance reduction. Some management measures, like signs and paths, will require periodic maintenance and updates, especially after periods of adverse weather.	Plan an appropriate management programme tailored to the location and species. Employ a combination of management measures to enhance and complement their effectiveness. Prior to implementation, identify and approach potential landowners and site managers to request permission to work on their land. At this stage, explain the project's goals and the nature of the work, as this may facilitate obtaining permission. Establish a regular maintenance schedule for signs and paths. Use of durable and weather-resistant materials for signs to reduce the frequency of repairs. Develop emergency response plans to address immediate repairs or

Key considerations	Potential issues	Potential solutions
		updates needed after severe weather events.
Other – Social	Open-air recreation can provide health benefits and can boost local economy. Providing access and proximity to wildlife can yield conservation revenue and also increase public appreciation of, and support for, conservation. Certain management measures, such as capping daily visitor numbers, may result in a decline in the total number of visitors, which could negatively impact education and limit appreciation of wildlife. Since the impacts of human disturbance on seabirds can be unclear (e.g. changes in cardiac rhythm), some people may not understand or be willing to comply with the imposed management measures.	Plan an appropriate management programme tailored to the location and its visitors, and residents. Employ a combination of management measures to enhance and complement their effectiveness. Offer environmental education and engage with visitors to raise awareness and foster understanding of the management measure and its key objectives. If management were to be conducted within a reserve, consider adding posters or signs explaining the ongoing management measures.
Other – Additionality	Existing guidelines, such as the Scottish Outdoor Access Code, Scottish Marine Wildlife Watching Code, Guide to Best Practice for Watching Marine Wildlife, and Scottish Drone Regulations, provide recommendations for behaviour around wildlife in Scotland to minimise human disturbance. Moreover, many of the proposed management measures are already implemented at reserves, including SPA colonies. Hence, most management measures are either already in place or should be. This is likely to be less of an issue for non-SPA colonies, colonies in remote locations with minimal visitor influx, and those outside protected areas.	Ensure coordinated approaches with those organisations responsible for management of protected sites (e.g. RSPB, NatureScot, and National Trust for Scotland). Undertake legal review to confirm position with respect to additionality.

Key considerations	Potential issues	Potential solutions
Other – Effectiveness will be hard to quantify	Changes in behaviour caused by human disturbance can be difficult to detect and to measure, especially when there are other variables that could be contributing to low productivity and survival. Therefore, monitoring the efficacy of the management measure can be extremely challenging, characterised by significant uncertainty.	Design and implement appropriate monitoring schemes that address this issue.

7.6.7 Species-specific aspects of implementation

The implementation of disturbance reduction management measures is mostly site-specific and will generally not vary between the focal species.

7.6.8 Overall conclusion

Different management measures would bring varying benefits to focal species. For instance, large gulls are likely to benefit most from UAV management, assuming these are causing significant disturbance. Guillemot and Razorbill, on the other hand, stand to gain the most from any form of human disturbance reduction, whether on land, at sea, or by UAVs. Puffin are expected to benefit primarily from visitor management measures that prevent burrow trampling and are unlikely to experience significant benefits from at-sea and UAV management.

An important consideration in this conservation action is additionality. Existing guidelines, such as the Scottish Outdoor Access Code, Scottish Marine Wildlife Watching Code, Guide to Best Practice for Watching Marine Wildlife, and Scottish Drone Regulations, provide recommendations for behaviour around wildlife in Scotland to minimise human disturbance and should be applied by all visitors across Scotland. Moreover, many of the proposed management measures are already implemented at reserves, including SPA colonies. Hence, most management measures are either already in place or should be. This conservation action might be one of the cheapest to undertake and would require less planning compared to most of the other conservation actions considered.

Since the effect of human disturbance at colonies on seabird demographic parameters is unclear and challenging to quantify, there is considerable uncertainty about whether implementing this action would effectively mitigate the impacts of offshore windfarms. It is difficult to ascertain whether this conservation action would work effectively as a strategic compensatory measure.

7.7 Practical feasibility: Bycatch mitigation in longline fisheries

7.7.1 Summary

This section focusses on bycatch mitigation in floated demersal longline fisheries. The focal species is Gannet with Fulmar listed as a secondary species.

Table 50. Summary of practical feasibility for bycatch mitigation in longline fisheries. Further detail is provided following the table.

	Bycatch mitigation in longline fisheries
Description	The reduction of incidental mortality of seabirds occurring during longline fisheries operations. This includes gear adaptations (e.g. change in hook designs or weights to increase sink rates); operation adaptations (e.g. changes to how offal is discarded); or management changes (e.g. area or time closures). The highest rates of seabird bycatch in Scottish fisheries are in the floated demersal longline fishery (primarily targeting Hake), so this action focusses on mitigation in this fishery.
Uncertainty	There is high uncertainty in the current level of bycatch mortality, meaning that the potential scale of benefit from bycatch mitigation is not possible to quantify with high confidence. However, for some species bycatch levels are significant, so population level benefits are likely to occur following enhanced bycatch mitigation. The longline fishery operating in Scottish Waters uses a unique gear (floated demersal longlines), for which there has been few bycatch mitigation trials conducted. Therefore, there is uncertainty on what bycatch mitigation methods may be most appropriate for this fishery. However, candidate options can be identified based on work in similar fisheries and limited existing work in this fishery, but further trials would be required with an adaptive management approach to improve mitigation over time. UK registered vessels comprise a minority of the fishery. Therefore, significant bycatch mortality could continue if mitigation measures are not implemented across all vessels (UK and non-UK). While there is high confidence that Fulmar would benefit and Gannet to a lesser extent, apportioning this benefit to individual SPAs would generally not be possible.
Species benefitting For detail see: Ecological effects of implementing action	The primary impact of bycatch is by mortality of adult or juvenile seabirds, secondary impacts include potential for sub-lethal impacts for surviving birds (e.g. physical injury), and reduced productivity (resulting from loss of parent birds). Bycatch is also an animal welfare concern, both through mortality and injury (hooked birds that are released alive).

	Bycatch mitigation in longline fisheries
	Focal species: Moderate benefit likely to Gannet colonies along west and north of Scotland via reduced adult mortality rates. Low benefit to east coast Gannet colonies. Other seabird species: Significant benefit likely to Fulmar colonies along west and north coast of Scotland via reduced adult and juvenile mortality rates, with low benefit to Fulmar at east coast colonies. Great Shearwater and Great Skua have been recorded as bycatch in this fishery in lower numbers, some benefit is therefore likely to both species.
Scale and degree of population benefit	Impact on Gannet: **Scale**: Local and Regional. **Degree of benefit**: Will range from small effect to moderate effect for western and northern colonies (including Shetland and Orkney), dependent on the bycatch rates for birds originating from each colony. For east coast colonies effect is likely to be negligible. At a medium to long term, potential for: • Slight increase in population growth rates with potential for more rapid recovery for HPAI impacted populations. Impact on Fulmar: **Scale**: Local and Regional. **Degree of benefit**: Will range from small effect to strong effect for western and northern colonies (including Shetland and Orkney), dependent on the bycatch rates for birds originating from each colony. For east coast colonies effect is likely to be negligible. At a medium to long term, potential for: • Lower rate of population decline and potential to arrest decline and have slow recovery in population size.
Sequence of steps to implement For detail see: Steps for implementation	1. Pre-implementation of action: • Establish baseline – refine estimates of bycatch rates and understanding of current bycatch mitigation practice. • Determine mechanism for establishing enhanced bycatch mitigation programme. Establish an associated oversight group with decision making responsibility. • Initiate bycatch mitigation trials. • Agree initial bycatch mitigation measures to apply. • Agree objectives for the bycatch mitigation programme. 2. During implementation: • Put in place the enhanced bycatch mitigation programme designed in step 1.

	Bycatch mitigation in longline fisheries
	• Put in place enhanced vessel monitoring. • Undertake further bycatch mitigation trials. • Initiate any seabird colony monitoring agreed. 3. Post-implementation of action: • Continue with the programme established in step 2. • Update bycatch mitigation requires as required.
Monitoring summary For detail see: Research and monitoring recommendations	Improved baseline bycatch monitoring through increased observer programme complemented by remote electronic monitoring. Providing higher precision in bycatch estimates and allowing better quantification of pre- and post-mitigation rates. Bycatch mitigation trials to quantify bycatch rates and identify the most effective mitigation methods. Seabird population responses to be tracked through regular seabird colony counts and ideally through adult survival studies (RAS).
Bycatch mitigation options For detail see: Bycatch mitigation options	There is a need for trials to determine which bycatch mitigation methods are most effective and suitable in this fishery. However, the following are identified as some potential options: • Night setting – effective for many species, though may be less effective for Fulmar which are active at night including around fishery vessels. • Bird scaring lines – a visual deterrent that reduces seabird activity in the risk zone when the baited-hooks are nearest the surface prior to sinking. • Increasing sink rates – likely to be one of the most effective methods, as this reduces the time when baited hooks are accessible to seabirds. Can also increase efficacy of bird scaring lines when used together.
Key considerations For detail see: Key considerations, potential barriers, and potential solutions	**Policy**: Need to align with existing policies and commitments around bycatch mitigation. **Ecological**: Quantification of population level benefits is not currently possible with high confidence due to wide confidence intervals around bycatch rates (arising from currently low monitoring effort). **Resources**: Compliance and monitoring arrangements would need to be put in place to ensure compliance with mitigation requirements. **Additionality**: Need for consideration of status with respect to additionality with existing policy commitments. Need to better understand what mitigation is currently used, so that it is clear what mitigation is additional to existing practice.

	Bycatch mitigation in longline fisheries
	International: A high proportion of floated demersal longline vessels operating in Scottish Waters are non-UK registered. If mitigation programme is restricted to UK registered fleet, significant bycatch mortality would remain.
Conclusion	An enhanced bycatch mitigation programme (for floated demersal longline fisheries) should be considered as a compensatory measure. It could bring significant population level benefits to Fulmar and potentially some benefit to Gannet. There are several important uncertainties and key considerations that would need to be resolved including how mitigation measures could be required for both UK and non-UK vessels (which are the majority) and its status with respect to additionality. However, as mitigation has been applied to effectively reduce bycatch in other longline fisheries globally, it should be practically feasible to apply to the fleet operating in Scottish Waters. If applying as compensation this could bring funding to support a more strategic approach with a coordinated programme of monitoring, mitigation trials, and funding for any gear modifications.

7.7.2 Background

The incidental bycatch of seabirds by fisheries has been assessed as one of the top three threats to seabird species globally, and the threat with the greatest average level of impact (Dias et al., 2019). Longline fisheries, in particular, have a high risk of seabird bycatch (Anderson et al., 2011) which has been most well studied in albatross and petrel species in the southern hemisphere with significant knowledge gaps for longline fisheries operating in the North-East Atlantic. Seabirds are attracted to fishing vessels for offal, bait, discards, and for the catch itself, depending on the fishery and the seabird species. Concerns of the potential for bycatch to impact UK breeding seabirds have prompted a series of studies. Initially, vulnerability assessments were conducted using fishery gear parameters and seabird species sensitivity (Bradbury et al., 2017). Subsequently, fishery observer programmes were established, along with assessments to quantify levels of bycatch mortality (Northridge et al., 2020; Kingston et al., 2023).

Miles et al. (2020) used the bycatch estimates of Northridge et al. (2020) to assess the potential for population level impacts. They found significant impacts from longline fisheries on Fulmar and Gannet, where it was estimated that the population could be up to 7% and ca. 1% larger in the absence of bycatch, respectively. This led to a further analysis on bycatch hotspots in UK fisheries (Northridge et al., 2023), which identified longline fisheries operating along the shelf edge west and north of Scotland as leading to significant mortality of Fulmar. Following this work, the Scottish Government commissioned a detailed study on bycatch in longline fisheries in Scotland, focussed on Fulmar (Kingston et al., 2023). This study confirmed significant levels of bycatch, although it produced lower estimates compared to Northridge et al. (2020).

Alongside research and monitoring, policies regarding seabird (and other wildlife) bycatch have been evolving over the past decade. This to support existing commitments around monitoring and to minimise bycatch included in the UK Marine Strategy (DEFRA, 2019), the Conservation of Habitats and Species Regulations (UK Government, 2017), and under the OSPAR Convention (OSPAR, 1992). This was brought together at a UK level under the Marine wildlife bycatch mitigation initiative (DEFRA, 2022), which outlined five policy objectives:

1. "Improve our understanding of bycatch and entanglement of sensitive marine species through monitoring and scientific research.
2. Identify "hotspot" or high-risk areas, gear types and/or fisheries for bycatch and entanglement in the UK in which to focus monitoring and mitigation.
3. Develop, adopt, and implement effective measures to minimise and, where possible, eliminate bycatch and entanglement of sensitive marine species.
4. Identify and adopt effective incentives for fisheries to implement bycatch and entanglement mitigation measures.
5. Work with the international community to share best practice and lessons learned to contribute to the understanding, reduction and elimination of bycatch and entanglement globally."

Seabird tracking data, when combined with fishery vessel tracking information (either from vessel monitoring system or automatic identification system data), provides insights into the seabird ecology that influences bycatch risk. Gannet are attracted to fishing vessels, which changes their behaviour when in the vicinity of vessels (Votier et al., 2010). Similarly, foraging distributions of Fulmar are associated with fishing vessels, with over half of individuals showing this association, although this was predominantly for trawl-type vessels (Darby et al., 2021). Studies using light-level sensors on Fulmar demonstrate that they also interact with fishing vessels at night (demonstrated by the detection of artificial light at night) and over the winter, including higher concentrations of interactions to the north and west of Scotland (Dupuis et al., 2021). The frequency of vessel interactions (as detected by artificial light at night) has increased over the past two decades, which could increase bycatch risk (Darby et al., 2023).

The primary longline fishery operating in Scottish Waters uses floated-demersal longlines (also referred to as 'piedra bola') to target European Hake (*Merluccius merluccius*). This gear is composed of longlines with a series of baited hooks interspersed with weights and floats that act to hold the hooks up above the seabed (Figure 31). Recently, the sink rates of the gear in Scottish longline fisheries has been investigated (Rouxel et al., 2022). Authors showed relatively slow sink rates (mean <0.1 ms^{-1} at the surface from 0-2 m depth for the centre point between the floats and hooks), which is below international guidance (>0.3 ms^{-1}) (ACAP, 2023).

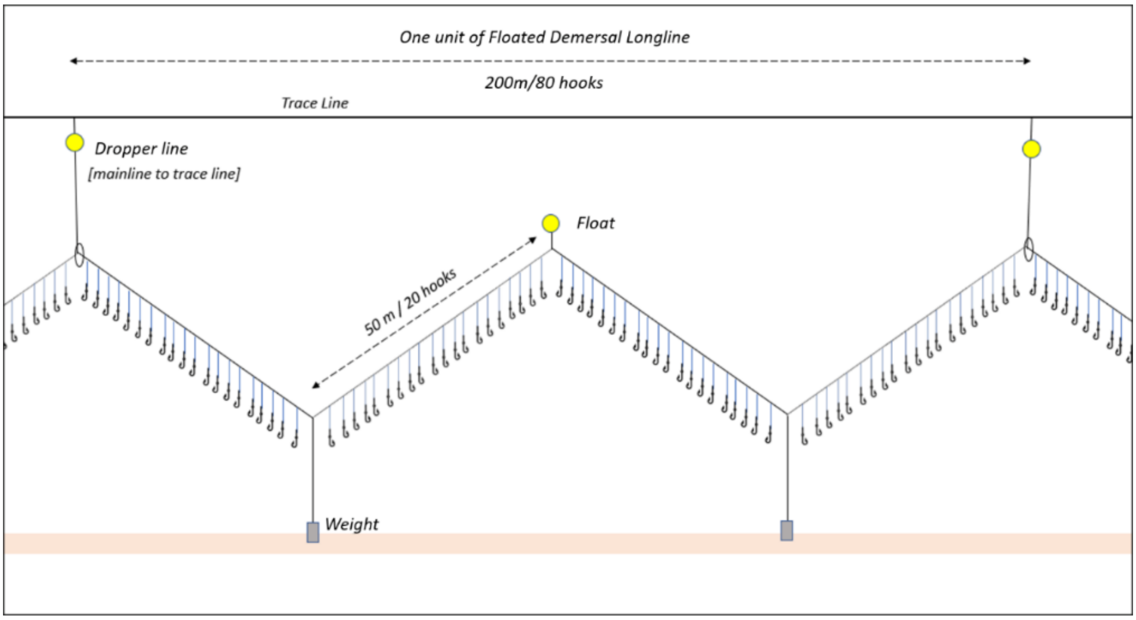

Figure 31. A schematic diagram showing the typical gear configuration of floated demersal longlines (also known as 'piedra bola') used in Scottish Waters to target European Hake. The gear is composed by a sequence of floats, weights, and baited hooks between these that sit above the seabed. Reproduced from Rouxel et al. (2022).

Given the concerns around seabird bycatch, various mitigation options have been developed. For UK operating fisheries, including longlines, bycatch mitigation options were reviewed by Anderson et al. (2022). For the floated demersal longline fisheries specifically, mitigation options were reviewed by Kingston et al. (2023). International best practice recommendations have been developed by the Agreement on the Conservation of Albatrosses and Petrels for pelagic and demersal longline fisheries (ACAP, 2023). Though many bycatch mitigation options have been identified (for further detail see Bycatch mitigation options below), only a few have been trialled in the floated demersal longline fishery operating in Scotland, which leads to uncertainty on which may be most effective.

The floated demersal longline fishery primarily targets European Hake and, to a lesser extent, other demersal fish (principally Ling, *Molva molva*). Hake is a shared stock between the UK and neighbouring states. For the stock shared between the UK and EU (representing most of the Scottish Waters for the fishery), in the North Sea (UK/EU Waters of ICES areas 2a and 4) 46% is allocated to UK vessels, while to the northwest (UK/EU Waters of ICES areas 6 and 7 and international waters of areas 5b, 12, and 14), 20% is allocated to UK vessels (DEFRA, 2023b). The UK longline fleet typically is comprised of 10 to 15 vessels each year (though the total number of vessels since 2010 is ca. 40, but this number is thought to be misleading given changes in the ownership and names of vessels and operators) (Kingston et al., 2023). As such, the UK registered fleet represents a significant, but not majority, component of vessels operating in Scottish Waters. This is important to consider both in terms of bycatch monitoring and mitigation, where this focusses only on UK/Scottish registered vessels.

We now have an understanding on the threats that bycatch in longline fisheries could pose to seabirds in the UK, policy commitments to reduce and eliminate bycatch where possible and potential bycatch mitigation options identified. However, there is still substantial uncertainty in bycatch estimates due to low monitoring effort, meaning that we cannot currently confidently quantify the population level impacts. There has also been some work on developing bycatch mitigation for Scottish longline vessels, so while there are a number of promising options, further work is required to develop best practice approaches. These points are developed further in the rest of this section.

7.7.3 Steps for implementation

The following steps focus on UK registered vessels. For non-UK registered vessels there would need to be coordination with the countries from which those boats are registered, though the broad approach would be similar.

1. **Pre-implementation:**
    1.1. Establish baseline: Refine estimates of bycatch rates and understanding of current bycatch mitigation practice.
    - Refine estimates of bycatch rates by enhanced monitoring (see Research and monitoring recommendations) with a high proportion of trips including observers and deploying observers using a stratified sampling approach (i.e. a less opportunistic sampling approach). Also, introduce remote electronic monitoring for all vessels. Note, initial work on this could commence immediately but this would continue through implementation and establishment of baseline should not delay trials.
    - Determine current bycatch mitigation practice. This is important context both for bycatch rates (i.e. to determine to what extent these rates are with some mitigation applied), and to understand what mitigation could be considered over and above existing practice (i.e. additional).

    1.2. Agree initial bycatch mitigation measures to apply.
    - Some bycatch mitigation measures may have sufficient evidence to apply immediately, e.g. use of bird-scaring lines (see Bycatch mitigation options), although some of these mitigations may already be in place for some (potentially all) vessels.

    1.3. Determine mechanism for establishing enhanced bycatch mitigation programme for floated demersal longline fisheries.
    - An enhanced bycatch mitigation programme should be developed to allow for continuous improvement. International best practice recommendations should be followed (see Good et al. (2020)).
    - Consider options to secure enhanced bycatch mitigation programmes, potential options include:
        - Voluntary approach – through a collaborative approach with the fleet, with uptake of mitigation measures being voluntary. This could foster a more collaborative environment, but mitigation measures may not be taken up by the whole fleet, leading to reduced overall mitigation and potential to undermine initiative due to lack of a level playing-field

between vessel operators. There would be a significant risk that the scheme would not ensure the long-term implementation of bycatch mitigation. This approach would require an auditing mechanism (underpinned by monitoring) to have confidence that all operators are following whatever approach is agreed to.

- Regulatory approach – this could be via licence conditions or other approaches (e.g. spatial management measures). This would provide a compliance mechanism. It would also help ensure all UK vessels/ and or vessels operating in Scottish/UK waters (depending on how it was implemented) are held to a common standard (level playing-field). However, this could lead to reduced goodwill from vessel operators if they feel it is imposed, reducing sense of agency. This could reduce scope for bycatch mitigation trials which are essential for continuous improvement. The mechanism would determine which vessels are subject to the bycatch mitigation requirements, e.g. licence conditions would only apply to UK registered vessels (though there may be potential for these conditions to be mirrored by other fishery licensing authorities), while area-based measures could apply to all vessels operating in an area but may take longer to develop, and what is possible may be limited outwith designated MPAs.
- In both cases an oversight group should be established including SNCBs, relevant stakeholders, industry representatives, and those with relevant scientific expertise. The oversight group would be responsible for making key decisions within the initially established framework for the enhanced bycatch mitigation programme.

1.4. Agree objectives for the bycatch mitigation programme.
- Specific and measurable objectives should be set for minimising bycatch (see Good et al. (2020) and Sharp (2016)).

1.5. Initiate bycatch mitigation trials.
- Trials could be undertaken both pre- and post-implementation of establishment of an enhanced bycatch mitigation programme. There are benefits in initiating trials at an early stage as this could allow more rapid reduction in bycatch once the programme is put in place. For details on trials see below.

2. Implementation of enhanced bycatch mitigation programme for longline fisheries:

2.1. Put in place the enhanced bycatch mitigation programme designed in the pre-implementation phase. The steps required for this will vary depending on the type of programme to be adopted, e.g. a voluntary or regulatory based approach.
2.2. Put in place enhanced vessel monitoring (see monitoring).
2.3. Consider enhanced colony monitoring for target seabird species (see monitoring).
2.4. Put in place initially agreed bycatch mitigation.
2.5. Undertake bycatch mitigation trials (see monitoring).
2.6. Establish compliance arrangements.

3. **Post-implementation:**
    3.1. Continue monitoring put in place in earlier steps.
    3.2. Continue bycatch mitigation trials.
    - Informed by agreed objectives, continue programme of bycatch mitigation trials until bycatch is reduced to agreed level.

    3.3. Update bycatch mitigation requirements as required.
    - Based on monitoring and bycatch mitigation trials, update bycatch mitigation requirements.

    3.4. Have ongoing compliance arrangements in place, with incentives (positive or negative) for full implementation of agreed mitigation.

7.7.4 Ecological effects of implementing action

The ecological background is covered further in the background section above and in the underpinning targeted review (see Bycatch mitigation in longline fisheries). These demonstrate that current bycatch rates are substantial for some species and that there are well proven successes in reducing bycatch rates of seabirds, so beneficial ecological effects are anticipated. Bycatch is also an animal welfare concern, both through mortality and injury (hooked birds that are released alive). The level of sub-lethal impacts for surviving birds (e.g. physical injury and stress) is not known with monitoring currently only recording dead birds. This could be substantial so could increase the population level benefit from bycatch mitigation compared to that anticipated if solely considering direct mortality levels.

7.7.4.1 Fulmar

The biggest benefits from bycatch mitigation in the longline fishery would accrue to Fulmar, where bycatch mortality is high (>1000 individuals/year for UK registered vessels) (Kingston et al., 2023). As bycatch mortality primarily affects adult and sub-adults at sea, its impact on the population is more significant to if it were predominantly young birds (Miles et al., 2020).

The fishery primarily operates along the shelf break along the west and north-west of Scotland and around the Shetland Isles. Fulmar have very extensive foraging ranges, suggesting that any UK breeding Fulmar could be bycaught in this fishery. However, given proximity and core forage range we would anticipate benefits to be greatest for Fulmar populations breeding along the west coast of Scotland and in the northern Isles with less benefit to colonies along the east coast of Scotland. However, as the fishery operate year-round, during the non-breeding season when Fulmar are less tied to their breeding colonies populations will be more mixed.

7.7.4.2 Gannet

Bycatch levels of Gannet in the longline fishery are substantially lower than for Fulmar but still at potentially significant levels in population terms (ca. 100 individuals/year in UK registered vessels) (Kingston et al., 2023).

In common with Fulmar, Gannet have wide foraging ranges, but given the distribution of the fishery, Gannet populations along the west coast of Scotland and in the north of Scotland would stand to benefit most with much lesser benefit to east coast populations.

7.7.4.3 Other species

Smaller numbers of bycatch have been recorded for Great Skua and Great Shearwater so there would be some benefit to these species from bycatch mitigation. Given recent significant mortality in Great Skua following the HPAI outbreak this source of additional mortality could be more significant, so bycatch mitigation could have population level benefits. Great Shearwater breed in the South Atlantic, so birds present in Scottish Waters will either be birds on migration or non-breeding sub-adults.

7.7.4.4 Time-lags for population level responses

As bycatch mortality acts directly on the adult populations of Gannet and Fulmar, reducing bycatch mortality can have near immediate population level benefits. However, as noted above, bycatch mitigation methods have only been trialled to a limited extent in the floated demersal longline fishery. Therefore, it could take a few years of trials and monitoring to arrive at the most effective bycatch methods. As such while reducing seabird mortality from bycatch would have immediate population level benefits, the effectiveness of bycatch mitigation should improve over the first few years post-implementation of a bycatch mitigation programme.

7.7.5 Research and monitoring recommendations

7.7.5.1 Bycatch monitoring (throughout)

Bycatch monitoring should follow standard practices (e.g. Dietrich et al. (2007)). This would best be done by building on the existing monitoring under the UK Bycatch Monitoring Programme[5], but with significantly increased coverage (coverage should be >20%, and ideally higher, to allow accurate quantification of bycatch rates, Babcock et al. (2003)). Incorporating remote electronic monitoring with cameras (see Kindt-Larsen et al. (2012); (WWF-UK, 2017)) could provide more complete coverage and allow more efficient use of observer time.

Remote electronic monitoring should be rolled out as standard on vessels using this gear and will be important for monitoring the efficacy of mitigation measures at minimising bycatch and improving understanding of bycatch rates. This will be best achieved with some human observer support to verify certain activities in the startup process. Given the relatively small number of vessels involved in this fishery all vessels should be covered. Acceptance of observers should be mandatory with mandating of REM use on vessels using this gear in Scottish Waters, this would ensure full coverage and reduce potential for any biases in monitoring (i.e. systematic biases where coverage is incomplete/only on subset of fleet).

With improved monitoring data, more detailed analyses will be possible to refine understanding on risk factors, e.g. locations, season, time of day; these can inform on which mitigation options may be most effective.

7.7.5.2 Bycatch mitigation trials

Bycatch mitigation trials should test mitigation methods under a variety of conditions. The data to collect in trials will mostly be the same as for regular bycatch monitoring, although some additional data may be collected depending on the method (e.g. sink-rates when using weighting). Bycatch mitigation trials should be carried out in a scientifically robust way (e.g. use of paired-trials). The ACAP review process is useful to consider here (see pages 8-9 in Petrels (2021)).

7.7.5.3 Seabird population monitoring

The key monitoring with respect to seabirds is the assessment of bycatch rates. However, to help understand population level impacts and any population response post bycatch mitigation, colony monitoring would be useful to inform on any changes to the population trajectories of colonies identified as likely to benefit. It may be possible to detect differences between pre- and post-mitigation for colonies in areas likely to experience higher bycatch than other areas (i.e. a BACI type design), though unless there is a very strong response it may not be possible to separate this out from other factors.

To better understand the demographic effects of bycatch and any changes in this pre/post application of mitigation, measuring annual survival rates for different age classes and sexes would be useful. Previous studies have shown that in many species bycatch rates are higher for adult males than other population components (Gianuca et al., 2017). This would follow standard recapture/resighting adults for survival (RAS) methods.

7.7.6 Key considerations, potential barriers, and potential solutions

Key considerations	Potential issues	Potential solutions
Policy	Must work with and be compliant with existing bycatch mitigation policy objectives (summarised in Background above). Potential for concerns from industry if bycatch mitigation requirements are set without their consent.	Ensure that an enhanced bycatch mitigation programme (for floated demersal longline fisheries) if implemented as a compensatory measure is compliant with and works in tandem with existing policy objectives (also see Other – Additionality below). Take a collaborative approach to developing a bycatch mitigation programme and use formal and informal consultation as relevant.
Legal	Additionality issues (see below).	
Financial	Enhancing monitoring would have financial costs through more observer time and/or the purchase, installation, and processing of remote electronic monitoring data. Bycatch mitigation trials will have costs both in preparation, running	The UK operating floated demersal longline fleet is relatively small (ca. 10-15 vessels operating each year, see Kingston et al. (2023)) which reduces the overall costs of rolling out bycatch mitigation and enhanced monitoring for this fleet.

Key considerations	Potential issues	Potential solutions
	the trials, and subsequent analysis and write-up of findings. Bycatch mitigation options requiring gear changes would have costs in replacement of previous gear. Bycatch mitigation could reduce target catches, depending on type of mitigation used.	Costs could potentially be fully or partially funded by those proposing this as a compensatory measure. Use of bycatch mitigation trials and associated monitoring should help select mitigation options that minimise any negative impacts on target catches. Reducing bycatch and loss of bait to seabirds could reduce costs for the fishery and has been another driver of reducing bycatch (Kühn, 2016).
Ecological	There is uncertainty in the overall population level benefits from reducing bycatch to specific breeding sites (e.g. SPAs) as where bycaught birds originate from is not known. Quantifying the benefit in terms of reduced mortality from applying mitigation measures would have high uncertainty. This is due to high uncertainty in current bycatch rates and the extent to which any given bycatch mitigation measure would reduce bycatch.	Further research on foraging distributions and movements would improve our ability to apportion bycaught birds to colonies of origin, however the relevant species (Gannet and Fulmar) have very wide foraging ranges and extensive movements during the non-breeding season. It is more possible to allocate benefits to a wider region (e.g. west coast versus North Sea populations). As such, supporting the wider SPA network for the relevant species rather than for specific SPAs would be a more appropriate objective. There is high confidence that bycatch rates could be reduced significantly though mitigation methods. However, trials are needed to identify which bycatch mitigation methods have most benefit. Enhanced monitoring pre- and post-implementation of additional (to any already applied) mitigation measures will increase ability to quantify benefits.

Key considerations	Potential issues	Potential solutions
Resources	Enhanced monitoring with associated compliance mechanism and bycatch mitigation trials would require fisheries observers and scientists.	There are existing observers through the UK Bycatch Monitoring Programme[5] but these would be insufficient for a wider programme, so additional observers would need to be recruited and funded. Use of remote electronic monitoring could replace some, but not all, observer functions. However, this would be crucial in any associated audit or compliance. REM would also allow observer time to be used more efficiently. For bycatch mitigation trials there would be potential to work with academic and ENGO partners. There are existing fishery compliance arrangements, but these may need additional resources, and as the fleet is relatively small this would be limited.
Other – Additionality	For measures to be additional they must be over and above current practice. Anecdotally, some bycatch mitigation measures are implemented by the floated demersal longline fleet. Some bycatch mitigation trials, and development are also ongoing (via the Coordinated Development and Implementation of Best Practice in Bycatch Reduction in the North Atlantic Region project - CIBBRiNA).	The recommended monitoring approach would improve our knowledge of the current baseline (including both current levels of bycatch and of what mitigation is in place), such that it can be transparent what is additional to existing practice. Undertake a legal review to understand whether bycatch mitigation can be undertaken as a compensatory measure.

Key considerations	Potential issues	Potential solutions
Other – International	A high proportion of the floated demersal longline fleet are non-UK registered vessels (see Background). If bycatch mitigation is only applied to UK registered vessels, then overall bycatch mortality could still be at high levels.	Coordinate with EU (which has an Action Plan for reducing incidental catches of seabirds, European Commission (2012)) and non-EU states using floated demersal longlines to implement bycatch mitigation measures. There would be significant benefits in sharing monitoring and mitigation trial findings to develop best practice methods. International standards could increase compliance rates and provide a level playing field across the industry.
Other – Health and safety	There are significant dangers to fisheries operations which could potentially be increased by bycatch mitigation requirements if not carefully designed. Bycatch observers and scientists are at higher risk than experienced fisheries staff when working offshore due to being unfamiliar with vessels and generally having less at sea experience.	Ensure fishery is consulted during the design of new mitigation methods to minimise any potential for additional risks. In bycatch trials include recording any health and safety issues, to allow mitigation options to be improved to reduce risks, and where appropriate eliminate mitigation options that lead to unacceptable dangers that cannot be sufficiently reduced. Ensure all observers and scientists complete all required training (e.g. Sea survival/Personal Survival Techniques) and are equipped with personal protective equipment.

7.7.7 Species-specific aspects of implementation

Bycatch mitigation methods will generally benefit all seabird species bycaught within the demersal longline fishery. However, it should be noted that the effectiveness of the methods will vary depending on the species.

7.7.8 Bycatch mitigation options

To reduce bycatch risk, mitigation options must counter the risk factors influencing bycatch rates. Key risk factors for longlines include:

- Time of day – bycatch risk is generally reduced when gear are set at night, however this may not be the case for Fulmar which are active also at night (Dupuis et al., 2021; Darby et al., 2023).
- Location – bycatch risk will be highest where fisheries operate in core foraging areas of seabirds. Gannet and Fulmar have long foraging ranges meaning that most of Scottish Waters will be within foraging range during the breeding period, though bycatch risk may be higher when vessels operate in core foraging areas.
- Sink rate – baited hooks are only accessible to seabirds when close to the sea surface, therefore if gear sinks slowly it will be accessible to seabirds for a longer period increasing bycatch risk (Rouxel et al., 2022).
- Hook type – birds may be more likely to become caught on some designs of hooks than other.
- Bait type – certain bait will be more attractive to seabirds and the risk of being hooked will also vary by bait type.
- Offal handling practices – how offal is handled and discarded by vessels will affect when and how seabirds are attracted to vessels (though they are also attracted for the bait itself). Changes in handling practice may reduce bycatch risk.

Bycatch mitigation options fall into three main types:

1. Gear adaptations – include any modifications to the fishing gear itself, e.g. change to weights, but also associated physical mitigation, e.g. bird-scaring lines.
2. Operational adaptations – these include changes to when and how gear are deployed, e.g. setting gear at night to reduce risk to diurnally active seabirds.
3. Management options – these include restrictions on when and where fisheries can be active, including seasonal spatial closures.

Bycatch mitigation options for UK operating fisheries, including longlines, were reviewed by Anderson et al. (2022). Specifically for the floated demersal longline fisheries, that are the subject of this account, mitigation options were reviewed by Kingston et al. (2023). International best practice recommendations have been developed by the Agreement on the Conservation of Albatrosses and Petrels for pelagic and demersal longline fisheries (ACAP, 2023). National and international[15] databases of bycatch mitigation methods also exist. In the below table (Table 51) we provide a summary of key options (for further details and options see the cited references). It is important to note that many bycatch mitigation options are possible to use in parallel, and bycatch will generally be best reduced through using a combination of mitigation options. Some mitigation options may also enhance the effect of others, for example increasing the sink-rate will also increase the effectiveness of bird-scaring lines by increasing the proportion of baited hooks at accessible depths (i.e. prior to sinking) that are covered by the scaring lines (Rouxel et al., 2022).

[15] Bycatch Management Information System. NB this is focussed on oceanic tuna and billfish fisheries but some techniques may be transferable.

Table 51. Summary of bycatch mitigation options for floated demersal longline fisheries (selected measures only). These are examples of potential measures rather than a list of recommended options.

Bycatch mitigation measure	Class of measure	Description	Note on potential for use in Scotland
Night setting	Operational adaptation	Set gear at night when diurnally active seabird species are less active.	It may not be effective, or even counterproductive, for Fulmar which have been shown to be active at night in the vicinity of fishing vessels (Dupuis et al., 2021). It may not be practical at high latitudes with only short periods of night in summer (and much of this still under twilight conditions), while in winter short daytime may necessitate night setting.
Bird-scaring lines (also known as 'streamer lines' and 'tori lines')	Gear adaptation	Visual deterrent lines held above the longlines during gear deployment. These reduce interactions of seabirds with baited hooks during the most sensitive period when these are close to the surface (i.e. before sinking out of reach) with the scaring lines extending ca. 100 m (depending on configuration) behind the vessel reducing.	It is reported that these lines are already used on some vessels in Scotland, so there may be limited potential to use as an additional measure. Bird-scaring lines have been demonstrated to reduce bycatch rates of Fulmar in demersal longline fisheries in Norway (Løkkeborg and Robertson, 2002). Due to low sink-rates baited hooks may remain close to the surface for several hundred meters behind vessels beyond the extent of the bird-scaring lines, limiting the effectiveness of the scaring lines (Rouxel et al., 2022). Were sink rates increased the efficacy of this mitigation measure would be expected to increase.
Increasing sink-rates	Gear adaptation	Increasing the rate at which the hooks sink to reduce the time spent at	The sink rates of existing gear in the floated demersal longline fishery were

Bycatch mitigation measure	Class of measure	Description	Note on potential for use in Scotland
		the riskiest depths for bycatch (close to the sea surface), by changing the configuration of weights and floats used.	explored by Rouxel et al. (2022). Increasing the sink rates for floated demersal longlines is more challenging than for standard demersal longlines, however it is feasible to do. This is likely to be one of the most effective measures when paired with bird-scaring lines (see above).
Spatial and seasonal closures	Management options	If bycatch rates are particularly high in certain regions in specific seasons, then bycatch could be reduced by seasonal spatial closures.	The foraging distribution of Fulmar in particular and to a lesser extent Gannet, is concentrated along the shelf edge which is the key area where the longline fishery operates. Given this spatial overlap, spatial closures may not be feasible.
Swivel-hooks	Gear adaptation	Replacing fixed hooks with swivelling hooks may reduce the chance of bycatch when birds are attempting to take bait from hooks.	A study in Norway demonstrated a large reduction in bycatch rates of Fulmar when swivel hooks were used instead of fixed hooks (Fangel et al., 2016). This was for a different fishery (demersal longline fishery) but the same principles likely would apply.

7.7.9 Overall conclusion

Bycatch rates have been assessed to be significant for some species (notably Fulmar) in the floated demersal longline fishery in Scotland. Bycatch mitigation measures have dramatically reduced bycatch rates in many longline fisheries worldwide, so it is likely that bycatch rates could be significantly reduced with consequent population level benefits for impacted species. As such, an enhanced bycatch mitigation programme could be suitable as a compensatory measure. However, there are some issues that need to be considered in its use as compensation.

Bycatch rates can only be quantified with wide confidence intervals currently due to low monitoring effort. This limits our capacity to quantify, with confidence, the potential population level benefits from a bycatch mitigation programme. Improving monitoring would be a priority as part of a coordinated enhanced bycatch mitigation programme. Based on currently available evidence, the benefits to Gannet could be relatively low, however, benefits for Fulmar are likely to be significant. Similarly, although many potential bycatch mitigation options have been identified, few have been trialled in floated demersal longline fisheries operating in Scotland. There is therefore uncertainty on which measures would be most effective and of how much each would reduce bycatch rates. However, the benefits of enhanced bycatch mitigation are likely to be significant.

There may be issues in implementing as compensation given existing bycatch reduction policies and commitments, i.e. its status with respect to additionality. However, there are potential benefits of implementing as compensation, as this could give a source of finance for monitoring, bycatch mitigation trials, and for any resulting costs in changes to gear or operating procedures.

The UK registered component of the floated demersal longline fleet operating in Scottish Waters is in the minority, so bycatch levels could not be fully reduced without international coordination (or potentially area-based restrictions) to ensure all vessels operating use effective mitigation methods.

Implementing bycatch mitigation through a programme approach (i.e. an enhanced bycatch mitigation programme) would deliver the greatest benefit. Through this approach, monitoring and bycatch mitigation trials would reduce current uncertainties. Over several years it is likely that significant bycatch reduction could be achieved. The monitoring elements would be particularly critical if implemented as compensation to give confidence on the level of compensatory effect (i.e. how much bycatch had been reduced).

7.8 Results summary for practical feasibility reviews

We evaluated seven actions (though the two forage fisheries-related actions were combined into a single chapter for this section), with the key findings summarised in Table 52. For each component considered in the table, we provide some general summary of results across the actions and highlight any key differences.

It is not possible to meaningfully provide an overall rank for the actions as there are many different criteria to consider and how these are weighted would vary on how these are prioritised. Furthermore, scoring will also depend on the species of interest. In this section, we provide a high-level summary of key results across actions assessed in WP2.

Table 52. Summary of practical feasibility for the seven assessed actions. For further detail see the action chapters. Type of measure – general refers to actions that act over a wide area and site to actions applied at one or more sites; direct to where the action benefits the species directly (e.g. reduced predation) and indirect to actions that are some steps removed from seabird population response (e.g. reducing fishing may increase prey abundance which may then lead to population level responses in seabird populations). Costs of implementing are high-level relative estimates (low-medium-high) of direct costs of implementing measures only and have high uncertainty (i.e. these do not include any indirect costs, e.g. to loss of earnings resulting from the implementation of a measure) and will depend on how a measure is implemented. The overall feasibility score provides a relative assessment from Low–High. Note this is in terms of considering these measures specifically in the context of compensatory measures and with current knowledge. We have not evaluated the measures in terms of their use for wider conservation purposes which would require consideration of different criteria with consequent changes in scoring.

	1 **Sandeel fishery closure**	**2** **Fishery closure or enhanced management of prey fisheries**	**3** **End of the Gannet harvest at Sula Sgeir**	**4** **Mammalian predator eradication and/or management**	**5** **Avian predator management**	**6** **Reduction of disturbance (at colony)**	**7** **Bycatch mitigation in longline fisheries**
Component actions	Sandeel fishery closure	Fishery closure or enhanced management of prey fisheries, focussed on Sprat and Herring	End harvest of Gannet chicks (‘guga’) at Sula Sgeir	Predator eradication (islands) Predator control or exclusion (mainland colonies and islands)	Diversionary feeding Removal (targeted or non-targeted removal of predators’ nest, eggs, or birds) Deterrence	On land At sea UAVs	Applying mitigation measures in the floated demersal longline fleet
Key report sections	Ecological feasibility: 5.1	Ecological feasibility: 5.2	Ecological feasibility: 5.3	Ecological feasibility: 5.4	Ecological feasibility: 5.5	Ecological feasibility: 5.6	Ecological feasibility: 6.4

	Practical feasibility: 7.2	Practical feasibility: 7.2	Practical feasibility: 7.3	Practical feasibility: 7.4	Practical feasibility: 7.5	Practical feasibility: 7.6	Practical feasibility: 7.7
Ecological effectiveness summary	Strong evidence for the abundance of Sandeel being linked to breeding success in Kittiwake. The abundance of forage fish is not only regulated by industrial fisheries, but also by predatory fish populations, competition for food sources, and changes in environmental conditions. Sandeel fishery closures may lead to increased Sandeel	Sprat and Herring are important prey fish for seabirds in Scotland. There is evidence that their abundance is linked to seabird demography (e.g. breeding success) though this is less strong than for Sandeel. As with Sandeel, the abundance of these prey fish is regulated by industrial fisheries, predatory fish populations,	Ending (or reducing) the traditional harvest of Gannet chicks at Sula Sgeir would lead to increases in breeding success. This should lead to an increase in the population growth rate for Sula Sgeir with potentially small benefits also for nearby colonies (through emigration/immigration). Resource competition increases as population size increases, so	Reducing predation from invasive mammals will increase productivity and, in some cases, adult survival. Evidence is strongest for the eradication of invasive mammals on islands, which can lead to population recovery or re-establishment. Predator control (reducing abundance) has similar benefits. Predator exclusion is	Reducing avian predation will increase productivity, and in some cases also adult survival. Overall, the level of predation/predator associated disturbance from avian predators on seabirds in Scotland is not well studied. Predator management could have population benefits, but this will be highly species- and site-specific.	Disturbance at seabird colonies can lead to behavioural and physiological impacts which can ultimately lead to population level impacts (e.g. via increased predation or increased energy use). Reducing disturbance is, thus, ecologically effective, though the level of benefit will be highly site- and	Bycatch mortality leads to decreased adult and juvenile survival for affected seabird species. Reducing this mortality can lead to increases in population size. Mitigation measures have been demonstrated to be highly effective in longline fisheries although are less studied in the demersal longline fishery. It is

	abundance and consequent increases in Kittiwake productivity and/or survival, but there is significant uncertainty around this.	competition for food sources, and changes in environmental conditions. Seabirds may benefit from changes to fishery management for Sprat or Herring, but there is significant uncertainty around this.	ultimate population sizes may be the same, though reached earlier. However, the population could better buffer for population perturbations.	most effective for reducing predation by medium sized mammalian predators (e.g. Fox). Ground and burrow nesting species will benefit most but some cliff nesting species will benefit at some sites.		species-specific.	anticipated that there would be significant population benefits for Fulmar and potentially smaller benefits for other species, including Gannet.
Practical feasibility summary	There is an existing Sandeel fishery closure in place (E of Scotland) and consultations have been held by Scottish Government and DEFRA on wider closures, so practically it	Fishery closure has been explored for Sandeel fisheries but not in detail for Sprat or Herring. Theoretically it would be possible in the same way. Other types of	Theoretically it is possible to stop the harvest, but practically this would be difficult without support from the community undertaking the traditional harvest.	Predator eradication (on islands) has been successfully achieved on a number of UK islands. The feasibility is site-dependent and includes whether it is	There is a lack of specific evidence available for the use of predator management measures for the benefits of seabird populations in the UK or Scotland.	It is practically feasible to reduce disturbance with measures already in place for many sites (e.g. paths to direct visitors away from more sensitive areas). The feasibility and	There are a number of bycatch mitigation measures available that could be applied. However, there have been few trials in the specific fishery, so an iterative

	is possible to close the fishery. However, there are political and policy risks around this, so it is not straightforward [16].	management (e.g. reduce Total Allowable Catch) could be done within existing management with introduction of additional management objectives.	Dialogue with the community from the outset would be imperative.	possible to prevent re-invasion. Effective biosecurity with a rapid re-incursion response plan is required to secure predator free status in the long-term. Predator control and exclusion are practically feasible being implemented at a variety of sites currently. However, this is site-dependent.	Further research and trials would need to be conducted to better understand which management approaches may be appropriate for a given context (*inter alia* predator species, seabird species impacted by predation, and the location). The specific management approaches are practically feasible having been used in other contexts, though this	which specific measures are appropriate will be site-specific.	process would be required to trial measures and implement the most effective ones. An enhanced mitigation programme would require an audit or compliance mechanism supported by monitoring.

[16] At the time of final revisions to the report The Sandeel (Prohibition of Fishing) (Scotland) Order 2024 had recently been made.

					feasibility is site- specific.		
Type of measure	General – indirect	General – indirect	Site – direct	Site – direct	Site – direct	Site – direct	General – direct
Requires Government intervention or involvement	Yes (lead)	Yes (lead)	Likely (not lead)	No, but would be beneficial	Generally not, but may be beneficial	Generally not, but may be beneficial	Yes (lead)
Key species that could benefit (i.e. focal species)	Kittiwake are most likely to benefit though there is high uncertainty.	Kittiwake, Common Guillemot, Razorbill, and Puffin are most likely to benefit though with high uncertainty. Gannet and large gull species are likely to have minimal benefit.	Gannet would likely benefit.	Puffin could benefit significantly. Common Guillemot and Razorbill may benefit depending on the site. Large gulls can benefit significantly from predator exclusion on mainland sites.	Common Guillemot, Razorbill, Puffin, and large gulls may benefit, though the extent of benefit is uncertain and will be site-specific.	Common Guillemot, Razorbill, and Puffin are likely to benefit. Large gulls may benefit but to a lesser extent.	Gannet could benefit.

Additional species that could benefit	Other species feeding primarily on forage fish could benefit, primarily auks (Common Guillemot, Razorbill, and Puffin).	A variety of species feeding on forage fish could benefit, including terns, skuas, and Red-throated Diver.	There will be limited benefits to other species, although there is potential for benefits to species breeding at the time of harvest from reduced disturbance (Fulmar, Leach's Petrel, and European Storm Petrel).	Burrow and ground nesting species will benefit most. Petrel species and Manx Shearwater could benefit significantly depending on site.	Ground-nesting colonial species (e.g. terns) are likely to benefit.	Kittiwake, Black Guillemot, Petrel species, and small ground nesting species are likely to benefit.	Fulmar are likely to benefit significantly. Some other species may benefit to a much lesser extent (Great Shearwater and Great Skua have been recorded as bycatch).
Scale of benefit and site- and region-specific considerations	Benefits would most likely occur to Kittiwake on the east and north-east of Scotland. There is considerable uncertainty around what the population level response of Kittiwake	Benefits could occur in all regions but especially to east of Scotland. There is considerable uncertainty in the scale of benefits, but these could be moderate.	Benefits would be primarily local, i.e. to Gannet on North Rona and Sula Sgeir SPA, with medium to high responses expected in the short to medium term though low	As a site-based measure, the benefits will mostly occur at sites where mammalian predation is reduced (or eliminated). Most candidate sites are to the north and west of Scotland	As a site-based measure, any benefits will be primarily to the sites where implemented. The degree of benefit will range from none to moderate effects depending on	As a site-based measure, benefits will primarily be to the sites where implemented. Effects will range from negligible to moderate.	Benefits are most likely to Gannet and Fulmar populations to the west and north of Scotland with no significant benefits likely to east coast populations.

	would be to additional Sandeel fishery closure (i.e. in addition to existing closure area on the east coast). However, in theory, there is potential for a moderate benefit. Small or no benefits may occur on northern and western regions.		benefits in the long term (once the population approaches carrying capacity). Low to moderate benefits may accrue to other colonies in north-west Scotland. No significant benefit is expected to Gannet more widely in Scotland.	with fewer potential sites to the east. Population level responses can be significant, but this is site-, predator-, and species-specific.	species and site.		For Gannet there may be small to moderate benefits. For Fulmar there are likely to be strong effects in those regions benefitting.
Costs of implementing	Low	Medium	Low	High	Low	Low	Low
Key uncertainties	The abundance of forage fish is not only regulated by industrial fisheries, but also by predatory fish populations, competition for food sources, and changes in environmental conditions.		The effects on other species may likely be limited, but unknown. There is	The potential gains for individual species cannot by predicted	The level of predation and/or disturbance associated with avian predators	The population level impacts of human disturbance are not well understood	There is high uncertainty in current bycatch estimates which means benefits cannot

	Consequently, predicting the response of forage fish populations to fishery closures, or any other form of fishery management, is highly challenging. It is even more challenging to quantify and predict the broader effects of prey fisheries management on the demography of the predator species themselves (here focussing on seabirds).	potential for both positive and negative impacts. Positive from reduced disturbance (e.g. petrels) and negative if Gannet expansion displaces other breeding bird (e.g. Fulmar)	with confidence. Feasibility is highly site-specific and detailed site-specific feasibility studies are required.	has not been well studied in Scotland, and avian predation management interventions have rarely been trialled for the benefit of seabirds. Consequently, there is a high uncertainty regarding the potential benefits.	limiting our ability to predict the impact of reducing disturbance. Many regulations and management measures are already in place for key seabird colonies in Scotland, so the scale of additional benefit is uncertain.	be quantified with confidence. Several potential mitigation options have been identified but few have been trialled in the fishery leading to uncertainty on which would be most effective. The UK registered fleet is in the minority, so overall bycatch rates cannot be significantly reduced by targeting UK registered vessels alone.
Key barriers and considerations	International political opposition as quota is shared with other countries.	Lack of community support could	A recent ban (not yet in operation) on	Good baseline knowledge on existing	Need to consider additionality	Bycatch could only be significantly

	Displacement of fisheries to other fish species/regions. Socio-economic impacts to those involved with affected fisheries. Lag effects for seabird population responses from changes in fisheries management may limit ability to detect any population level response.	make it politically difficult to implement. Permanent loss of cultural heritage. Long-term benefits may be overestimated if harvest rates were to continue to decline. Negative impacts on other conservation initiatives, depending on community goodwill.	the most widely used rodenticides commonly used in rodent eradication projects may pose significant risk to viability of future eradication/co ntrol projects. Eradication must be supported by long-term biosecurity requiring long-term funding.	predator impacts is required to design measures effectively, which is lacking for most sites. Certain actions will only be feasible at more accessible sites.	issues given laws and guidance on minimising disturbance to wildlife. Effectiveness of reducing disturbance is difficult to quantify.	reduced with international coordination as component of fleet that is UK registered is small. Need to consider additionality issues given existing commitments around bycatch minimisation.

Overall feasibility (as strategic compensation)	Low-medium	Low-medium	Low-medium	High	Low	Low-medium	Medium

8 Discussion and recommendations

This report has provided an assessment of twelve potential strategic compensatory measures that could be used to compensate for assessed impacts from offshore wind developments following derogation procedure under Article 6(4) of the Habitats Directive. Of these twelve measures, seven were considered in detail for ecological feasibility (section 5). Where measures were less well defined, or where we could not readily identify specific conservation actions, these were considered via scoping reviews (section 6), with one measure assessed via a targeted review (bycatch mitigation). Seven measures were then considered for practical feasibility (section 7). The report has helped clarify some of the key issues that need to be considered when evaluating options for strategic compensation. While we have provided overall assessments of feasibility for measures (see section 1), we caution that the relative ranking of measures is highly dependent on the context in which measures are used (e.g. for which species) and how different criteria or considerations are weighted in decision making.

This report has the following general limitations (these are discussed further below):

- Starting point was a list of measures provided by Scottish Government (see Table 4). While we consider that this includes most measures being discussed in the context of strategic compensatory measures, it is not an exhaustive list of potential options.
- This is a technical review, while it does include wider considerations, especially in the practical feasibility section (see section 7), it does not fully assess issues which are more of a policy or legal nature, e.g. additionality; or sociological or socioeconomic considerations which will be important to consider for some potential measures.
- During the preparation of this report, the full impacts of HPAI on seabird populations was unknown, which is particularly relevant for some of the species most impacted by offshore wind developments (e.g. Gannet). Dedicated HPAI census results were published (Tremlett et al., 2024) during preparation of the final report revision, which limited the extent to which they could be fully integrated. Nonetheless, some edits were made to highlight this).
- It is reliant on the evidence that is available and what could be located for our review.
- In a review covering such a wide suite of measures, we were only able to partially cover some ecological aspects of the measures; e.g. seasonal, regional differences, and different population components (e.g. juveniles vs. breeding adults).
- The scoring used throughout considers measures in terms of their potential for application as strategic compensation (not e.g. as project-level compensation nor as wider conservation measures). The scoring is highly dependent on the criteria used and how these criteria are weighted. As such, the scores provided here should be treated as a guide only and not be considered definitive. For the practical feasibility assessments, we were not able to cover all site-specific aspects which are crucial to feasibility, so would need to be considered if implementing measures as strategic compensation.

The policy and guidance around compensation measures for offshore wind is developing rapidly. Following the Energy Act there is expected to be various legislative and non-legislative (statutory guidance) changes that will affect how compensatory measures are assessed and delivered, including enabling strategic delivery of compensatory measures. However, at the time of this review there was no clear framework or set of criteria for assessing potential strategic compensatory measures (see recommendation 1), so a bespoke approach was taken for the report. This report considers technical and ecological factors which are fundamental to selecting between options. However, the approach to selecting measures is ultimately also dependent on factors that are more of a policy nature, for example, how compensatory measures relate to other policy objectives, e.g. SPA network objectives[17]. While it is desirable to score and rank potential compensatory measures, the reality is that the choice of the most appropriate is highly context-specific and dependent on how different criteria are weighted. For the systematic reviews of ecological feasibility (see section 5, summarised in (Table 2), we used a standardised scoring approach developed for this report. In theory, this scoring approach makes it possible to directly compare the ecological efficacy scores between measures. However, in practice, due to variation in the evidence available and in the types of measures (see next paragraph), we could not achieve absolutely comparable scores.

Our ability to assess a measure's ecological efficacy is clearly dependent on the volume of evidence and the relevance of that evidence (how closely the published evidence relates to the proposed compensatory measure). However, the ability to assess measures is not just determined by the volume and relevance of evidence, but also by the type of measure itself. The more indirect measures are fundamentally harder to assess, as the effects on the target seabird species are several steps removed from the compensatory action. These types of measures, that are usually ecosystem-based (e.g. targeting forage fish availability), may require delivery at wide spatial scales or evidence to be collected over many years (even decades), before unequivocal conclusions on their efficacy can be reached.

Developing an approach that allows decisions to be made following a sound scientific basis based in ecological theory, while acknowledging the uncertainty on the specific outcomes from a given compensatory measure, is likely to be necessary to develop some broader ecosystem-based measures. Here, it will be useful to learn from approaches developed in restoration ecology (see e.g. Palmer et al. (2016)), where ecological theory is applied to guide restoration initiatives but where confident predictions on specific outcomes cannot be formed. In these cases, we will often need to rely on projections or forecasting, rather than evidence from existing trials, to make anticipatory predictions (Mouquet et al., 2015), because until certain novel or wide scale measures are applied, we will not be able to observe their effects directly. While a predictive approach may allow consideration of a wider suite of potential compensatory measures than if limited to those that have been empirically tested (i.e. trialled in some way), it is important to consider accuracy in predictions (Beckage et al., 2011; Elliott-Graves, 2019). However, when used appropriately,

[17] For the management objectives of the national site network see regulation 16A of The Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019.

predictive models can have a useful role in informing policy and management decisions (Sutherland and Freckleton, 2012). This issue is, in part, mirrored by uncertainty in predicting the effects of offshore wind developments. Some of the thinking that has been developed for accounting for this uncertainty (Searle et al., 2023b) may be useful to apply also in the context of how we assess compensatory measures and apply adaptive management.

For a measure to lead to a compensatory response it must have a positive effect on one or more demographic rates (e.g. adult survival or productivity). When selecting amongst alternative options for compensatory measures it is important to consider the ecological context, both of the impacted population and of what the effect is that is triggering the need for compensation (e.g. whether it is collision mortality or loss of habitat). For example, if adult mortality is the key effect (e.g. from collision mortality) leading to a requirement for compensation, then the most effective compensatory measures will usually be those measures that reduce some other source of adult mortality. However, there is potential for measures not directly countering such effects to also function as compensation. For example, a measure that boosts productivity could allow a population to withstand higher mortality rates.

Climate change adds an additional complexity, as even if we are able to demonstrate that a certain measure is effective at the current time, or that it has been in the past, we cannot necessarily be confident that it will continue to be in future as ecosystems change. For example, the North Sea is currently experiencing fundamental shifts in its ecology with shifts in zooplankton communities having potential for cascading effects at higher trophic levels (MacDonald et al., 2015; Lindegren et al., 2017; Olin et al., 2022). Recent studies have predicted profound changes in UK breeding seabird populations over the coming decades due to climate change (Searle et al., 2022; Davies et al., 2023). The theory and practice of how we consider this threat in conservation decision-making is still developing (see e.g. Hirsch and Long (2021)). While there has been work to consider options for conserving seabirds in the face of climate change (Pearce-Higgins et al., 2021; Hakkinen et al., 2022), there has been less consideration in terms of how we develop conservation and restoration measures that are resilient to and/or remain effective as conditions change. We recommend that this is considered when developing compensatory measures (see recommendation 5) including considering how we can make better uses of predictive approaches (see above).

Coordinated delivery of multiple measures can potentially increase the effectiveness of individual measures and thus increase overall confidence that measures will deliver the desired compensatory effect. For example, improving nesting habitat may only have limited effects on productivity if breeding success is limited by foraging conditions. Therefore, where possible, when designing strategic compensatory measures, consideration should be given to delivering a suite of measures (potentially some as compensation and others for wider nature restoration/enhancement purposes).

We provide the following recommendations for further work around strategic compensatory measures for seabird populations:

1. When considering a specific measure, consider the recommendations included within the corresponding report sections.
2. Developing guidance for how strategic compensatory measures should be assessed, including key criteria to consider (see also, recommendation 3).
3. For more indirect measures, including those acting at a wider ecosystem scale, we recommend that a decision-making framework is developed for how such measures can be evaluated. This framework would support developing a better understanding on how to link these measures to population level responses for the target seabird populations. Without this, it will rarely be possible to have confidence that such measures can deliver as compensation by helping support coherence of the network for the impacted feature species. This framework would include policy and technical aspects and would help inform on research and adaptive management. For example, selection of appropriate proxies (e.g. prey availability) for use in adaptive management where the ultimate effects (e.g. seabird productivity) cannot be realistically related directly to the compensatory measure. Note these proxies would only be appropriate where there is confidence that there is a link between the proxy and the ultimate effect and that all key ecological factors have been considered (e.g. increasing forage fish may not increase prey for seabirds if they are outcompeted by predatory fish). Applying path analysis and structural equation modelling approaches (Garrido et al., 2022) could be beneficial here.
4. For many potential categories of compensatory measures (e.g. habitat management at breeding colonies) there has been a lack of detailed work to scope out what specific conservation actions could be delivered as compensation. This report includes a scoping section from some of these potential measures (see section 6), but many areas would benefit from their own dedicated reviews and research, including field trials.
5. Developing an integrative approach to compensatory measures that accounts for, and works to support, adaptation in seabird populations to the impacts of climate change.

This report has demonstrated that there are multiple conservation measures that have potential to be applied as strategic compensation for offshore wind impacts. However, all the measures considered had varying challenges to overcome if they were to be developed as strategic compensation. This report has mapped out some of these issues and provided recommendations on how these can be addressed.

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11 Glossary and common acronyms

11.1 Glossary: Definitions for key terms used in the report

Biosecurity: Measures to prevent new invasive species arrivals, or re-invasion by previously eliminated invasive species.

Breeding success/productivity: Number of chicks fledged per breeding pair.

Burrow-nesting birds: Birds, such as puffins, petrels, and some species of auklets, excavate burrows in the soil or use pre-existing burrows to nest.

Cliff-nesting birds: Birds. such as Guillemot, Razorbill, and Kittiwake, that lay their eggs on narrow ledges in steep cliffs or rocky ledges along coastal areas.

Compensatory measure: Any type of management intervention that could act to offset an assessed loss or damage to a protected site or population. Specifically, here in terms of compensation under the Habitats Directive for impacts on seabird populations, this includes management interventions that (fully or partially) offset assessed findings of an adverse effect on site integrity to a seabird species as a qualifying feature of an SPA. Compensatory measure is often used as a more general term referring to a potential suite or category of conservation actions. Compensatory measure is synonymous with **compensatory measure**.

Conservation action: A specific management intervention carried out to deliver a gain and/or recovery of a habitat or population. Specifically, here we refer to those management interventions that have potential to lead to population level gains and/or recovery for a seabird species. Conservation actions have potential to be used as compensatory measures subject to meeting various tests (both relating to efficacy and other factors such as additionality).

Control of invasive species: The ongoing management of an invasive species to minimise its impact on the environment. Control measures aim to maintain a low near zero density of an invasive species; to reduce the population, prevent its spread, or mitigate its effects on native species and ecosystems.

Crevice-nesting birds: Birds, such as shearwaters, petrels (also burrow nesting), and sometimes Razorbills (also cliff-nesting), that lay their eggs in narrow crevices or cavities, often found in rocky cliffs or boulder fields.

Deterrence: In this context, 'deterrence' refers to a management action to control avian predators (see Ecological feasibility: Avian predator management). It involves the use of physical objects and/or bioacoustics, along with other methods, to impede avian predators from predating on other species (e.g. seabirds).

Diversionary feeding: The use of food to divert the activity or behaviour of a target species (avian predators) from an action that causes a negative impact on other species (e.g. seabirds and waterbirds), without the intention of increasing the density of the target population.

Eradication of invasive species: The complete and permanent removal of wild populations of an invasive species from a defined area. Eradication efforts aim to eliminate all individuals of the target species, thereby preventing its spread and restoring the ecosystem to its previous state.

Extinction: Global loss of a species.

Extirpation: Loss of a species from part of its global range, e.g. a region or a country. Sometimes also called 'local extinction'.

Focal seabird species: The seabird species that have been identified as those species that could benefit from the initial list of compensatory measures both due to ecologically and over general likelihood of them requiring compensation for offshore wind impacts. See Table 4.

Google Scholar: A freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines.

Ground-nesting birds: Birds such as gulls and some species of terns that lay their eggs on the ground in open areas or rocky outcrops.

Harvest: The act of collecting, capturing, or killing of eggs, chicks or mature individuals for food, sport, or other purposes.

Highly Pathogenic Avian Influenza (HPAI): A highly contagious and highly pathogenic (that is often leading to severe disease including fatal disease) viral agent causing disease. Also known as 'bird flu'. An outbreak of HPAI caused by a H5NI strain of influenza is affecting wild bird populations globally including seabird populations in the UK, this has been underway since late 2021 and is ongoing at the time of writing (2023).

Invasive alien species: See invasive non-native species.

Invasive non-native species (INNS): Species that have been introduced, either accidentally or deliberately, to a region where they are not present and have serious negative ecological consequences where they establish.

Metapopulation: A group of spatially separated populations of the same species which interact at some level.

Scoping review: Used to broadly characterise the available evidence and to use that evidence to clarify definitions, understand what type of research have been conducted, and understand knowledge gaps around a topic. Specifically in the context of this project this approach is used where no specific conservation actions have been identified corresponding to a compensatory measure, or where many potential actions are identified (with no clearly defined preferred options). These reviews seek to identify potential conservation actions and where possible to evaluate the evidence to support these (though not in a more narrative way than for systematic reviews).

ScotWind: The leasing round ran by Crown Estate Scotland for rights to develop offshore wind projects under the Scottish Government's Sectoral Marine Plan for Offshore Wind.

Seabird Monitoring Programme (SMP): A coordinated programme of annual seabird monitoring across the UK, the Republic of Ireland, the Channel Islands and the Isle of Man established in 1986.

Search strings: A combination of keywords, truncation symbols, and Boolean operators that are entered into the search box of a library database or search engine.

Special Protection Areas (SPAs): Protected areas for birds in the UK classified under: the Conservation of Habitats and Species Regulations 2017 (as amended) in England and Wales (including the adjacent territorial sea) and to a limited extent in Scotland (reserved matters) and Northern Ireland (excepted matters); The Conservation (Natural Habitats &c.) Regulations 1994 (as amended) in Scotland; the Conservation (Natural Habitats &c.) (Northern Ireland) Regulations 1995 (as amended) in Northern Ireland; the Conservation of Offshore Marine Habitats and Species Regulations 2017 (as amended) in the UK offshore area.

Strategic compensation*: This follows the same general principles as compensatory measures (see 'compensatory measures') but is where such measures are to be delivered at scale and/or over extended timeframes, which cannot generally be delivered by individual offshore wind project developers alone. Such measure(s) would usually be led and delivered by a range of organisations, including Government, industry and relevant stakeholders. Strategic compensatory measures would normally be identified at a plan level and applied across multiple offshore wind projects to provide ecologically meaningful compensation to designated site habitats and species adversely impacted, to compensate for identified adverse effects on site integrity, thus to support maintaining the coherence of the site network (SPA or SAC sites). *This definition is adapted from the working definition for strategic compensation developed by the Collaboration of Offshore Wind Strategic Compensation (COWSC).

Sula Sgeir: A small, uninhabited rocky Scottish island in the North Atlantic, 18 kilometres west of Rona. It is one of the most remote islands of the British Isles.

Supplementary feeding: The use of feeding as a conservation method to improve the population viability or density of a particular species or population.

Systematic review: A literature review approach that seeks to provide an objective and valid summary of primary research findings by following a fully documented and pre-planned procedure that is repeatable. In this report this approach is used for compensatory measures where one (or a few) specific conservation actions had been identified initially.

Records: Here we use records to refer to the documents (e.g. research articles, review papers, reports, theses, databases) that arose from the literature searches from Web of Science and Google Scholar, as well as additional references.

Removal: In this context, 'removal' refers to a management action to control avian predators (see Ecological feasibility: Avian predator management). It involves the removal of an avian predator's nest, offspring, and/or mature individuals, employing either lethal or non-lethal means, with the objective of avoiding them from causing further negative effects on other species (e.g. seabirds).

Targeted review: Similar to a Scoping Review, but for where a recent detailed review already exists. In this report this type of review is to put an existing synthesis in context of strategic compensation and supplement with findings from other relevant literature. It seeks to identify which conservation actions are ecologically effective in strategic compensation terms.

Web of Science: A bibliographic database (or search engine) of scholarly articles from >20,000 peer-reviewed journals worldwide. The platform provides tools for advanced search, citation analysis and bibliometrics.

11.2 Common acronyms used in the report

AEOSI: Adverse Effect on Site Integrity

ANOVA: Analysis of Variance

BACI: Before-After-Controlled-Impact

DET: Deterrence techniques used for avian predator management

DF: Diversionary feeding

GAM: Generalised Additive Models

GLM: Generalised Linear Models

HPAI: Highly Pathogenic Avian Influenza

HRA: Habitats Regulation Appraisal

ICES: International Council for the Exploration of the Sea

INTOG: The Scottish Government's Sectoral Marine Plan for Innovation and Targeted Oil and Gas Decarbonisation.

IUCN: International Union for Conservation of Nature

LMM: Linear Mixed Models

MSY: Maximum Sustainable Yield (fisheries management target)

NAEOSI: No Adverse Effect on Site Integrity

REM: Removal techniques used for avian predator management

OWF: Offshore wind farm

SMP: Seabird Monitoring Programme

SST: Sea Surface Temperature

TAC: Total Allowable Catch

WP: Work package

12 Appendices

Appendix 1: Table A 1 – Compensatory measures table with potential conservation actions identified

Table A 1. Measures table (following Table 4) with potential conservation actions identified, key points from discussion with steering group summarised, and outcome stated (see Table 6 for details of the reviews identified). Difficulty allocating measure to actions is scored from 1 to 5; 1 = measure corresponds to conservation action, 5 = measure and/or associated actions are unclear.

Compensatory Measure	Focal species	Secondary Species	Difficulty allocating to action	Potential conservation actions	Steering group discussion*	Outcome
1. Sandeel fishery closure	Kittiwake		1	Closure of Sandeel fishery in Scottish Waters	Keep as is	**Systematic review**
2. Fishery closure or enhanced management of prey fisheries	Kittiwake, large gulls, Guillemot, Razorbill, Puffin, Gannet	Fulmar, petrels, skuas	2	Closure or enhanced management measures for other (non-Sandeel) seabird prey fish/shellfish species in Scottish waters (excluding aquaculture)	Agreement to list of fish stocks considered: sprat, herring, mackerel	**Systematic review**
3. End of the Gannet harvest at Sula Sgeir	Gannet		1	Ending harvesting of Gannet chicks at Sula Sgeir	Keep as is	**Systematic review**

Compensatory Measure	Focal species	Secondary Species	Difficulty allocating to action	Potential conservation actions	Steering group discussion*	Outcome
4. Habitat Management (terrestrial breeding colonies)	Gannet, Guillemot, Razorbill, Puffin, gulls	terns	3	1. Removal invasive plant species (e.g. tree mallow and bracken); 2. Combating erosion/reinforcing nesting sites; 3. Removal of rubbish/plastic waste at nesting sites?? 4. Nest boxes at natural colonies	Exclude predator eradication/manageme nt (as separate measure). Review management plans for SPAs for other possible habitat management actions. Possible suggestion to include nest boxes at natural colonies but not artificial colonies (e.g. 'Kittiwake towers' or 'tern rafts').	**Scoping review**
5. Bycatch mitigation in longline fisheries	Gannet, Fulmar		3		MS commissioned review on bycatch to be published soon. Otherwise no real discussion	**Targeted review** Focussed on summarising key findings from recent MS commissioned review in context of compensatory measures but potentially considering some wider

Compensatory Measure	Focal species	Secondary Species	Difficulty allocating to action	Potential conservation actions	Steering group discussion*	Outcome
						literature beyond this (including for international).
6. Predator eradication/ management (i.e. rodents, foxes)	Guillemot, Razorbill, Puffin, gulls	terns	3	1. Mammalian predator eradication and/or management 2. Avian predator management	Asked that scope be both mammalian and avian predators	**Systematic reviews (x2)**: 1. Mammalian predators (including biosecurity); 2. Avian predators
7. Biosecurity (prevention of threats, including HPAI)	Guillemot, Razorbill, Puffin, gulls, skuas, Gannet	terns	5		Commented that too early to understand what actions may help counter HPAI. Suggestion to include biosecurity with predator eradication/manageme nt measure, though that it can also be prevention but that this should not be considered as	**Combine with other related measures** Combine biosecurity with predator eradication/manageme nt (i.e. Measure 6) HPAI - include with Disease/Environmental event mitigation (i.e. Measure 12)

Compensatory Measure	Focal species	Secondary Species	Difficulty allocating to action	Potential conservation actions	Steering group discussion*	Outcome
					compensation as is not measurable.	
8. Diversionary feeding (of gulls/skua/raptors)	Guillemot, Razorbill, Puffin		3	1. Diversionary feeding	One comment that may work in specific circumstances, then likely as project-based compensation (not strategic). Mention of use for little terns. Comment that would be helpful to review under what conditions it may work.	To be integrated with Avian predator management

Compensatory Measure	Focal species	Secondary Species	Difficulty allocating to action	Potential conservation actions	Steering group discussion*	Outcome
9. Population management interventions	Large gulls		4	1. Reforms around gull management regime. 2. Consideration of SPA designation of non-natural gull colonies. 3. Translocating eggs and external rearing.	Population management for benefit of other seabirds to be considered under predator eradication/manageme nt. Here consider population management reform for benefit of gulls. Suggestion to consider SPA designation for some non-natural gull colonies. Potential to translocate eggs (with external rearing) to other sites (from ECOWINGS).	**Scoping review** Specific conservation actions could be considered by a systematic review but given range and type of potential actions a scoping review is likely to be more useful.

Compensatory Measure	Focal species	Secondary Species	Difficulty allocating to action	Potential conservation actions	Steering group discussion*	Outcome
10. Behavioural Disturbance: reduction/mitigation (Including shipping and recreation)	Large gulls, Guillemot, Razorbill, Puffin	terns, Fulmar	4	1. Reduction of disturbance (at colony) 2. Reduction of disturbance (at sea)	Suggestion to include UAVs. Include vessel disturbance both by colonies and at sea with foraging areas. Mention also to consider the sensitive swimming migration in auks.	**Systematic reviews (x2):** 1. Reduction of disturbance at colonies (including near shore) 2. Reduction of disturbance at sea (away from colony including in foraging areas/post-breeding aggregations etc.).
11. Manage supporting habitats (e.g., restrict seaweed removal, litter,	Large gulls, Gannet, petrels, Guillemot, Razorbill, Puffin	terns	4		Suggestion to focus on aspects of supporting habitat related to prey. Scallop dredging was mentioned as potential threat to prey habitat (for Sandeel).	**Scoping review** Aim to better understand what options may be for managing supporting habitat and reducing

Compensatory Measure	Focal species	Secondary Species	Difficulty allocating to action	Potential conservation actions	Steering group discussion*	Outcome
seagrass, sandbanks)					Seagrass restoration may have benefits to seabird populations. NatureScot's supporting habitat definition was given: "Supporting habitats refer to the characteristics of the seabed and water column relevant to their use by the qualifying features. Supporting processes relates to wider oceanographic processes such as upwellings, tidal flows, hydrological movements which may be necessary for the habitat, and thus affects nutrient cycling and prey distribution"	indirect threats to seabirds emanating from threats to/management of supporting habitat.

Compensatory Measure	**Focal species**	**Secondary Species**	**Difficulty allocating to action**	**Potential conservation actions**	**Steering group discussion***	**Outcome**
12. Disease/ Environmental event mitigation	Those spp. affected (i.e. all species potentially affected if HPAI, auks if weather event)		5		Suggestion that actions to prevent disease spread could be considered (e.g. prevent gulls gathering at fresh water, removing carcasses). It was discussed that if there were no examples of actions that have been put into place, then could remain at a scoping level.	**Scoping review** Focus on disease mitigation through preventing/reducing disease spread. Exclude environmental event mitigation.

*The initial measures table (Table 4) was discussed at the 1st project steering group meeting held on 20th March 2023. The focus of the discussion was largely restricted to the interpretation of each measure and how these should be considered in the project rather than e.g. inclusion of any additional measures or change in focal species that had been decided prior to the project.

Appendix 2: Description of the different type of reviews considered within the project

Systematic reviews aim to provide an objective and valid summary of primary research findings by following a fully documented and pre-planned procedure that is repeatable (Kugley et al., 2016; Foo et al., 2021). As such, systematic reviews are generally considered to be the most rigorous form of review. A systematic review typically follows the following sequential steps (Kugley et al., 2016; Foo et al., 2021; Higgins et al., 2022): identifying and defining the research questions and associated keywords; conducting the search using database search engines (e.g. Web of Science); screening retrieved literature against a set of inclusion criteria; extracting data from the studies; then finally analysing the data extracted to summarise across all studies. A variant on systematic reviews are meta-analysis studies, which are a more quantitative or statistical approach to collating and summarising the results across studies.

Scoping reviews have a broader more exploratory purpose than systematic reviews. They are generally used to broadly characterise the available evidence and to use that evidence to clarify definitions, understand what type of research has been conducted, and understand knowledge gaps around a topic (Munn et al., 2018). A scoping review can be used as a precursor to a systematic review to inform the questions to be addressed by the review and whether a systematic review may be useful to address these (i.e. whether a systematic review is likely to find sufficient suitable evidence). Researchers are using scoping reviews increasingly, and as a result, there has been development towards their standardisation (Pham et al., 2014; Tricco et al., 2016).

A targeted review is essentially a special case of a scoping review, where there are one or more existing recent detailed reviews for a topic. In this case it does not make sense to duplicate those by undertaking a new review. Instead, a targeted review seeks to summarise the findings of those existing reviews and put the findings in the relevant context (i.e. here strategic compensation) and where further relevant studies or reports have since come available, update the findings.

In addition to a review-based methodology there are alternative approaches to summarising information and reaching conclusions from these. The main alternative approaches are variants on using expert opinion, where instead of using primarily published information, the informed opinions of experts in an area are summarised (in this case this would generally be research scientists [academic and non-academic] and conservation practitioners). This can be achieved in a very structured way using an expert elicitation methodology (Martin et al., 2012) or using a looser methodology with interviews or an opinion piece informed by the existing knowledge of one or more expert authors and a non-systematic use of published literature. Approaches based on expert opinion are most useful where there is a need to rapidly produce informed but preliminary (given that they don't directly use evidence) conclusions on a topic, or where it is not possible to wait for sufficient evidence to be collected (i.e. by new research studies) to use a more structured review approach. This was the approach used outwith this project to identify candidate compensatory measures (Table 4).

The aim of WP1 was to assess the ecological feasibility of the proposed compensatory measures. While any of the above approaches could have been taken, a systematic review was the approach most likely to reach clear, unbiased, and unambiguous outcomes on ecological feasibility. However, a systematic review is only possible where there is a clearly defined and specific question to address and will only reach a clear outcome where sufficient evidence exists. In the context of this project, this requires that one or a small number of specific conservation actions are first identified such that a small number of research questions are defined. For some compensatory measures it may have been possible to use a meta-analysis approach, however this is a more time-consuming approach and was not possible to do within the timescale of this project.

For those compensatory measures where it was not possible to reach a short list of specific conservation actions, a scoping review was conducted. The scoping review was used to identify a candidate list of conservation actions corresponding to each compensatory measure, deliver judgement on which of these conservation actions are most likely to be ecologically feasible, and provide recommendations around further evidence needs. However, it was not possible to reach firm conclusions on the ecological feasibility of these compensatory measures as subsequent systematic review on the identified conservation actions would be required. It was therefore not possible to take these compensatory measures forward to WP2, the practical feasibility component.

In one case we used a targeted review approach (see Bycatch mitigation in longline fisheries), which is a similar approach to a scoping review but drawing on a smaller range of literature. We used this approach where recent highly relevant reviews already existed, thus it did not make sense to replicate these. Instead, we summarised and set out the findings of the existing reviews in the context of strategic compensation (which the existing reviews did not consider) and, where relevant, supplemented these with findings from other literature. The purpose here was to determine whether the associated conservation actions would be ecologically effective – but this was not scored quantitatively in the same way as with the systematic reviews.

Appendix 3: Table A 2 – List of inclusion/exclusion criteria used during screening in systematic literature reviews at the title and abstract level and full-text level

Table A 2. List of inclusion and exclusion criteria during screening in systematic literature reviews at the title and abstract level and full-text level.

Review Number	Systematic review	Title/abstract screening		Full-text screening	
		Inclusion criteria	Exclusion criteria	Inclusion criteria	Exclusion criteria
1	Sandeel fishery closure	• Mention of Sandeels and Kittiwake • Mention of Sandeel fishery closures or other type of fishery management • Mention of causes of Kittiwake decline	• Unrelated to Sandeels or Kittiwake • No mention of Sandeel fishery closures or other type of management • Abstracts could not be found	• Tested, directly or indirectly, the effect that a Sandeel fishery closure had on any demographic parameter of Kittiwake?	• Did not test the effect of a Sandeel fishery closure on Kittiwake • Did not provide new evidence on the matter • Full-texts were not available
2	Fishery closure or enhanced management of prey fisheries	• Includes focal seabird species • Includes focal prey species • Geographic region is North Atlantic or Europe • Fisheries must be considered whether directly or indirectly • Fisheries must be considered in terms of	• Where fisheries only referred to in passing, e.g. as context around prey depletion but without any consideration of fisheries impacts • Where geographic region is not Europe or North Atlantic • Exclude studies that consider fisheries only	• Assess qualitatively or quantitatively relationship between fishing activity and prey availability (or demographic consequences for) to seabirds • Includes the focal seabird species. • Includes the focal prey species	• Fisheries mentioned but only in more speculative or contextual way (e.g. a brief mention in the introduction or discussion sections) • Other aspects of fisheries (not prey depletion) considered only (e.g. bycatch or discards)

Review Number	Systematic review	Title/abstract screening		Full-text screening	
		Inclusion criteria	**Exclusion criteria**	**Inclusion criteria**	**Exclusion criteria**
		prey abundance/depletion	in terms of bycatch or discards • Where prey species considered are not the focal prey species • Abstracts could not be found	• Includes relevant region (North Atlantic/Europe)	• Doesn't include relevant region (North Atlantic/Europe) • Full texts were not available
3	End of the Gannet harvest at Sula Sgeir	• Studies that tested the effect of seabird chick and/or egg harvest on seabird populations, anywhere in the world • Mention of sustainable chick and/or egg seabird harvest	• When harvest was unrelated to seabird chicks or eggs (e.g. adults, shorebirds or marine mammals, prey-related studies, guano, seabird harvest by fisheries) • Harvest at Sula Sgeir was briefly mentioned • Measured the effect of Skua predation • Abstracts could not be found	• Measured, in any way, empirically or theoretically, the impact of chick an/or egg harvests on seabird populations • Provided threshold for sustainable harvest	• Harvest was briefly mentioned as a potential threat, but the degree of the effect was not measured • Measured the impact/role played by harvest on species extirpations/extinctions • Full-texts were not available
4	Mammalian predator eradication and/or management	• Measure of success and/or failure of eradication/ management/control on seabirds • If unclear, but may be useful	• Eradication effect on seabirds is not measured (mostly studies on islands mentioning effect of invasive predator on ecology of the island)	• Measure of success and/or failure of eradication/ management/control on any demographic parameter of any seabird species	• The impact on seabirds was not measured • Could not extract species-specific information (e.g. global assessments)

Review Number	Systematic review	Title/abstract screening: Inclusion criteria	Title/abstract screening: Exclusion criteria	Full-text screening: Inclusion criteria	Full-text screening: Exclusion criteria
			• Impact of invasive species on seabirds (predation pressures, behavioural change, population trends after introduction) • Biology of invasive mammalian species • Origin of invasive species • Avian predators • Effect of eradication on small passerine birds • Abstracts could not be found		• Only mentions eradication/control procedure • Full-texts were not available
5	Avian predator management	• Measure of success and/or failure of management action (i.e. diversionary feeding, deterring, removal, control) on seabird and other waterbird colonies • If unclear, but may be useful	• The effect of the management action is not measured (mostly studies that documented the management action per se or mentioned it as a potential solution without testing it) • Studies focussed on toxicity, pollutants, or contaminants on birds	• Studies that clearly measured the success and/or failure of a specific management action (i.e. diversionary feeding, deterring, removal, control) on any demographic parameter of a seabird or waterbird species	• Broad reviews that did not provide a measure on the effect of the conservation action on any seabird or waterbird species. • The effect of the management action is not clearly measured • Did not provide new evidence on the matter or there were

Review Number	Systematic review	Title/abstract screening		Full-text screening	
		Inclusion criteria	Exclusion criteria	Inclusion criteria	Exclusion criteria
			• Studies that measured or recorded avian predation on seabirds • Studies where supplementary feeding was undertaken to benefit species, and not to avoid predation on other species • Biology, ecology or behaviour of avian predators • Deterring of predators from non-seabird colonies (e.g. landfills and airports) • Management of mammalian predators • Avian predators were passerines • Abstracts could not be found		more recent studies from the same authors and study system and that used the same, but more complete database. • Full texts were not available
6	Reduction of disturbance (at colony)	• Includes key species (guillemot; murre; razorbill; puffin; seabird; large gull) or similar species.	• Studies which did not focus on disturbance (e.g. studies on anthropogenic debris and plastics)	• Tests a management intervention (regulation) • Studies that can infer changes in behaviour	• Studies where results are too general. • Studies that do not test the effect of a management action.

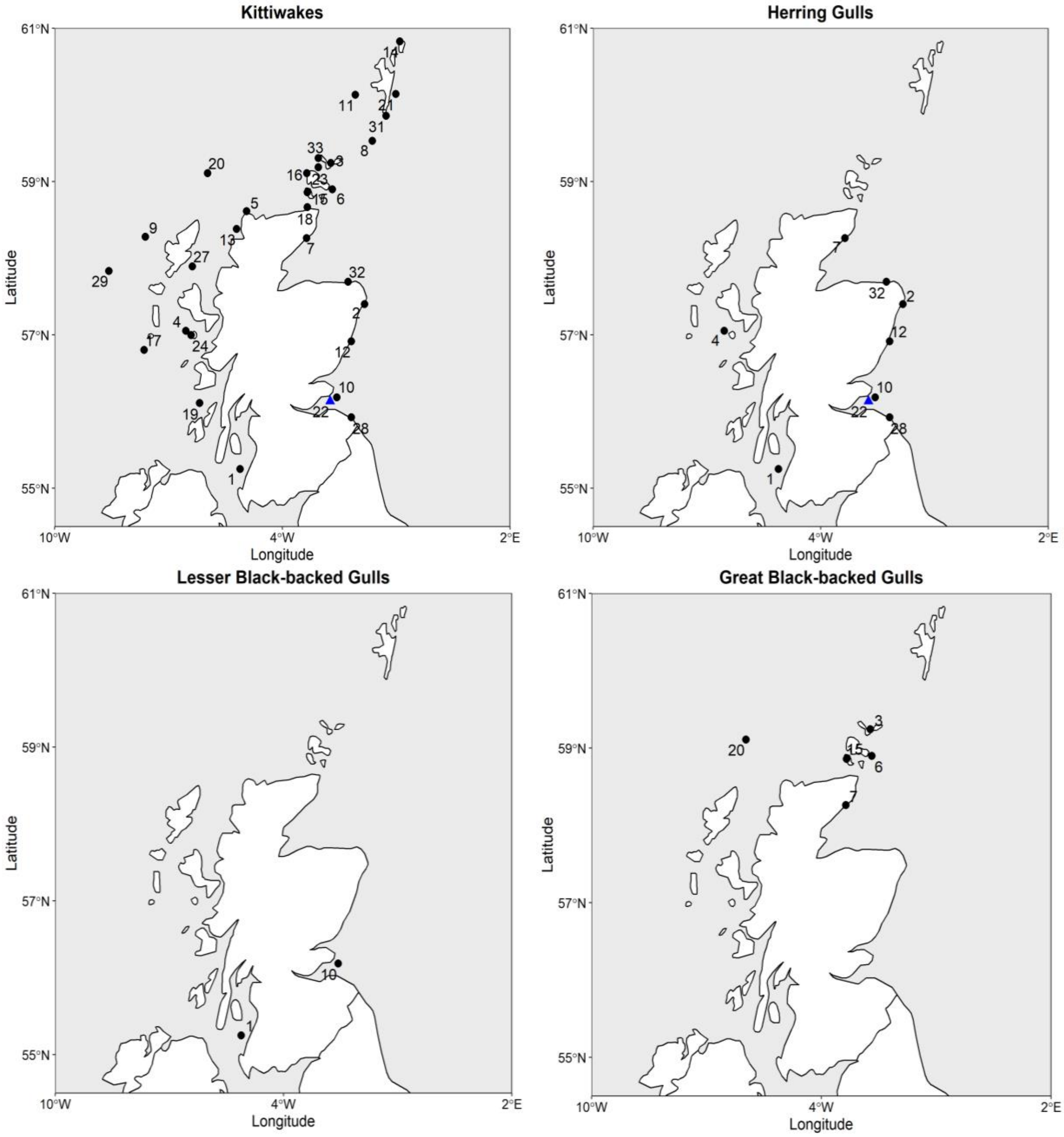
Review Number	Systematic review	Title/abstract screening		Full-text screening	
		Inclusion criteria	**Exclusion criteria**	**Inclusion criteria**	**Exclusion criteria**
		• Focus is at/in close vicinity to the colony • Includes some stressor activity that could lead to disturbance • Includes some management intervention intended to reduce or mitigate disturbance • Measures outcome in some way (demographic rate/behaviour)	• The effect of the management action is not measured; mostly studies that documented the management action per se or mentioned it as a potential solution without testing it. These studies were considered for the introduction and/or discussion but not for the final assessment • Studies that do not focus on seabirds (e.g. waterbirds, marine mammals) • Studies relating to seabirds breeding on Alcatraz Island, which were mostly focussed on Brandt's Cormorant. These were excluded as the species and context are not generally transferable to	and/or demography based on changes in disturbance. • Experiments identifying distance at which species change behaviour.	• Review studies. • Studies focussed on waterbirds, or non-relevant seabirds, • Studies which only highlight the impact of a disturbance without providing management recommendations. • Studies which conduct questionnaires to understand most common human disturbance on an area. • Where context is not transferable to Scotland (e.g. ecotourism in the polar regions). • Full texts were not available.

Review Number	Systematic review	Title/abstract screening		Full-text screening	
		Inclusion criteria	Exclusion criteria	Inclusion criteria	Exclusion criteria
			Scotland seabird colonies. • More general review (or book/book chapter) that only considers disturbance in passing. • Abstracts could not be found.		
7	Reduction of disturbance (at sea)	• Measure, directly or indirectly, of the effect of reducing disturbance at sea has on seabirds or waterbirds • Disturbance occurs at sea and are vessel-related • If unclear, but may be useful	• Disturbance occurs close to the colony but not at sea (examples of disturbance: mammalian invasive species, effect of light on chick weight or productivity, visitors, small vessels close to colonies) • The effect of the management action is not measured; mostly studies that documented the management action per se or mentioned it as a potential solution without testing it.	• A vessel-related disturbance was measured on any ecological aspect of waterbirds or seabirds. The nature of this action implies that many effects will be tested indirectly. • Use of a model to estimate degree of disturbance and its effect on birds	• Duplicated record in some way • Does not measure disturbance • Studies that overlapped vessels and wildlife to calculate threat risk, without measuring some sort of effect • Full texts were not available

Review Number	Systematic review	Title/abstract screening		Full-text screening	
		Inclusion criteria	Exclusion criteria	Inclusion criteria	Exclusion criteria
			These studies were considered for the introduction and/or discussion but not for the final assessment • Does not research at-sea disturbance on seabirds or waterbirds (e.g. at-sea disturbance in mammals) • Studies on the effect of bycatch, overfishing, discards, etc • Studies on seabird ecology at sea • Studies focussed on the impacts of oil spills, and collisions with windfarms and oil and gas platforms on seabirds • Studies focussed on monitoring, tracking, and surveying techniques of seabirds at sea		

Review Number	Systematic review	Title/abstract screening		Full-text screening	
		Inclusion criteria	**Exclusion criteria**	**Inclusion criteria**	**Exclusion criteria**
			• Abstracts could not be found		

Appendix 4: Figure A 1 – Location of Scottish breeding SPAs of each focal species



ID	SPA	ID	SPA
1	Ailsa Craig	17	Mingulay and Berneray
2	Buchan Ness to Collieston Coast	18	North Caithness Cliffs
3	Calf of Eday	19	North Colonsay and Western Cliffs
4	Canna and Sanday	20	North Rona and Sula Sgeir
5	Cape Wrath	21	Noss
6	Copinsay	22	Outer Firth of Forth and St Andrews Bay Complex
7	East Caithness Cliffs	23	Rousay
8	Fair Isle	24	Rum
9	Flannan Isles	25	Seas off Foula
10	Forth Islands	26	Seas off St Kilda
11	Foula	27	Shiant Isles
12	Fowlsheugh	28	St Abb's Head to Fast Castle
13	Handa	29	St Kilda
14	Hermaness, Saxa Vord and Valla Field	30	Sule Skerry and Sule Stack
15	Hoy	31	Sumburgh Head
16	Marwick Head	32	Troup, Pennan and Lion's Heads
		33	West Westray

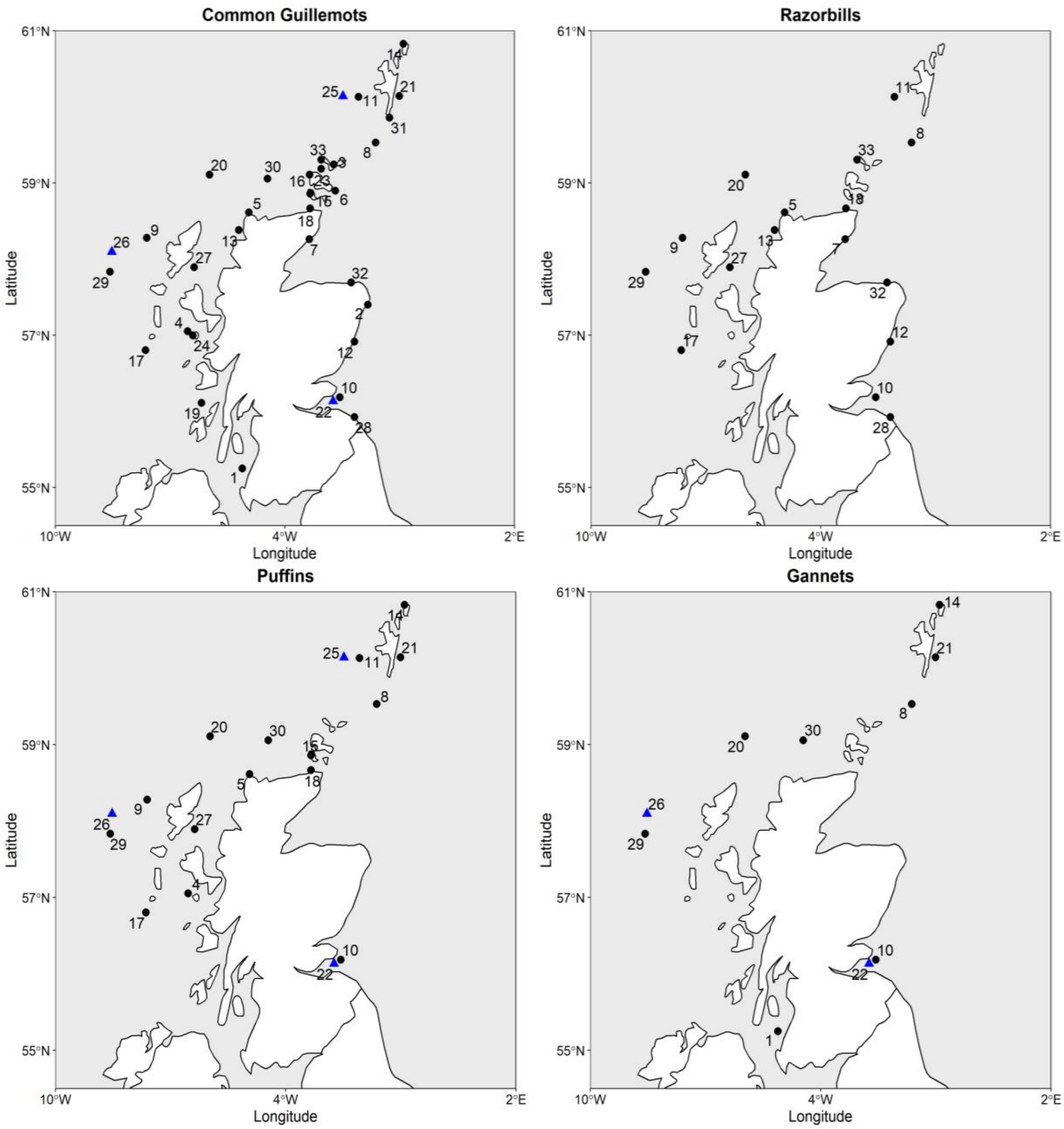


Figure A 1. Location of Scottish breeding SPAs of each focal species. Terrestrial colonies are shown with a black dot. Blue triangles correspond to marine SPAs. The ID number correspond to each SPA identifier. Only SPAs where a species is a named feature are shown (i.e. those SPAs where a species is included as part of an assemblage feature are not shown).

Appendix 5: Table A 3 – Key findings of studies for each seabird species and seabird species group for mammalian predator eradication and/or management review

Table A 3. Key findings and details of the studies for each seabird species and group of seabird species for the mammalian predator eradication and management review. Focal species are in italics. Information regarding boobies, frigatebirds, noddies, and tropicbirds were excluded as it was deemed less relevant. Colour coded by effect; red = no effect, yellow = small effect but not enough for population increase (e.g. populations stabilised, recolonizations but no evidence of breeding, decreased rate of decline), blue = effect that can lead to an increase in the population (e.g. measured increase in productivity).

Seabird species	Location	Predator - control/eradication	Effect		Source
Great Black-backed Gull	Archipelago National Park, Finland	Mink - control	No evidence that they benefited from removal	No effect	(Nordstrom et al., 2003) and (Banks et al., 2008)
	Canna and Sanday, Scotland	Brown rats - eradication	Population stabilised but prior to eradication it was decreasing	Small effect	(Luxmoore et al., 2019)
Lesser Black-backed Gull	South Wanley, England	Fox – control	Higher breeding success	Effect	(Davis et al., 2018)
	Canna and Sanday, Scotland	Brown rats - eradication	Population slightly increasing	Effect	(Luxmoore et al., 2019)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Breeding success increased despite a decline in breeding pairs	Effect	(Zonfrillo, 2001)
Herring Gull	South Wanley, England	Fox - control	Higher breeding success	Effect	(Davis et al., 2018)
	Canna and Sanday, Scotland	Brown rats - eradication	Population stabilised but prior to eradication it was decreasing	Small effect	(Luxmoore et al., 2019)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Breeding success increased	Effect	(Zonfrillo, 2001)

Seabird species	Location	Predator - control/eradication	Effect		Source
Guillemot	Canna and Sanday, Scotland	Brown rats - eradication	Population still in decline but at lower rates	Small effect	(Luxmoore et al., 2019)
Razorbill	Archipelago National Park, Finland	Mink - control	Recolonised	Small effect	(Nordstrom et al., 2003) and (Banks et al., 2008)
	Canna and Sanday, Scotland	Brown rats - eradication	Population still in decline but at lower rates	Small effect	(Luxmoore et al., 2019)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Recolonised and bred successfully	Effect	(Zonfrillo, 2001)
Puffin	Handa Island, Scotland	Black and Brown rats - eradication	Expansion and increase in breeding pairs	Effect	(Stoneman and Zonfrillo, 2005)
	Canna and Sanday, Scotland	Brown rats - eradication	Expansion and increase in breeding pairs	Effect	(Luxmoore et al., 2019)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Recolonised and bred successfully	Effect	(Zonfrillo, 2001)
Terns (Arctic Tern, Common Tern, Little Tern)	Handa Island, Scotland	Black and Brown rats - eradication	Breeding success increased but fluctuated according to external factors. Arctic Terns increased up to ~400% (in a 'good' year), and Common Terns up to ~300% (in a 'good' year)	Effect	(Stoneman and Zonfrillo, 2005)
	Archipelago National	Mink - control	Higher breeding success	Effect	(Nordstrom et al., 2003)

Seabird species	Location	Predator - control/eradication	Effect		Source
	Park, Finland				and (Banks et al., 2008)
	West coast of Scotland	Mink - control	Higher breeding success at controlled sites (0.84), compared to uncontrolled sites (0.33)	Effect	(Ratcliffe et al., 2008)
	The Uists and Isle of Lewis, Scotland	Mink - control	Breeding success was more than three times higher on sites with lower mink densities	Effect	(Ratcliffe et al., 2006)
Common Gull	Handa Island, Scotland	Black and Brown rats - eradication	Breeding success increased up to ~ 200%	Effect	(Stoneman and Zonfrillo, 2005)
	Canna and Sanday, Scotland	Brown rats - eradication	Population increasing	Effect	(Luxmoore et al., 2019)
	Archipelago National Park, Finland	Mink - control	Higher breeding success	Effect	(Nordstrom et al., 2003) and (Banks et al., 2008)
Kittiwake	Canna and Sanday, Scotland	Brown rats - eradication	Population increasing	Effect	(Luxmoore et al., 2019)
Fulmars	Handa Island, Scotland	Black and Brown rats - eradication	No evidence that they benefited from removal	No effect	(Stoneman and Zonfrillo, 2005)
	Canna and Sanday, Scotland	Brown rats - eradication	No evidence that they benefited from removal, population still declining	No effect	(Luxmoore et al., 2019)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Increased breeding success	Effect	(Zonfrillo, 2001)

Seabird species	Location	Predator - control/eradication	Effect		Source
European Shag	Canna and Sanday, Scotland	Brown rats - eradication	Population is stable and breeding success increased		(Luxmoore et al., 2019)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Recolonised and bred successfully	Effect	(Zonfrillo, 2001)
Arctic Skua	Archipelago National Park, Finland	Mink - control	Higher breeding success	Effect	(Nordstrom et al., 2003) and (Banks et al., 2008)
Auks (Ancient Murrelet, Cassin's Auklet, Scripp's Murrelet, Black Guillemot)	Langara Island, Canada	Black and Brown rats - eradication	Breeding population of Ancient Murrelets doubled, and breeding success increased	Effect	(Regehr et al., 2007)
	Langara Island, Canada	Black and Brown rats - eradication	Cassin's Auklets recolonized and evidence of breeding	Effect	(Regehr et al., 2007) and (Whitworth et al., 2015)
	Anacapa Island, USA	Black rats - eradication	Scripp's Murrelet population was 2.83 times greater after eradication. AONs increased 4.11 times. Breeding success increased	Effect	(Whitworth and Carter, 2018)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Black Guillemots recolonised	Small effect	(Zonfrillo, 2001)
Petrels and Shearwaters (European Storm petrel,	Handa Island, Scotland	Black and Brown rats - eradication	European Storm Petrels recolonised	Effect	(Stoneman and Zonfrillo, 2005)

Seabird species	Location	Predator - control/eradication	Effect		Source
Manx Shearwaters, Yelkouan Shearwaters, White-tailed Shearwater, Cory's Shearwater)			and bred successfully		
	Lundy Island, Scotland	Black and Brown rats - eradication	Population of Manx Shearwaters will increase exponentially after 12 years of eradication and will stabilise when density dependent factors limit growth	Effect	(Appleton et al., 2006)
	Malta	Black and Brown rats - control	On sites where rats were controlled, Yelkouan Shearwaters, had up to 73% higher breeding success than non-controlled sites	Effect	(Lago et al., 2019)
	Moku'auia Island, Hawaii	Black rats - eradication	White-tailed Shearwater more than doubled breeding success	Effect	(Marie et al., 2014)
	Chafarinas Islands, Spain	Black rats - control	Cory's Shearwaters' breeding success oscillated in parallel to rat control effort – higher breeding success with	Effect	(Igual et al., 2006)

Seabird species	Location	Predator - control/eradication	Effect		Source
			sites with more control		
	Ramsey Island, Wales	Brown rats - eradication	Manx Shearwater increased breeding pairs by 560%. Storm petrels increased breeding presence	Effect	(Bell et al., 2019)
	Island of Rum, Scotland	Brown rats - control	Manx Shearwaters showed no evidence that they benefited from control, likely due to other rodents present	No effect	(Lambert et al., 2021)
	Canna and Sanday, Scotland	Brown rats - eradication	Manx Shearwaters showed evidence of breeding	Effect	(Luxmoore et al., 2019)
	Lavezzu Island, Corsica	Black rats – eradication and control	The breeding success of Cory's Shearwater doubled when rats were controlled or eradicated (0.82) compared to the situation without rat management (0.45)	Effect	(Pascal et al., 2008)
	Ailsa Craig, Scotland	Black and Brown rats - eradication	Manx Shearwaters recolonised	Small effect	(Zonfrillo, 2001)

Seabird species	Location	Predator - control/eradication	Effect		Source
	Ascension Island, UK	Feral cats	Madeiran Storm Petrel did not show evidence that they benefited	No effect	(Ratcliffe et al., 2010)
	Isla Natividad, Mexico	Cats	Increased survival rates of Black-vented Shearwater	Effect	(Keitt and Tershy, 2003)

Annex 1: Systematic literature reviews

Table of Contents

1 Comprehensive overview of the steps taken during the systematic literature reviews

Following Foo et al. (2021) and Higgins et al. (2022), for each systematic literature review we undertook the steps shown in Figure 4 (Figure 3 within main document).

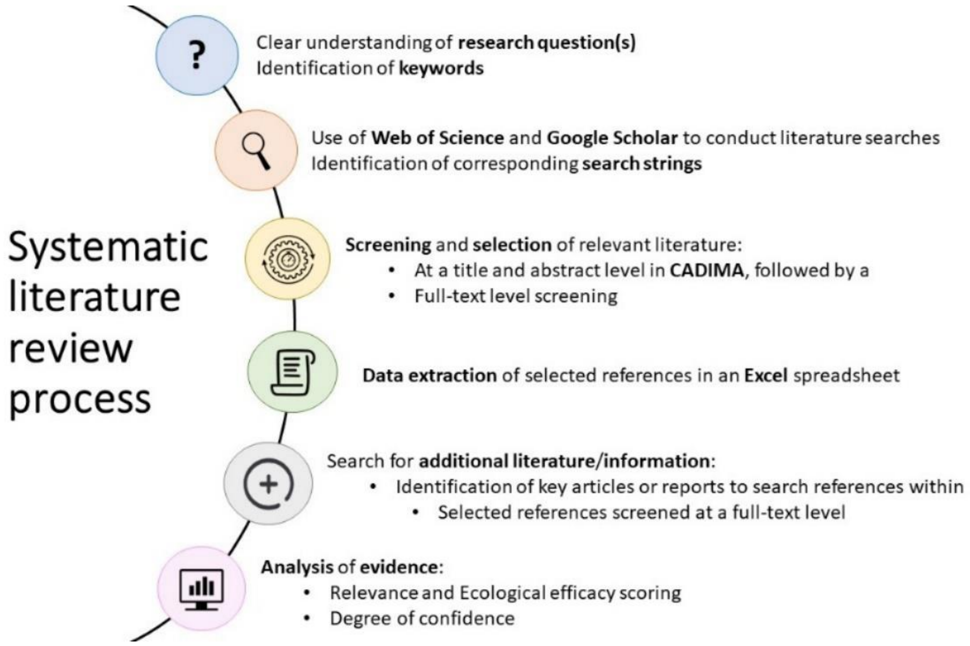


Figure 32. A visual representation illustrating the steps taken to conduct each systematic review.

1. **Defining and identifying the research questions and keywords:** Overall, research questions had the following structure: 'Would '*conservation action/s'* benefit *species*?' Appropriate research questions should be sufficiently general to address the topic of interest, but not so broad that the search becomes impractical. Therefore, while in most cases a single research question was used for a single systematic review, in some instances, several research questions were tackled within a single systematic review. Keywords varied depending on the scope of the research questions. In most instances, however, keywords included synonyms of the conservation actions, the species, Genus and English name of the focal seabirds, and other relevant key words.

2. **Conducting the literature search:**

    a. *Search engines*: We chose to undertake the literature search using two complementary search engines: Web of Science (WoS) and Google Scholar (GS). Although both are widely used academic search engines, they have different strengths and limitations. WoS is a platform that provides access to multiple databases and collections (e.g. Web of Science Core Collection and Zoological Record), which in turn provide access to peer-reviewed journals, conference proceedings, books, and other scholarly material. WoS also offers more advanced search features, such as Boolean operators, which allow for more precise searching, making it one of the most frequently used search engines in the natural sciences, especially within the ecology and evolution fields (Gusenbauer and Haddaway, 2020). On the other hand, GS is subject to limitations that make it unsuitable as the principal search engine (e.g. limited Boolean search functionality that may not allow for precise searching, results are influenced by stored research histories/geographic locations; (Gusenbauer and Haddaway, 2020)). However, here we use GS as a tool, with the specific benefit of finding relevant grey literature (unpublished research or those published outside of traditional academic publishing) that would otherwise not be found using WoS. We believed that, by using both search engines, we would find different, but often equally important and relevant literature. Although we did consider using other search engines, we are confident that the combination of WoS and GS substantially minimises the possibility of overlooking key literature.

b. *Search strings*: We used a selection of the previously identified keywords to produce appropriate search strings. In WoS we used longer search strings using Boolean operators (e.g. AND, OR). We used the Advanced Search options to search all databases and collections, and to search by Topic, which included searching titles, abstract, and indexing. We performed WoS searches with the 'Exact Search' option off. With this option disabled, WoS uses stemming and lemmatisation to expand search terms to include closely related words, though not all synonyms (e.g. searching for mouse would also include mice). For GS we used shorter and broader search strings. We searched any type of reference and did not set a publication date limit. In both engines, references were sorted by relevance. For each review, we formulated a set of different search strings and refined them through a pilot screening. The goal was to provide a key string broad enough to provide all relevant literature, but not broad enough as to make the search impractical. The selection of the number of references varied according to the review and the search engine. When five consecutive articles were not relevant to the topic, we stopped and all references up to that point, were saved for screening. We anticipated that most search results would be in English, since the search terms were based on English keywords but studies in other languages that are comprehensible to the authors (e.g. Spanish, French, Portuguese) were also considered. Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

3. **Screening and selection of relevant literature:** References obtained from WoS and GS were uploaded and screened in CADIMA (Kohl et al., 2018), a free web tool that facilitates the execution and documentation of systematic literature reviews. After eliminating duplicated records, we screened all references following a pre-defined set of inclusion criteria (see Table A 2 within main document). References were first screened at a title and abstract level, and those that advanced to the next stage

were then screened at a full-text level. Inclusion criteria depended on the scope of the topic, but overall, we were looking for studies that tested, either indirectly or directly, the effect of the conservation action on seabirds. In some instances, when several annual results of the same species at the same colony was found, we kept the most recent study and excluded the rest (e.g. Annual species status reports). While we primarily focussed on studies conducted within Scotland and the UK and on focal species, relevant information collected elsewhere or from closely related species were also included. Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

4. **Data extraction**: In a Microsoft Office Excel spreadsheet, we recorded details of all references screened at a full-text level (this information can be found in Annex 4):
    a. Initials of whoever undertook the screening: Tom Evans (TE), Claudia Tapia Harris (CTH)
    b. Title
    c. Authors
    d. Publication year
    e. Type of document: research article, review paper, report, thesis (PhD or Master's), conference proceedings, book, or book chapter
    f. Access to full text: yes or no
    g. A brief summary of the reference, including reasons for exclusion
5. **For those references that were deemed relevant for the final assessment, we also recorded the following information** (note that additional information specific to the actions was extracted if deemed relevant. This information can be found in Annex 4):
    a. Study species
    b. Duration of study
    c. Location of study
    d. Region of study: OSS (Orkney and Shetland), NWS (Northwest Scotland), NES (North and Northeast Scotland), Southwest Scotland (SWS), Southeast Scotland (SES), NEE (Northeast England), EE (East England), SEE (Southeast England), SWE (Southwest England), or name of the country if not within the UK. Regional definitions followed those previously defined for the Seabird Monitoring Programme (see Figure 2.3 in Cook and Robinson (2010)), though with the Orkney Islands and Shetland Islands combined as one region and the North and Northeast Scotland regions combined (Moray Firth and Aberdeenshire coasts).

e. What seabird demographic parameters were being tested plus any potential drivers of demographic parameters: e.g. productivity, survival, diet, abundance

f. Age class of studied individuals: adults, chicks, fledglings, breeding pairs

g. How conservation action was tested: directly, indirectly

h. Sample size: in terms of location, years, individuals, pairs

i. Study design: methods, statistical analysis

j. A brief summary of the methods

k. Whether the action had an impact on the species: yes, no

l. If yes, the direction of impact: beneficial, detrimental

m. A brief summary of the results

6. **Additional literature**: We are aware that relevant studies could have been missed during this literature search. Therefore, we also made use of expert judgment and subject knowledge of the authors, to identify highly relevant key studies (from publications both identified and not identified by the literature search). All references within these studies were scanned to identify any additional relevant references. All newly identified references were screened at full-text level, repeating steps 4 and 5.

Steps 3–5 were performed by one of the authors (either TE or CTH). The inclusion/exclusion criteria, however, were agreed on prior to these steps. Early in this process, we met regularly to refine the inclusion and exclusion criteria, standardise data extraction methods, and to jointly screen several examples. In instances where there was uncertainty regarding whether a study should progress to the following stage, the other author assisted in its evaluation.

2 Methods of the systematic literature review on 'Sandeel fishery closure'

2.1 Research questions, keywords, and search strings

The corresponding research question to this conservation action is: 'Would Kittiwake populations benefit from widening the spatial extent of the closure of the sandeel fishery?'

We identified the following keywords: 'sandeel' and any variation thereof ('Sand eel', 'sandlance', 'sand lance', 'prey'), main sandeel genera ('*Hyperoplus*', '*Gymnammodytes*', '*Ammodytes*'), 'fishery' and any variation thereof ('industrial fishery', 'fishery management'), closure synonyms ('closure', 'termination', 'cessation'), and the species, genus, and English name of 'Kittiwake' ('*Rissa*', '*Rissa tridactyla*', 'Kittiwake').

We identified the most relevant keywords and undertook a pilot screening with several search strings in Web of Science (WoS) and Google Scholar (GS). The search strings and corresponding number of records for each search engine are listed below. The option highlighted in bold indicates the search string that was used for the systematic literature review. Note that "TS" means "topic search", and it is an operator used in Web of Science.

1. Web of Science (WoS)

Option 1: TS = (sandeel fishery closure) = 19 results

Option 2: ((TS=(kittiwake)) AND TS=(sandeel)) AND TS=(fishery) = 42 results

Option 3: (TS=(sandeel OR sand eel or Hyperoplus OR Gymnammodytes OR Ammodytes)) AND TS=(Fishery OR Industrial* fishery) = 609 results

Option 4: (((TS=(sandeel OR sand eel or Hyperoplus OR Gymnammodytes OR Ammodytes)) AND TS=(Fishery OR Industrial* fishery)) AND TS=(Closure)) AND TS=(Kittiwake OR Rissa) = 14 results

Option 5: ((TS=(kittiwake* OR Rissa)) AND TS=(prey OR sandeel* OR sand eel* OR sand lance* OR Hyperoplus OR Gymnammodytes OR Ammodytes)) AND TS=(fisher*) = 106 results

2. Google Scholar (GS)

Option 1: Sandeel fishery = 12,000 results

Option 2: Sandeel fishery closure = 2,400 results

Option 3; Sandeel fishery and kittiwake = 1,350 results

Option 4: Sandeel fisher* and kittiwakes Rissa = 872 results

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

2.2 Study selection

On 23 February 2023 we conducted a literature search on WoS and GS (Figure 7; Figure 6 within main document). A total of 978 references were identified; 106 in WoS, of which all were exported for screening, and 872 in GS, of which the first 100 records were exported. This first search yielded a total of 206 records, of which 32 were duplicates (i.e. included by both WoS and GS) and were automatically removed prior to screening. All 174 unique records were screened at title and abstract level to identify and exclude studies outside the review's scope, such as those studies unrelated to sandeels, sandeel fisheries, fishery management and Kittiwakes, and those from which the abstract could not be assessed (see Table A 2 within the main document). Studies where this criterion was unclear, were kept for full-text screening. At this stage, we excluded 79% (137) of the records. All 37 remaining records were screened in their entirety and relevant information was recorded. At this stage, we excluded studies that did not test the effect, directly or indirectly, of a sandeel fishery closure, or a similar type of sandeel fishery management, on any demographic parameter of Kittiwakes, those that did not focus on sandeels and Kittiwakes, and those that did not provide new evidence on the matter. We retained 15 records for final assessment.

Additionally, we identified five key articles and reports that explored the effect of sandeel fishery closure on Kittiwakes: Furness et al. (2013a), Furness (2021), Pearce-Higgins et al. (2021), McGregor et al. (2022), and Searle et al. (2023), and searched references within to identify additional relevant literature that may have been overlooked. We identified, read the full text, and extracted relevant information from seven references. From this process, we retained three additional records for final assessment. Overall, 18 references were included for the final review.

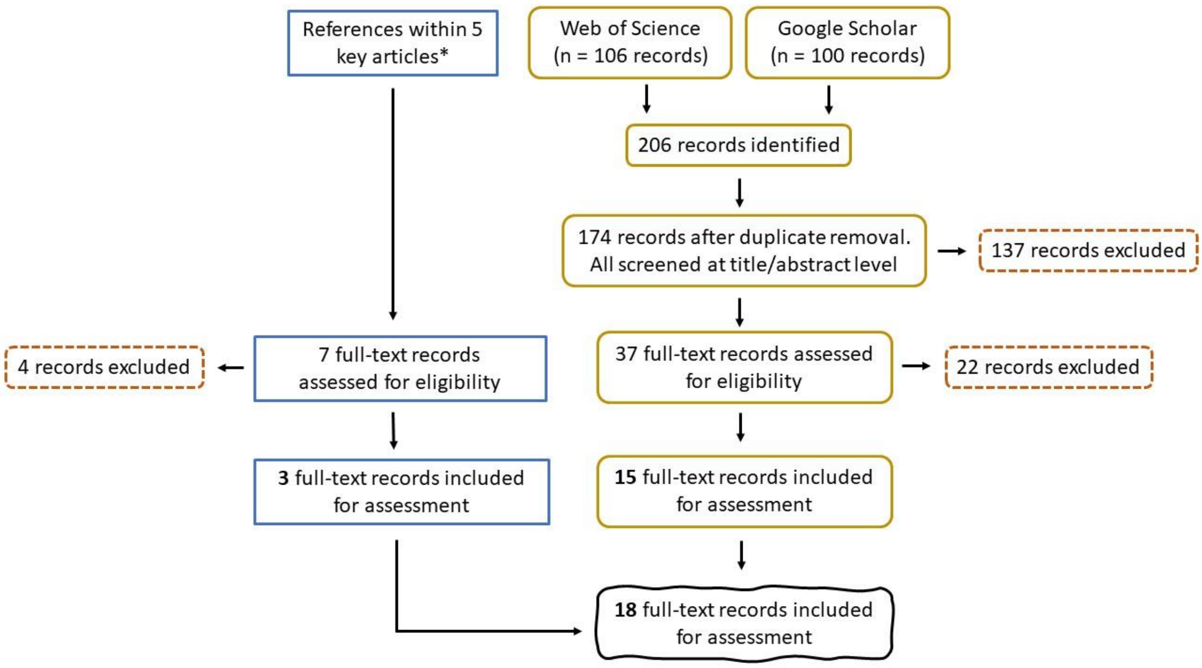


Figure 33. Flow diagram depicting the study selection process for the sandeel fishery closure. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within

the undulating black polygon. *Key articles are: Furness et al. (2013a), Furness (2021), Pearce-Higgins et al. (2021), McGregor et al. (2022), and Searle et al. (2023).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

3 Methods of the systematic literature review on 'Fishery closure or enhanced management on prey fisheries'

3.1 Research questions, keywords, and search strings

The corresponding research question to this conservation action is: '*Would the focal seabird species benefit from enhanced management of fisheries that target seabird prey fish species in Scotland*?' In addition to the key question, we also sought to identify which prey species may be most impacted by fisheries and which seabird species could most benefit from any changes in management.

We identified the following keywords: Fishery/management related: Fishery/fishery management/sustainable management/sustainability/sustainable fishing

Prey: sprat, herring, mackerel; Sprattus sprattus, Atlantic herring, Clupea harengus, Atlantic mackerel, Scomber scombrus

Seabirds (focal): Seabirds/Marine birds; Kittiwake/Rissa/Rissa tridactyla; Larus/Great Black-backed Gull/Larus marinus/Herring Gull/Larus argentatus/Lesser Black-backed Gull/Larus fuscus; Auk/alcid; Guillemot/Common Murre/Uria aalge; Razorbill/Alca torda; Atlantic Puffin/Puffin/Fratercula arctica; Gannet/Morus/Morus bassanus/Sula bassana

We identified the most relevant keywords and conducted a pilot screening by using multiple search strings in Web of Science (WoS) and Google Scholar (GS). The search strings and corresponding number of records for each search engine are listed below. The bolded options denote the search strings used for the systematic literature review. All have a brief explanation as to why they were or were not used.

1. Web of Science (WoS)

Option 1: ((TS=(Fisher* OR "fishery management" OR (sustain* AND fisher*) OR ("ecosystem based" AND fisher*))) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(Kittiwake OR Rissa OR "Rissa tridactyla" OR Larus OR "Great Black-backed Gull" OR "Larus marinus" OR "Herring Gull" OR "Larus argentatus" OR "Lesser Black-backed Gull" OR "Larus fuscus" OR Auk OR alcide OR "Common Guillemot" OR "Common Murre" OR "Uria aalge" OR "Razorbill" OR "Alca torda" OR "Atlantic Puffin" OR "Fratercula arctica" OR "Northern Gannet" OR "Morus bassanus" OR "Sula bassana") = 113 results. First page of results generally not relevant, more diet focused than relating to fisheries

Option 2: ((TS=(Fisher* OR "fishery management" OR (sustain* AND fisher*) OR ("ecosystem based" AND fisher*))) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR

"Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(seabird OR "marine bird" OR Kittiwake OR Rissa OR "Rissa tridactyla" OR Larus OR "Great Black-backed Gull" OR "Larus marinus" OR "Herring Gull" OR "Larus argentatus" OR "Lesser Black-backed Gull" OR "Larus fuscus" OR Auk OR alcid OR "Common Guillemot" OR "Common Murre" OR "Uria aalge" OR "Razorbill" OR "Alca torda" OR "Atlantic Puffin" OR "Fratercula arctica" OR "Northern Gannet" OR "Morus bassanus" OR "Sula bassana") = 192 results. Results relevance low.

Option 3: ((TS=(Fisher* OR "fishery management" OR (sustain* AND fisher*) OR ("ecosystem based" AND fisher*) OR "prey depletion")) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(seabird OR "marine bird") = 154 results. Results ordered better in terms of relevance – first page of results generally relevant in terms of fisheries impacting prey availability.

Option 4: (TS=(Fisher* OR "fishery management" OR (sustain* AND fisher*) OR ("ecosystem based" AND fisher*) OR "prey depletion" OR "prey availability")) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(seabird OR "marine bird") = 179 results. Results generally relevant, though some less specifically related to fisheries.

Option 5: ((TS=(fisher* AND (management OR sustainable OR "ecosystem based"))) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(seabird OR "marine bird") = 56 results. Mostly relevant, though quite a few non NE Atlantic.

Option 6: ((TS=("prey depletion" OR overfish* OR (fisher* AND (management OR sustainable OR "ecosystem based")))) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(seabird OR "marine bird") = 61 results. Similar level of relevance to above

Option 7: (((TS=(fisher*)) AND TS=("prey depletion" OR overfish* OR "prey availability" OR "prey abundance" OR "diet")) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(seabird OR "marine bird" OR Kittiwake OR Rissa OR "Rissa tridactyla" OR Larus OR "Great Black-backed Gull" OR "Larus marinus" OR "Herring Gull" OR "Larus argentatus" OR "Lesser Black-backed Gull" OR "Larus fuscus" OR Auk OR alcide OR "Common Guillemot" OR "Common Murre" OR "Uria aalge" OR "Razorbill" OR "Alca torda" OR "Atlantic Puffin" OR "Fratercula arctica" OR "Northern Gannet" OR "Morus bassanus" OR "Sula bassana") = 99 results. Results partially relevant though doesn’t seem that well ordered in terms of relevancy.

Option 8: ((TS=(Fisher* OR "fishery management" OR (sustain* AND fisher*) OR ("ecosystem based" AND fisher*) OR "prey depletion")) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(seabird OR "marine bird"OR Kittiwake OR Rissa OR "Rissa tridactyla" OR Larus OR "Great Black-backed Gull" OR "Larus marinus" OR "Herring

Gull" OR "Larus argentatus" OR "Lesser Black-backed Gull" OR "Larus fuscus" OR Auk OR alcide OR "Common Guillemot" OR "Common Murre" OR "Uria aalge" OR "Razorbill" OR "Alca torda" OR "Atlantic Puffin" OR "Fratercula arctica" OR "Northern Gannet" OR "Morus bassanus" OR "Sula bassana") = 192 results. Fairly relevant and ok order, though still quite a few not relevant results on first page.

Option 9: ((TS=(Fisher* OR "fishery management" OR (sustain* AND fisher*) OR ("ecosystem based" AND fisher*) OR "prey depletion")) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(Kittiwake OR Rissa OR "Rissa tridactyla" OR Larus OR "Great Black-backed Gull" OR "Larus marinus" OR "Herring Gull" OR "Larus argentatus" OR "Lesser Black-backed Gull" OR "Larus fuscus" OR Auk OR alcide OR "Common Guillemot" OR "Common Murre" OR "Uria aalge" OR "Razorbill" OR "Alca torda" OR "Atlantic Puffin" OR "Fratercula arctica" OR "Northern Gannet" OR "Morus bassanus" OR "Sula bassana") = 113 results. Better than #8 being more specific to the seabird species of interest.

Option 10: **((TS=(Fisher* OR "fishery management" OR (sustain* AND fisher*) OR ("ecosystem based" AND fisher*) OR "prey depletion" OR "prey abundance" OR "prey availability")) AND TS=(sprat OR herring OR mackerel OR "Sprattus sprattus" OR "Atlantic herring" OR "Clupea harengus" OR "Atlantic mackerel" OR "Scomber scombrus")) AND TS=(Kittiwake OR Rissa OR "Rissa tridactyla" OR Larus OR "Great Black-backed Gull" OR "Larus marinus" OR "Herring Gull" OR "Larus argentatus" OR "Lesser Black-backed Gull" OR "Larus fuscus" OR Auk OR alcide OR "Common Guillemot" OR "Common Murre" OR "Uria aalge" OR "Razorbill" OR "Alca torda" OR "Atlantic Puffin" OR "Fratercula arctica" OR "Northern Gannet" OR "Morus bassanus" OR "Sula bassana")** = 137 results. Better than #9 as appears to include more studies related to prey abundance/availability.

2. Google Scholar (GS)

Option 1: seabird fishery prey availability abundance = 25,300 results. First results relevant though very large number of results.

Option 2-4: As for Option 1 with addition of the prey species (i.e. a separate search for each prey species):

- **seabird "Sprattus sprattus" fishery prey availability abundance** = **1,490 results**
- **seabird "Clupea harengus" fishery prey availability abundance** = **4,880 results**
- **seabird "Scomber scombrus" fishery prey availability abundance** = **1,930 results**

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

3.2 Study selection

On 11 April 2023 we conducted a literature search on WoS and three literature searches in GS (Figure 10; Figure 9 within main document). With this review having three target prey fish species, for the GS searches we used a separate search for each prey species, otherwise there were insufficient relevant results for each prey species. In total, 8,630 references were identified; 340 in WoS, of which 110 were exported for screening. Then for the GS searches, there were 1490 results for the Sprat specific search, of which the first 50 records were exported. For Herring, 4870 results, with the first 74 results exported for screening. Then finally for Mackerel, 1930 results, of which the first 52 results were exported for screening. Together all searches yielded a total of 286 records, of which 81 were duplicates (i.e. included at least twice) and were automatically removed prior to screening. All 205 unique records were screened at title and abstract level to identify and exclude studies outside the review's scope. Excluded studies included those where the seabird and prey target species were not researched, the geographic region was not North Atlantic/Europe, where fisheries were only considered in terms of bycatch or discards (rather than in terms of prey depletion) and those where the abstract could not be assessed (see Table A 2 within the main document). Studies where it was unclear whether they met the inclusion criterion were retained for full-text screening. At this stage, we excluded 75% (153) of the records.

The remaining 52 records were screened in their entirety and relevant information was recorded. We, additionally, recorded information on the prey fish species included, what type of fisheries management was used, and the seabird season that studies occurred in. At this stage, we were looking for studies that measured, directly or indirectly, empirically, or theoretically, the effect that changes in the management of fisheries that target seabird prey fish species could have on seabird population (see Table A 2 within the main document). Our ideal studies would have been those where any seabird demographic parameter was researched and compared under different fishery management regimes, but due to the nature of this topic, few studies addressed this directly. Therefore, we included studies that provided any type of measure (empirically or theoretically) of the impact to seabirds of fisheries targeting fish species that were also seabird prey fish. We excluded studies that mentioned fisheries but only in a more speculative or contextual way (e.g. a brief mention in the introduction or discussion sections), those that did not include the relevant region (North Atlantic/Europe), and those where the full texts were not available. We retained 8 records for final assessment.

Additionally, we identified 7 key articles and reports that included consideration of fishery impacts on seabirds in terms of prey depletion (Furness et al., 2013a; Heath et al., 2017; Furness, 2021; Pearce-Higgins et al., 2021; Cunningham et al., 2022; McGregor et al., 2022; Montevecchi, 2023). Cited literature within these were checked to identify relevant literature that may have been overlooked during the systematic literature search. We identified, read the full text, and extracted relevant information from five references. From this process, we retained four records for final assessment. Overall, 12 references were included for the final review.

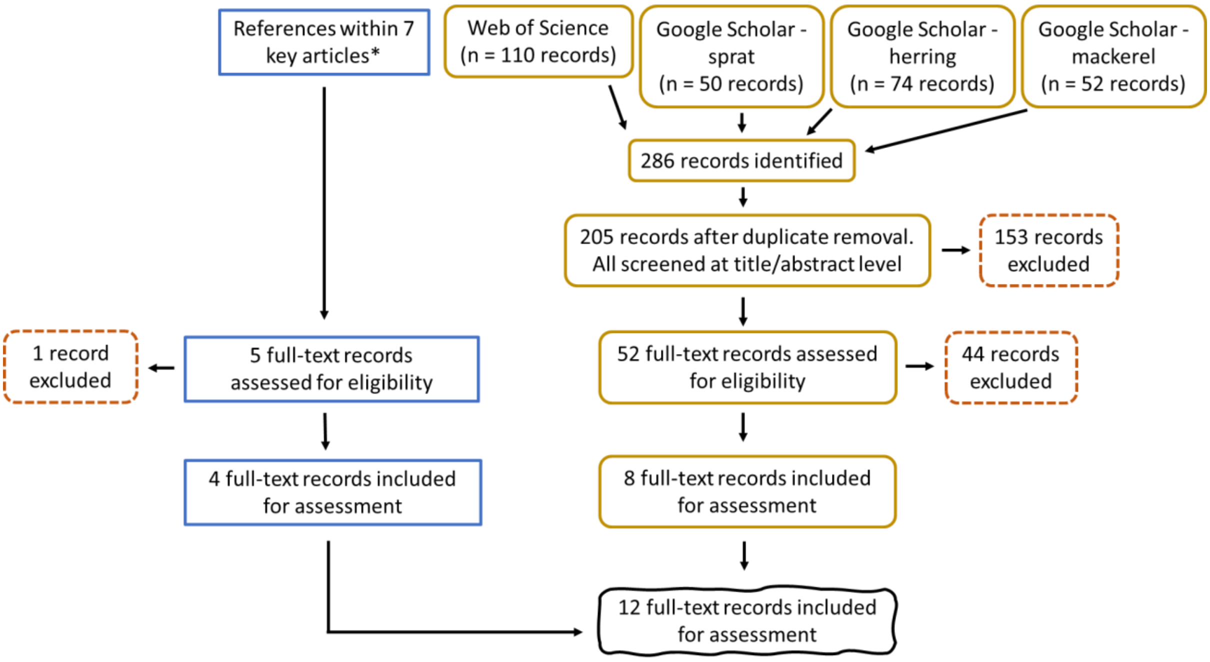


Figure 34. Flow diagram depicting the study selection process for the systematic review on enhanced management of prey fisheries. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: (Furness et al., 2013a); Heath et al. (2017); (Furness, 2021; Pearce-Higgins et al., 2021; Cunningham et al., 2022; McGregor et al., 2022; Montevecchi, 2023).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

4 Methods of the systematic literature review on ‘End of the Gannet harvest at Sula Sgeir’

4.1 Research questions, keywords, and search strings

The corresponding research question to this conservation action is: ‘*Would the Gannet population at Sula Sgeir and/or in the wider SPA network benefit from ending the harvest of Gannet chicks at Sula Sgeir*?’

We identified the following keywords: ‘harvest’, its synonyms and related activities (‘cessation’, ‘termination’, ‘poach’, ‘hunt’), the objects subject to harvest (‘chicks’, ‘eggs’, ‘young’, ‘adults’) and the species, genus, previous genus, closely related species, and the English and Scottish Gaelic name of ‘Gannet (‘*Morus*’, ‘*bassanus*’, ‘Sula’, ‘booby’, ‘guga’, ‘seabird’), ‘conservation’, ‘population’, ‘Sula Sgeir’, and ‘Scotland’.

We identified the most relevant keywords and conducted a pilot screening by using multiple search strings in Web of Science (WoS) and Google Scholar (GS). The search strings and corresponding number of records for each search engine are listed below. The bolded options denote the search strings used for the systematic literature review. All have a brief explanation as to why they were or were not used.

1. Web of Science (WoS)

Option 1: (TS=(‘chick harvest*’ OR ‘egg harvest*’ OR ‘guga harvest*’ OR ‘harvest*’ OR ‘poach’)) AND TS=(Gannet OR Morus OR Sula OR booby OR guga) = 359 results. Too broad.

Option 2: (TS=(chick* OR egg*) AND TS=(Gannet OR Morus OR Sula OR booby OR guga) AND TS=(harvest* OR poach*)) = 21 results. Restricted.

Options 3 and 4: (TS=(‘harvest*’ OR ‘poach’)) AND TS=(Gannet OR Morus OR Sula OR booby OR guga) AND TS=(Sula Sgeir) = 4 results and (TS=(‘harvest*’ OR ‘poach’)) AND TS=(Gannet OR Morus OR Sula OR booby OR guga) AND TS=(Scotland) = 6 results. Both extremely restricted.

Option 5: ((TS=(chick* or egg*)) AND TS=(Gannet OR Morus OR Sula OR boob* OR guga OR seabird)) AND TS=(harvest* OR poach* OR hunt*) = 157 results. Many results were not pertinent, as they mostly investigated prey-related activities (e.g. food web processes, influence of diet on reproductive success).

Option 6: (TS=(Gannet OR Morus OR Sula OR boob* OR guga OR seabird)) AND TS=(harvest* OR poach* OR hunt*) AND TS=(chick* OR egg* OR young*) AND TS=(conservation OR population) = 135 results. This search excluded all prey-related studies, expanded the search to consider all seabirds, and narrowed the searches to studies considering the conservation and population effect of harvests.

2. Google Scholar (GS)

Option 1: egg and chick harvest of Gannets = 1900 results. Too broad.

Option 2: pause of seabird egg and chick harvest = 9510 results. Too broad.

Option 3: effect of ending seabird harvests = 18,200 results. Too broad.

Option 4: harvest of Gannet egg and chick in Sula Sgeir = 72 results. Too narrow.

Option 5: harvest and hunt of Gannet Sula egg and chick = 490 results. Did not provide many relevant studies.

Option 6: effect of ending seabird harvest = 19,300 results. Broad search to obtain a comprehensive understanding of the most relevant studies regarding the effect of ending seabird harvests around the world.

Option 7: harvest of Gannets in 'Sula Sgeir' = 115 results. Additional search term to retrieve all relevant information relating to Gannets in Sula Sgeir.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

4.2 Study selection

On 4 April 2023 we conducted a literature search on WoS and two literature searches in GS (Figure 13; Figure 12 within main document). Due to the nature of the conservation action, we aimed to understand the effect of ending harvests on seabird populations, and to identify all available information regarding Gannets on Sula Sgeir, the colony specifically referred to in this action. Because we could not produce a single search string in GS that could provide all this information, we undertook two different searches. In total, 19,550 references were identified; 135 in WoS, of which all were exported for screening, 19,300 in the broader GS search, of which the first 50, most relevant, records were exported, and 115 in the limited GS search, of which the first 50 records were exported. We selected the first 50 records from both GS searches because studies from the 6th page onwards (i.e. results 50+) did not seem relevant. All searches yielded a total of 235 records, of which 16 were duplicates (i.e. included at least twice) and were automatically removed prior to screening. All 219 unique records were screened at title and abstract level to identify and exclude studies outside the review's scope, such as those records where the harvest was unrelated to seabird chicks or eggs (e.g. harvest of adults, shorebirds or marine mammals, prey-related studies, guano harvest, seabird harvest by fisheries), where chick or egg harvest was mentioned as a potential threat, but was not tested, where harvest at Sula Sgeir was briefly mentioned, and those from which the abstract could not be assessed. Studies where this criterion was unclear, were kept for full-text screening. At this stage, we excluded 71% (156) of the records.

All remaining 63 records were screened in their entirety and relevant information was recorded. We, additionally, recorded information on whether eggs or chicks were being harvested, as well as the proportion of the population that was harvested at each study site. At this stage, we were looking for studies that measured, directly or indirectly, empirically, or theoretically, the effect that egg and/or chick harvest had on seabird populations (see Table A 2 within the main document). Our ideal studies would have been those where any seabird demographic parameter was researched and compared before the period when harvest started, during the harvest, and once the harvest was stopped completely, but due to the nature of this activity, these studies were difficult to come by. Therefore, we included studies that provided any type of measure (empirically or theoretically) of the impact of the harvest on seabirds, including studies that modelled or simulated population trends under different levels of harvest intensities and those that provided a threshold for a sustainable harvest. We excluded studies that briefly mentioned harvest as a potential threat, but was not measured or tested in any way, those that did not provide new evidence on the matter, and those where the full texts were not available. We retained 11 records for final assessment.

Additionally, we identified six key articles and reports that explored the effect of harvest or end of harvest on seabirds or that could provide references related to the Gannet harvest at Sula Sgeir: Furness et al. (2013a), Trinder (2016), Lewis et al. (2017), Furness (2021), Pearce-Higgins et al. (2021), and Naves and Rothe (2023), and searched references within to identify relevant literature that may have been overlooked during the systematic literature search. We identified, read the full text, and extracted relevant information from six references. From this process, we retained two records for final assessment. Overall, 13 references were included for the final review.

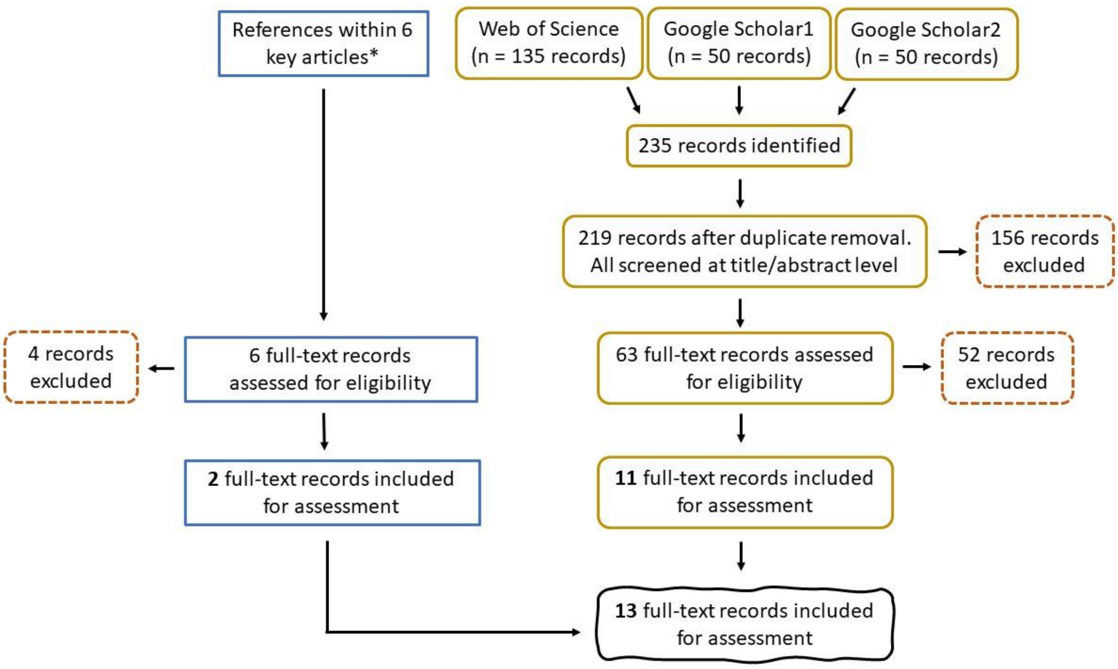


Figure 35. Flow diagram depicting the study selection process for the systematic review on ending the Gannet harvest at Sula Sgeir. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Furness et al. (2013a), Trinder (2016), Lewis et al. (2017), Furness (2021), Pearce-Higgins et al. (2021), and Naves and Rothe (2023).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

5 Methods of the systematic literature review on 'Mammalian predator eradication and/or management'

5.1 Research questions, keywords, and search strings

This conservation action was associated with two research questions. The first, '*What is the potential for seabirds to have increased productivity or survival from mammalian predator eradication/control*?' explores the effect of eradication and/or control of mammalian predators on seabird populations. Then the second question, '*Among mammalian predators, which ones offer the most potential for effective eradication and/or control*?', aims to identify the mammalian species with higher probabilities of eradication and/or management success.

We identified the following keywords: 'Eradication' and synonyms ('extermination', 'annihilation', 'elimination', 'management', 'control', 'lethal control', 'removal'), 'predator' and related terms ('invasive species', 'non-native species', 'alien', 'exotic'), the English, scientific, and species group names of the focal species ('Gull', 'Larus', 'Great Black-backed Gull', '*Larus marinus*', 'Herring Gull', '*Larus argentatus*', 'Lesser Black-backed Gull', '*Larus fuscus*', 'Guillemot', 'Common Murre', '*Uria aalge*', 'Razorbill', '*Alca torda*', 'Atlantic Puffin', 'Puffin', '*Fratercula arctica*', 'Auk', 'Alcid', 'seabird'), the most common mammalian predators in the UK[18] ('mammal', 'Black rat', '*Rattus rattus*', 'Brown rat', '*Rattus norvegicus*', 'Polynesian rat', '*Rattus exulans*', 'rodent', 'House Mice', '*Mus musculus*', 'fox', '*Vulpes vulpes*', 'American Mink', '*Neogale vison*', 'cat', '*Felis catus*', 'stoat', '*Mustela erminea*', 'mustelids'), and a Scottish-related geographic scope ('UK', 'British Isles', 'Scotland', 'Scottish islands'). Hedgehogs were also identified as potential mammalian predators of seabirds in the UK, however, we excluded them as focal predators because their eradication would mostly benefit ground-nesting waders rather than seabird species (Thompson and Ferguson, 2019).

We identified the most relevant keywords and conducted a pilot screening by using multiple search strings in Web of Science (WoS) and Google Scholar (GS). The search strings and corresponding number of records for each search engine are listed below. The bolded options denote the search strings used for the systematic literature review. All have a brief explanation as to why they were or were not used.

1. Web of Science (WoS)

Option 1: ((TS=("mammal*" OR "Black rat*" OR "Rattus rattus" OR "Brown rat*" OR "Rattus norvegicus" OR "Polynesian rat*" OR "Rattus exulans" OR "Rodent*" OR "House Mice" OR "House Mouse" OR "Mus musculus" OR "Fox*" OR "Vulpes vulpes" OR "American Mink*" OR "Neogale vison" OR "Cat*" OR "Felis catus" OR "Stoat*" OR "Mustela erminea" OR "Mustelid*" OR "mammal* predator*" OR "invasive non-native mammal*" OR "mammal* alien species")) AND TS=("eradicate" OR "control" OR "management" OR "removal")) AND TS=("Seabird*" OR "Gull*" OR "Larus" OR "Great Black-backed Gull*" OR "Larus marinus"

[18] https://biosecurityforlife.org.uk

OR “Herring Gull*” OR “Larus argentatus” OR “Lesser Black-backed Gull*” OR “Larus fuscus” OR “Guillemot*” OR “Common Murre*” OR “Uria aalge” OR “Razorbill*” OR “Alca torda” OR “Atlantic Puffin*” OR “Puffin*” OR “Fratercula arctica” OR “Auk*” OR “alcid*”) = 6,394 results. List of all identified mammalian predators, synonyms for eradication, and all focus species. Too broad.

Option 2: ((TS=(“mammal*” OR “Black rat*” OR “Rattus rattus” OR “Brown rat*” OR “Rattus norvegicus” OR “Polynesian rat*” OR “Rattus exulans” OR “Rodent*” OR “House Mice” OR “House Mouse” OR “Mus musculus” OR “Fox*” OR “Vulpes vulpes” OR “American Mink*” OR “Neogale vison” OR “Cat*” OR “Felis catus” OR “Stoat*” OR “Mustela erminea” OR “Mustelid*” OR “mammal* predator*” OR “invasive non-native mammal*” OR “mammal* alien species”)) AND TS=(“eradication” OR “control” OR “management” OR “removal”)) AND TS=(“Gull*” OR “Larus” OR “Great Black-backed Gull*” OR “Larus marinus” OR “Herring Gull*” OR “Larus argentatus” OR “Lesser Black-backed Gull*” OR “Larus fuscus” OR “Guillemot*” OR “Common Murre*” OR “Uria aalge” OR “Razorbill*” OR “Alca torda” OR “Atlantic Puffin*” OR “Puffin*” OR “Fratercula arctica” OR “Auk*” OR “alcid*”) = 4,462 results. Like Option 1 but without ‘seabird*’. Still too broad.

Option 3: ((TS=(“mammal*” OR “Black rat*” OR “Rattus rattus” OR “Brown rat*” OR “Rattus norvegicus” OR “Polynesian rat*” OR “Rattus exulans” OR “Rodent*” OR “House Mice” OR “House Mouse” OR “Mus musculus” OR “Fox*” OR “Vulpes vulpes” OR “American Mink*” OR “Neogale vison” OR “Cat*” OR “Felis catus” OR “Stoat*” OR “Mustela erminea” OR “Mustelid*” OR “mammal* predator*” OR “invasive non-native mammal*” OR “mammal* alien species”)) AND TS=(“eradication” OR “control” OR “management” OR “removal”)) AND TS=(“Seabird*” OR “Gull*” OR “Larus” OR “Great Black-backed Gull*” OR “Larus marinus” OR “Herring Gull*” OR “Larus argentatus” OR “Lesser Black-backed Gull*” OR “Larus fuscus” OR “Guillemot*” OR “Common Murre*” OR “Uria aalge” OR “Razorbill*” OR “Alca torda” OR “Atlantic Puffin*” OR “Puffin*” OR “Fratercula arctica” OR “Auk*” OR “alcid*”) AND TS=("UK" OR “Brit*” OR “Ireland” OR “Scotland” OR “Scott*”) = 506 results. Like Option 1 but added a string regarding geographic scope.

Option 4: (((TS=(“mammal*” OR “Rat*” OR “Rattus” OR “Rodent*” OR “Mice” OR “Mouse” OR “Mus” OR “Fox*” OR “Vulpes” OR “Mink*” OR “Neogale” OR “Cat*” OR “Felis” OR “Stoat*” OR “Mustela” OR “Mustelid*” OR “mammal* predator*” OR “invasive non-native mammal*” OR “mammal* alien species”)) AND TS=(“eradication” OR “control” OR “management” OR “removal”)) AND TS=(“Seabird*” OR “Gull*” OR “Larus” OR “Great Black-backed Gull*” OR “Larus marinus” OR “Herring Gull*” OR “Larus argentatus” OR “Lesser Black-backed Gull*” OR “Larus fuscus” OR “Guillemot*” OR “Common Murre*” OR “Uria aalge” OR “Razorbill*” OR “Alca torda” OR “Atlantic Puffin*” OR “Puffin*” OR “Fratercula arctica” OR “Auk*” OR “alcid*”)) AND TS=("UK" OR “Brit*” OR “Ireland” OR “Scotland” OR “Scott*”) = 737 results. Like Option 3 but changed mammalian predators to broader terms. Results did not seem to be relevant. Most references focussed on research on avian (gull) as predators, seabird population status, or effects of mammal predation on seabirds.

Option 5: ((TS=(“mammal*” OR “Black rat*” OR “Rattus” OR “Brown rat*” OR “Polynesian rat*” OR “Rodent*” OR “House Mice” OR “House Mouse” OR “Mus” OR “Fox*” OR

"Vulpes" OR "Mink*" OR "Neogale" OR "Cat*" OR "Felis" OR "Stoat*" OR "Mustela" OR "Mustelid*" OR "mammal* predator*" OR "invasive non-native mammal*" OR "mammal* alien species")) AND TS=("eradication" OR "control" OR "management" OR "removal")) AND TS=("Seabird*" OR "Gull*" OR "Larus" OR "Great Black-backed Gull*" OR "Larus marinus" OR "Herring Gull*" OR "Larus argentatus" OR "Lesser Black-backed Gull*" OR "Larus fuscus" OR "Guillemot*" OR "Common Murre*" OR "Uria aalge" OR "Razorbill*" OR "Alca torda" OR "Atlantic Puffin*" OR "Puffin*" OR "Fratercula arctica" OR "Auk*" OR "alcid*") AND TS=("UK" OR "Brit*" OR "Ireland" OR "Scotland" OR "Scott*") = 511 results. Like Option 4 but removing the species of mammalian predators. This search excluded all avian predator studies, expanded the search to consider all seabirds, and narrowed the searches to provide studies undertaken within the British Isles and Ireland.

Option 6: ((TS=("mammal*" OR "Black rat*" OR "Rattus" OR "Brown rat*" OR "Polynesian rat*" OR "Rodent*" OR "House Mice" OR "House Mouse" OR "Mus" OR "Fox*" OR "Vulpes" OR "Mink*" OR "Neogale" OR "Cat*" OR "Felis" OR "Stoat*" OR "Mustela" OR "Mustelid*" OR "mammal* predator*" OR "invasive non-native mammal*" OR "mammal* alien species")) AND TS=("eradication" OR "control" OR "management" OR "removal")) AND TS=("Seabird*" OR "Gull*" OR "Larus" OR "Great Black-backed Gull*" OR "Larus marinus" OR "Herring Gull*" OR "Larus argentatus" OR "Lesser Black-backed Gull*" OR "Larus fuscus" OR "Guillemot*" OR "Common Murre*" OR "Uria aalge" OR "Razorbill*" OR "Alca torda" OR "Atlantic Puffin*" OR "Puffin*" OR "Fratercula arctica" OR "Auk*" OR "alcid*") = 6,416 results. Like Option 5 but without the geographic scope aspect. This search expanded the search to consider mammalian eradication and/or management on all seabirds around the world.

2. Google Scholar (GS)

Option 1: Mammal predator eradication for seabirds = 20,000 results.

Option 2: Mammal predator eradication for seabird in UK or Britain = 18,800 results.

Option 3: Rat, Mouse, Fox, Mink, Cat eradication to protect Gulls, Razorbills, Guillemots, and Puffins = 97 results.

Option 5: Mammal predator eradication to protect UK seabird colonies = 17,200 results.

Option 6: Mammal predator eradication, control, or management to protect UK, British, Scottish seabird colonies = 1,300 results. Broad search to obtain a comprehensive understanding of the most relevant studies regarding the effect of mammalian predator eradication and management on UK seabird colonies.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

5.2 Study selection

On 26 April 2023 we conducted two literature searches on WoS and a literature search in GS (Figure 16; Figure 15 within main document). This conservation action is well studied around the world and within the UK. Therefore, we aimed to retrieve the most relevant studies on the effect of mammalian predator eradication and/or control efforts on seabird colonies within the British Isles and Ireland (results from first search in WoS), as well as at a global scale (results from second search in WoS).

In total, 8,227 references were identified; 511 in the first WoS search, of which the first 50, most relevant, records were exported, 6,416 in the second WoS search, of which the first 50, most relevant, records were exported, and 1,300 in the GS search, of which the first 80 records were exported. We selected the first 50 – 80 records after identifying a string of five consecutive less-relevant studies. The searches yielded a total of 180 records, of which 18 were duplicates (i.e. included by both WoS and GS) and were automatically removed prior to screening. All 162 unique records were screened at a title and abstract level to identify and exclude studies outside the review's scope, such as those records where the effect of the eradication and/or control of mammalian predators on seabirds was not tested, studies that only mentioned the effect of invasive species on seabirds (and not of the eradication/control), those that researched avian predators, and those from which the abstract could not be accessed (see Table A 2 within the main document). Studies where this criterion was unclear were kept for full text screening. At this stage, we excluded 79% (128) of the records.

The remaining 34 records were screened in their entirety (i.e. full text) and relevant information was recorded. We additionally recorded information on the mammalian predators, the year of eradication, whether study sites were islands or on mainland, if the prior, then the distance to the mainland, the eradication/control method, whether the eradication/control efforts were successful, the effect seen on each seabird species population, a list of species that benefitted or that were negatively affected from the eradication/control, any observation regarding other wildlife changes, and comments that authors mentioned relating to biosecurity measures. At this stage, our aim was to identify studies that assessed the impact of mammalian predator eradication and/or control projects on seabird populations. We excluded studies that described the eradication/management procedure but that did not test its effect on seabirds, those that did not provide new evidence on the matter, and those where the full texts were not available. We retained 18 records for final assessment.

Additionally, we identified four key articles and reports that were highly relevant to this topic, Furness et al. (2013a), Veitch et al. (2019), Furness (2021), and Holmes et al. (2023), and searched references within to identify relevant literature that may have been overlooked during the systematic literature search. We identified, read the full text, and extracted relevant information from nine references. From this process, we retained five records for final assessment. Overall, 23 references were included for the final review. While searching for additional references, we came across two studies, Jones et al. (2016) and Brooke et al. (2018), which explored the impact of successful eradication projects on seabirds and animals worldwide. Despite the high relevance of these studies to the review, we decided to exclude them from our ecological efficacy scoring. This choice was based on their broad nature and the challenges associated with extracting the specific information required for our analysis. Nonetheless, in the results section, we provide a brief mention of the overall findings from Brooke et al. (2018) due to its greater relevance to our study, specifically in relation to seabirds.

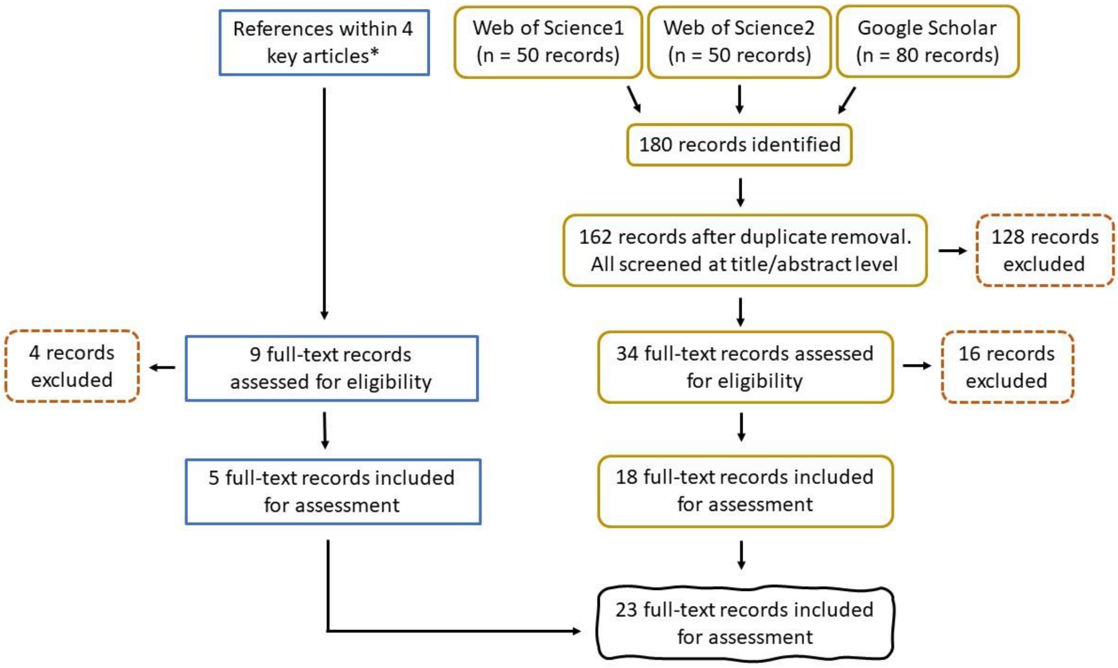


Figure 36. Flow diagram depicting the study selection process for the systematic review on mammalian predator eradication and/or management. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Furness et al. (2013a), Veitch et al. (2019), Furness (2021), and Holmes et al. (2023).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

6 Methods of the systematic literature review on 'Avian predator management'

6.1 Research questions, keywords, and search strings

The conservation action, the management of avian predators, involves a set of different management actions and was, therefore, associated with three research questions. The first research question, '*What is the potential for seabirds to experience increased productivity or survival through avian predator management*?', investigates the impact of avian predator management actions on seabird populations. The second question, '*Which management action is more effective*?' aims to identify the management action that has the strongest beneficial effect on seabird populations. The third question, '*For which avian predator is there the most potential for effective management*?', aims to identify the avian species with higher probabilities of management success.

We identified the following keywords: 'Management' and related terms ('eradication', 'avian predator management', 'removal', 'avian population control', 'control', 'deter', 'removal', 'exclude', 'top-down control'), 'avian predator' and related terms ('birds of prey', 'raptors', 'corvids', 'apex predators', 'eagles', 'falcons', 'skuas', 'gulls'), the English, scientific, and species group names of the focal species ('Gull', 'Larus', 'Great Black-backed Gull', '*Larus marinus*', 'Herring Gull', '*Larus argentatus*', 'Lesser Black-backed Gull', '*Larus fuscus*', 'Guillemot', 'Common Murre', '*Uria aalge*', 'Razorbill', '*Alca torda*', 'Atlantic Puffin', 'Puffin', '*Fratercula arctica*', 'Auk', 'Alcid', 'seabird'), the most common avian predators that are likely to affect UK seabird colonies ('Carrion Crow', '*Corvus corone*', Raven, '*Corvus corax*', 'Hooded Crow', '*Corvus cornix*', 'White-tailed eagle', '*Haliaeetus albicilla*', 'Golden eagle, '*Aquila chrysaetos*, 'Peregrine falcon', '*Falco peregrinus*', 'Gulls', 'Great skua', '*Stercorarius skua*'), and a Scottish-related geographic scope ('UK', 'British Isles', 'Scotland', 'Scottish islands', 'NE Atlantic').

We identified the most relevant keywords and conducted a pilot screening in both search engines, Web of Science (WoS) and Google Scholar (GS). We first generated a set of search string which compiled all keywords associated with 'management', avian predators and a list of the focal seabird species (example: ((*TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR gull* OR skua*)) AND TS=(management OR removal OR control* OR deter* OR remov* OR exclud* OR "avian management")) AND TS=(seabird* OR Gull* OR Auk* OR alcid**)). Although these searches produced significant number of results, most studies were not deemed relevant, as they mostly focussed on deterring avian predators from non-seabird colonies, or focussed on gull ecology or on contaminants and toxicity in birds of prey, and other unrelated topics. Therefore, we decided to generate more specific search strings. To do so, we searched for examples of avian predator management actions that could be undertaken at seabird colonies within the UK. During this time, we realised that evidence on the topic was going to be limited. However, we identified three management actions: (1) diversionary feeding (Smart and Amar, 2018), (2) deterrence of avian predators with bioacoustics or physical objects (Boothby et al., 2019; Sutherland et al., 2021), and (3) targeted nest and/or individual removal or translocation (Donehower et al., 2007). We proceeded to generate search strings for each management action for both search engines. A selection of the search strings (including all those retained for the final review) and corresponding number of records for each management action and search engine are listed below. The bolded options denote the search strings used for the systematic literature review. All have a brief explanation as to why they were or were not used.

1. Web of Science (WoS) – diversionary feeding

Option 1: TS=("Diversionary feeding" OR "Supplementary feeding" OR "artificial feeding") AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua* OR Crow OR "Carrion Crow" OR "Corvus corone" OR Raven OR "Corvus corax" OR "Hooded Crow" OR "Corvus cornix" OR "White-tailed eagle" OR "Haliaeetus albicilla" OR "Golden eagle" OR "Aquila chrysaetos" OR "Peregrine falcon" OR "Falco peregrinus" OR "Great skua" OR "Stercorarius skua" OR "Larus") AND TS=("Seabird*" OR "Gull*" OR "Larus" OR "Great Black-backed Gull*" OR "Larus marinus" OR "Herring Gull*" OR "Larus argentatus" OR "Lesser Black-backed Gull*" OR "Larus fuscus" OR "Guillemot*" OR "Common Murre*" OR "Uria aalge" OR "Razorbill*" OR "Alca torda" OR "Atlantic Puffin*" OR "Puffin*" OR "Fratercula arctica" OR "Auk*" OR "alcid*") = 22 results. Diversionary feeding and list of identified avian predators and focal species. Studies not relevant. They mostly focus on diversionary feeding and the effect it has on survival of the species. No mention of seabird colonies.

Option 2: TS=("Diversionary feeding" OR "Supplementary feeding" OR "artificial feeding") AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua* OR Crow*) = 352 results. Eliminated focal seabird species. Although many records appeared, studies were focussed on diversionary and supplementary feeding at non-seabird colonies, and therefore were not in the scope of this review.

Option 3: TS=("Diversionary feeding" OR "Supplementary feeding" OR "artificial feeding") AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua* OR crow*) AND TS=("Seabird*" OR "Seabird colon*" OR "Gull*" OR "Auk*" OR "alcid*") = 11 results. Retained diversionary feeding, groups of avian predators, and seabirds. Although results are limited, they are more relevant to the topic than results from other searches. Note that gulls were removed from the avian predator list because, when kept, most studies focussed on their ecology or movement on non-seabird colonies.

2. Google Scholar (GS) – diversionary feeding

Option 1: Diversionary feeding of avian predators = 1,450 results. Many results about diversionary feeding of mammals rather than avian predators, not many relevant to our aims.

Option 2: Diversionary or supplementary feeding of avian predators at seabird colonies = 78 results. Broad search to obtain all evidence related to diversionary feeding at seabird colonies.

3. WoS – deterrence of avian predators

Option 1: TS=(“Deterrence” OR deterr* OR “bioacoustic deter*” OR scarecrow* OR cane* OR laser* OR scare* OR exclud*) AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua* OR Crow OR “Carrion Crow” OR “Corvus corone” OR Raven OR “Corvus corax” OR “Hooded Crow” OR “Corvus cornix” OR “White-tailed eagle” OR “Haliaeetus albicilla” OR “Golden eagle” OR “Aquila chrysaetos” OR “Peregrine falcon” OR “Falco peregrinus” OR “Great skua” OR “Stercorarius skua”) AND TS=(“Seabird*” OR “Gull*” OR “Larus” OR “Great Black-backed Gull*” OR “Larus marinus” OR “Herring Gull*” OR “Larus argentatus” OR “Lesser Black-backed Gull*” OR “Larus fuscus” OR “Guillemot*” OR “Common Murre*” OR “Uria aalge” OR “Razorbill*” OR “Alca torda” OR “Atlantic Puffin*” OR “Puffin*” OR “Fratercula arctica” OR “Auk*” OR “alcid*”) = 132 results. Many examples of deterring gulls but most not from seabird colonies (so out of the scope of this review). Few examples of this on seabird colonies.

Option 2: TS=(“Deterrence” OR deterr* OR “bioacoustic deter*” OR scarecrow* OR cane* OR laser* OR scare* OR exclud*) AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua* OR Crow OR “Carrion Crow” OR “Corvus corone” OR Raven OR “Corvus corax” OR “Hooded Crow” OR “Corvus cornix” OR “White-tailed eagle” OR “Haliaeetus albicilla” OR “Golden eagle” OR “Aquila chrysaetos” OR “Peregrine falcon” OR “Falco peregrinus” OR “Great skua” OR “Stercorarius skua”) AND TS=(“Seabird*” OR “seabird colon*” OR “Auk*” OR “alcid*” OR “gull*”) = 122 results. Most relevant, but still few studies that tackled the topic.

Option 3: TS=(avian predator deterrence) = 55 results. Studies mainly focussed on deterring mammals.

4. GS – deterrence of avian predators

Option 1: Deterrence of avian predators at seabird colonies = 6,800 results. Most results focus on mammalian predators. A few studies mention the impact of avian predation on seabirds.

Option 2: Impact of deterring "avian predators" at seabird colonies = 1,060. By using quotes, we eliminate studies focussed on mammalian predators. Overall, more studies on the evidence of avian predation and not the action of deterring of them.

Option 3: Impact of deterring "avian predators" at European seabird colonies = 672. Added a geographic scope within Europe. More relevant studies.

5. WoS – targeted removal and translocation

Option 1. TS=(translocat* OR remov* OR nest removal OR targeted removal OR culling OR management) AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua* OR Crow OR “Carrion Crow” OR “Corvus corone” OR Raven OR “Corvus corax” OR “Hooded Crow” OR “Corvus cornix” OR “White-tailed eagle” OR “Haliaeetus albicilla” OR “Golden eagle” OR “Aquila chrysaetos” OR “Peregrine falcon” OR “Falco peregrinus” OR “Great skua” OR “Stercorarius skua”) AND TS=(“Seabird*” OR “Gull*” OR “Larus” OR “Great Black-backed Gull*” OR “Larus marinus” OR “Herring Gull*” OR “Larus argentatus” OR “Lesser Black-backed Gull*” OR “Larus fuscus” OR “Guillemot*” OR “Common Murre*” OR “Uria aalge” OR “Razorbill*” OR “Alca torda” OR “Atlantic Puffin*” OR “Puffin*” OR “Fratercula arctica” OR “Auk*” OR “alcid*”) = 1154 results. Results are mainly on Gull ecology and behaviour and not on avian predator management. Many studies focussed on toxicity and contaminants in raptors.

Option 2. TS=(translocat* OR remov* OR nest removal OR targeted removal OR culling) AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua* OR Crow OR “Carrion Crow” OR “Corvus corone” OR Raven OR “Corvus corax” OR “Hooded Crow” OR “Corvus cornix” OR “White-tailed eagle” OR “Haliaeetus albicilla” OR “Golden eagle” OR “Aquila chrysaetos” OR “Peregrine falcon” OR “Falco peregrinus” OR “Great skua” OR “Stercorarius skua”) AND TS=(“Seabird*” OR “Gull*” OR “Larus” OR “Auk*” OR “alcid*”) = 178 results. Reduced list of focal seabird species. Most results are irrelevant. Many studies on toxicity in raptors.

Option 3. TS=(translocat* OR remov* OR nest removal OR targeted removal OR culling) AND TS=("avian predator" OR "bird* of prey" OR raptor* OR corvid* OR eagle* OR falcon* OR skua*) AND TS=(“Seabird*” OR “Gull*” OR “Larus” OR “Auk*” OR “alcid*”) = 160 results. More relevant results.

6. GS – targeted removal and translocation

Option 1: Management, removal and translocation of avian predators on seabird colonies = 2,840. Too broad. Studies focussed mainly on translocation and restoration projects.

Option 2: Management, removal, and translocation of "avian predators" on seabird colonies = 237 results. Did not improve much.

Option 3: Effectiveness of management and removal of "avian predators" on European seabird colonies = 960 results. Most relevant.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

6.2 Study selection

On 2 June 2023 we conducted three literature searches in WoS and three literature searches in GS (Figure 19; Figure 18 within main document), two for each identified management action (i.e. diversionary feeding, deterrence, and targeted removal and translocation).

In total, 2,003 references were identified. For each search, we selected the first 20 – 40 records after identifying a string of five consecutive less-relevant studies. In WoS, 11 records were obtained from the first search, of which all were exported, 122 from the second search, of which the first 20, most relevant, records were exported, and 160 from the third search, of which the first 40 records were exported. In GS, 78 records were obtained from the first search, of which the first 20, most relevant, records were exported, 672 from the second search, of which the first 40, most relevant, records were exported, and 960 from the third search, of which the first 40 records were exported. The searches yielded a total of 181 records, of which 25 were duplicates (i.e. identified in more than one search) and were automatically removed prior to screening. All 156 unique records were screened at a title and abstract level to identify and exclude studies outside the review's scope. Excluded studies were those records that: did not research the effect of the avian predator management action at seabird or waterbird colonies, only provided evidence of avian predation on seabirds but did not measure the effect, researched mammalian predators, focused on toxicity, pollutants or contaminants in birds of prey, studies where diversionary feeding was for the benefit of the species being fed (i.e. supplementary feeding) and not to avoid predation on seabird colonies, when avian predator was a small passerine, and when the abstract could not be accessed (see Table A 2 within the main document). Studies where the inclusion criteria was unclear were kept for full-text screening. We decided to retain studies where the management action was also tested on waterbirds within the Charadriiformes order (same order as gulls and auks), as results from these could be relevant and could be applied to seabird colonies (but note that we did not expand the search strings or undertook further, more directed searches to include them). At this stage, we excluded 84% (131) of the records.

The remaining 25 records were screened in their entirety (i.e. full text) and relevant information was recorded. Similar to the ‘eradication and/or control of mammalian predators’ review, we recorded additional information: avian predator species, year that management occurred, whether study sites were islands or on mainland, if the first, then the distance to the mainland, management action and a brief description of it, effect seen on each focal seabird species, a list of species that benefitted or that were negatively affected from the management, observations regarding other changes in wildlife, and comments that authors mentioned relating to biosecurity or recuring measures. At this stage, our aim was to identify studies that assessed the impact of avian predator management on seabird or waterbird colonies. We excluded studies that described the management procedure but that did not test its effect on seabirds or waterbirds, those that did not provide new evidence on the matter, broad reviews on the subject, and those where the full texts were not available. We retained 8 records for final assessment.

Additionally, we identified three key references that were highly relevant to this topic: Lavers et al. (2010), Laidlaw et al. (2021), and Sutherland et al. (2021), and searched references within to identify relevant literature that may have been overlooked during the systematic literature search. We identified, read the full-text, and extracted relevant information from seven references. From this process, we retained three records for final assessment. Overall, 11 references were included for the final review.

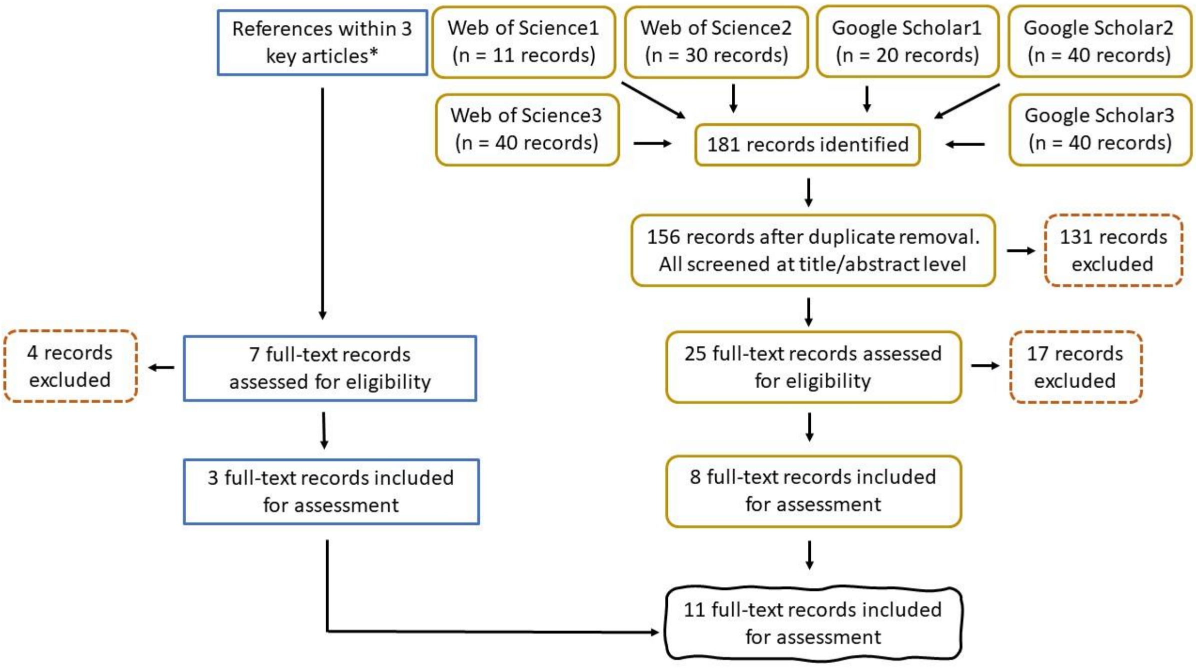


Figure 37. Flow diagram depicting the study selection process for the systematic review on avian predator management. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Lavers et al. (2010), Laidlaw et al. (2021), and Sutherland et al. (2021).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

7 Methods of the systematic literature review on 'Reduction of disturbance (at colony)'

7.1 Research questions, keywords, and search strings

This conservation action was associated with two research questions. The first research question, '*What are the potential population level benefits from reducing on-land and coastal disturbance at seabird colonies*?', investigates the impact of disturbance management measures on seabirds when present at the colonies. The second question, '*What types of disturbance management measures will provide the strongest benefit*?' aims to identify the measure/s that could have the strongest beneficial effect on seabirds. Note that this review focusses solely on disturbance occurring during the breeding season, and management actions will focus on reducing disturbance directly on land, or at sea, but close to shore, enough to disturb birds breeding on land.

We identified the following keywords: 'Regulation and related terms ('management action', 'reduction, 'mitigation', 'management'), examples of regulations on land ('paths', 'signage, 'access restriction', 'education', 'warden'), examples of regulations at sea but near the colony ('buffer area', 'speed limit', 'closure'), the different type of vessels that could cause disturbance ('boat', 'kayak', 'canoe', 'water sports', 'jet ski', 'sailboat', 'kite surf', 'yacht', 'motorboat', 'recreational boat', 'tourist boat', 'wildlife watching boat'), activities on land which could cause disturbance ('tourist', 'visitor', 'photographer', 'dog', 'farm', 'ecotourism', 'fishing on shore'), and the English, scientific, and species group names of the focal species ('Gull', 'Larus', 'Great Black-backed Gull', '*Larus marinus*', 'Herring Gull', '*Larus argentatus*', 'Lesser Black-backed Gull', '*Larus fuscus*', 'Guillemot', 'Common Murre', '*Uria aalge*', 'Razorbill', '*Alca torda*', 'Atlantic Puffin', 'Puffin', '*Fratercula arctica*', 'Auk', 'Alcid', 'seabird').

We identified the most relevant keywords and undertook a pilot screening with several search strings in Web of Science (WoS) and Google Scholar (GS). We decided to conduct separate searches, one focussed on land-based management measures and another one focussed on management measures at sea, but close to the colonies (disturbance away from land is considered in the 'reduction of disturbance (at sea)' review). The search strings and corresponding number of records for each search engine are listed below. The option highlighted in bold indicates the search string that was used for the systematic literature review.

7. Web of Science (WoS) – land-based measures

Option 1: ((TS=(colony OR nest* OR breeding site)) AND TS=(seabird*)) AND TS=(path OR signage OR access restrict*) = 125 results. The first few results were relevant, but subsequently results were not.

Option 2: ((TS=(colony OR nest* OR breeding site)) AND TS=(seabird*)) AND TS=(path OR signage OR access restrict* OR visitor OR tourist) = 215 results. Many references were broadly relevant, but most measured the impacts of disturbance rather than management interventions.

Option 3: ((TS=(colony OR nest* OR breeding site)) AND TS=(seabird* OR guillemot OR murre OR uria aalge OR razorbill OR alca torda OR puffin OR fratercula arctica OR larus OR

gull*)) AND TS=(path OR signage OR access restrict* OR visitor OR tourist) = 330 results. Most relevant results.

8. Google Scholar (GS) – land-based disturbance

Option 1: Reducing or mitigating disturbance by visitors at seabird colonies = 8,040 results. Too broad.

Option 2: Reducing or mitigating disturbance by visitors at seabird colonies auks or gulls = 1,030 results.

9. WoS – sea-based management measures near colonies

Option 1: (((TS=(colony OR nest* OR breeding site)) AND TS=(seabird*)) AND TS=("speed restrict*" OR "exclusion" OR "closure")) AND TS=(boat* OR kayak* OR canoe* OR "water sport*" OR "jet ski*" OR "sailing" OR "sailboat" OR "tourist boat" OR "wildlife watching boat") = 2 results. Too specific.

Option 2: ((TS=(colony OR nest* OR breeding site)) AND TS=(seabird* OR guillemot OR murre OR uria aalge OR razorbill OR alca torda OR puffin OR fratercula arctica OR larus OR gull*)) AND TS=(boats OR kayaks OR canoes OR jetskis OR “sailing boats” OR surfing OR “recreational fishing” OR angling OR sailboat OR yacht OR motorboat OR tourist boat OR wildlife watching boat) = 224 results. Not many top results were relevant.

Option 3: (((TS=(colony OR nest* OR breeding site)) AND TS=(seabird*)) AND TS=(boats OR kayaks OR canoes OR jetskis OR “sailing boats” OR surfing OR “recreational fishing” OR angling OR sailboat OR yacht OR motorboat OR tourist boat OR wildlife watching boat)) AND TS=(mitigat* OR reduc* OR management) = 67 results. Results mostly not relevant.

Option 4: (((TS=(colony OR nest* OR breeding site OR inshore OR coast)) AND TS=(seabird* OR guillemot OR murre OR uria aalge OR razorbill OR alca torda OR puffin OR fratercula arctica OR larus OR gull*)) AND TS=(boats OR kayaks OR canoes OR jetskis OR “sailing boats” OR surfing OR “recreational fishing” OR angling OR sailboat OR yacht OR motorboat OR tourist boat OR wildlife watching boat)) AND TS=(mitigat* OR reduc* OR management) = 147 results.

10. GS – sea-based management measures near colonies

Option 1: **Reducing or mitigating disturbance by boats or kayaks at seabird colonies** = 806 results. Top results seem highly relevant.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

7.2 Study selection

On 17 June 2023 we performed two literature searches in WoS and two in GS (Figure 22; Figure 21 within main document); one search string was focused on land-based management measures, while the other focused on sea-based management measures.

In total, 2,313 references were identified. For each search, we selected the first 30 to 50 records after identifying a string of five consecutive less-relevant studies or to set a minimum number of served searches. In WoS, 330 records were obtained from the first search, of which the first 30, most relevant, records were exported and 147 from the second search, of which the first 30 records were exported. In GS, 1,030 records were obtained from the first search, of which the first 32, most relevant, records were exported, and 806 from the second search, of which the first 50 records were exported. The searches yielded a total of 142 records, of which 6 were duplicates (i.e. identified in more than one search) and were automatically removed prior to screening. All 136 unique records were screened at a title and abstract level to identify and exclude studies outside the review's scope, such as those records where the effect of the regulation was not tested on seabirds, studies that exclusively provide evidence of disturbance on seabirds but do not measure the effect, those that provided a general review on disturbance, and those from which the abstract could not be accessed (see Table A 2 within the main document). Studies where this criterion was unclear were kept for full-text screening. At this stage, we excluded 81% (110) of the records.

The remaining 26 records were screened in their entirety (i.e. full text) and relevant information was recorded. We additionally recorded information on the type of regulation that was tested and whether they were land-based, sea-based., or air-based (use of flying objects such as drones). We excluded studies that did not measure the effect of a disturbance, studies focused on waterbirds or non-relevant seabirds (e.g. Pelicans, Cormorants), studies which only highlight the impact of a disturbance without providing recommendations for management measures, studies focused on at-sea disturbance away from the colony, and studies where measures may not be transferable to Scotland (e.g. management of ecotourism at polar regions), and broad reviews on the subject. We retained 6 records for final assessment.

Additionally, we identified four key references that were presumed highly relevant to this topic: Batey (2013), Méndez-Roldán (2013), Dias et al. (2019) and Sutherland et al. (2021), and searched references within to identify relevant literature that may have been overlooked during the systematic literature search. We additionally searched for studies that were identified during the ‘reduction of disturbance (at sea)’ literature search. We identified, read the full-text, and extracted relevant information from six references. From this process, we retained four records for final assessment. Overall, ten references were included for the final review.

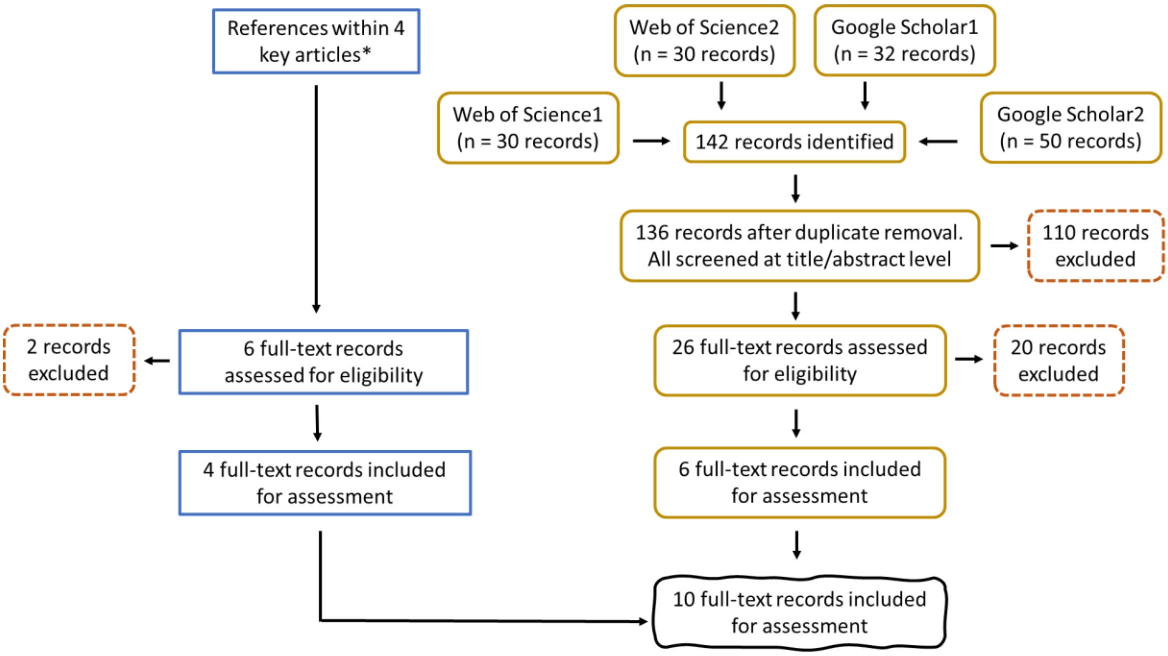


Figure 38. Flow diagram depicting the study selection process for the systematic review on reducing disturbance at and around the colony. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Batey (2013), Méndez-Roldán (2013), Dias et al. (2019) and Sutherland et al. (2021).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

8 Methods of the systematic literature review on 'Reduction of disturbance (at sea)'

8.1 Research questions, keywords, and search strings

The conservation action, the reduction of disturbance at sea, is similar to the previous conservation action, 'reduction of disturbance (at colony)'. This review, however, will focus on the period when individuals are at sea, away from the colony during both the breeding and non-breeding period. It mainly focusses on marine vessels and on what management actions can be undertaken to decrease their impact on seabirds at sea. Therefore, the review was associated with two research questions. The first research question, '*What are the potential population level benefits from at-sea vessel management*?', investigates the impact of disturbance management actions on seabirds whilst at sea. The second question, '*Which management action on what type of vessel provides the strongest benefit*?' aims to identify the management action, as well as the type of vessel, that has the strongest beneficial effect on seabirds.

We identified the following keywords: 'Disturbance' and related terms ('disruption', 'marine traffic', 'speed'), 'management', 'management action' and related terms and examples ('spatial management, 'closure', 'reduction', 'mitigation', 'speed limit, 'shipping lane', 'closure', 'seasonal closure'), the different type of vessels that could be found in Scotland and synonyms ('fishing vessel', 'boat', 'cargo ship', 'ship', 'vessel', 'container', 'tanker', 'tugboat', 'sailboat', 'passenger ship', 'yacht', 'commercial vessel', 'motorboat', 'recreational boat'), and the English, scientific, and species group names of the focal species ('Guillemot', 'Common Murre', '*Uria aalge*', 'Razorbill', '*Alca torda*', 'Atlantic Puffin', 'Puffin', '*Fratercula arctica*', 'Auk', 'Alcid', 'seabird').

We identified the most relevant keywords and conducted a pilot screening in both search engines, Web of Science (WoS) and Google Scholar (GS). During a preliminary search, during the refinement of the search strings, it was clear that there was going to be limited evidence on the topic, as most studies focused on the impact of at-sea disturbance on seabirds, rather than the effect of a management action. This observation is consistent with the findings of Sutherland et al. (2021), which also observed a lack of evidence regarding a list of management actions relating to at-sea disturbance on birds. Therefore, we decided to generate broad and specific search strings. To do so, we searched for examples of at-sea disturbance management actions that could be benefit seabirds in Scotland and identified two actions: reducing vessel speed limits and shipping lanes. We proceeded to generate search strings for each management action for both search engines. A selection of the search strings (including all those retained for the final review) and corresponding number of records are listed below. The bolded options denote the search strings used for the systematic literature review. All have a brief explanation as to why they were or were not used.

11. Web of Science (WoS) – broad search

Option 1: (TS=(vessel* OR ship* OR boat* OR cargo* OR yacht* OR sailing boat* OR recreation)) AND TS=(seabird*) AND TS=(disturbance) AND TS=(mitigat* OR reduc*) = 209 results. See option 3.

Option 2: (TS=(vessel* OR ship* OR boat* OR cargo* OR yacht* OR sailing boat* OR recreation)) AND TS=(seabird*) AND TS=(disturbance) AND TS=(mitigat* OR reduc*) AND TS=(offshore) = 22 results. Mainly studies on offshore windfarms, and less relevant to the review.

Option 3: (TS=(vessel* OR ship* OR boat* OR cargo* OR yacht* OR sailing boat* OR recreation*)) AND TS=(seabird*) AND TS=(disturbance) AND TS=(mitigat* OR reduc* OR management) = 428 results. Like Option 1 but seems to list more relevant studies. After study #50, many are focused on fishery-relating activities such as bycatch and fishing activity.

12. Google Scholar (GS) – broad search

Option 1: Management at-sea vessel disturbance on seabirds = 19,200 results. Too broad.

Option 2: Reducing the impact of at-sea vessels on auks = 7,130 results. Still too broad. Many studies relating to behaviour and threats at-sea.

Option 3: Effect of management actions of vessels at-sea to conserve auks = 5,320 results.

Most searches provide the same top 20 results.

13. WoS – reducing speed limit

Option 1: (TS=(vessel* OR ship* OR boat* OR cargo* OR yacht* OR sailing boat* OR recreation)) AND TS=(seabird*) AND TS=(disturbance) AND TS=(mitigat* OR reduc* OR management) AND TS=(speed limit*) = 6 results. Decided to keep this as it is highly likely that results will be useful for the final assessment.

14. GS – reducing speed limit

Option 1: Effect of speed limit regulation of vessels on seabirds = 19,400 results

Option 2: Effect of speed limit regulation of vessels or boats on seabirds = 18,600 results. Seem to provide the most relevant results.

Option 3: Effect of speed limit regulation of vessels on auks = 7,820 results. Mostly results on the effect of shipping activity on auks.

Similar results from all searches.

15. WoS – shipping lanes

Option 1: (TS=(vessel* OR ship* OR boat* OR cargo* OR yacht* OR sailing boat* OR recreation)) AND TS=(seabird*) AND TS=(disturbance) AND TS=(mitigat* OR reduc* OR management) AND TS=(shipping lane*) = 7 results. Too narrow.

Option 2: (TS=(vessel* OR ship* OR boat* OR cargo* OR yacht* OR sailing boat* OR recreation)) AND TS=(seabird*) AND TS=(disturbance) AND TS=(mitigat* OR reduc* OR management) AND TS=(shipping lane* OR spatial manag* OR closure) = 111 results. Added 'spatial management' and 'closure'. Could provide more relevant results.

16. GS – shipping lanes

Option 1: Shipping lanes of vessels to protect seabirds = 19,700 results. Too broad.

Option 2: Effect of shipping lanes on seabirds = 5,390 results. More relevant results.

Information on the time and date that search strings were used, as well as the number of records retained for screening can be found in Annex 2.

8.2 Study selection

On 14 June 2023 we conducted three literature searches in WoS and three literature searches in GS (Figure 25; Figure 24 within main document); one broad search string and two specific search strings (one for each identified management action: reducing speed limits and shipping lanes) in each search engine.

In total, 29,855 references were identified. For each search, we selected the first 30 – 50 records after identifying a string of five consecutive less-relevant studies or to set a minimum number of served searches, and due to the time constraints of the project. In WoS, 428 records were obtained from the first search, of which the first 50, most relevant, records were exported, 6 from the second search, of which all were exported, and 111 from the third search, of which the first 30 records were exported. In GS, 5,320 records were obtained from the first search, of which the first 40, most relevant, records were exported, 18,600 from the second search, of which the first 30, most relevant, records were exported, and 5,390 from the third search, of which the first 30 records were exported. The searches yielded a total of 186 records, of which 35 were duplicates (i.e. identified in more than one search) and were automatically removed prior to screening. All 151 unique records were screened at a title and abstract level to identify and exclude studies outside the review's scope, such as those records where the effect of the conservation was not tested on seabirds or waterbirds, studies that exclusively provide evidence of at-sea disturbance birds but do not measure the effect, those that record and measure disturbance at the colony or close to the colony, those that researched marine mammals, those that focused on the effect of fishery-related activities on seabirds (e.g. bycatch, overfishing, discards), those that only researched seabird ecology at sea, those that focused on the impact of oil spills and collisions with windfarms or oil platforms on seabirds, those that focused on monitoring, tracking and/or surveying techniques of seabirds at sea, and those from which the abstract could not be accessed (see Table A 2 within the main document). Studies where this criterion was unclear were kept for full-text screening. We decided to retain studies where the management action was also tested on waterbirds, as results from these could be relevant and applicable to seabirds (but note that we did not expand the search strings or undertook further, more directed searches to include them). At this stage, we excluded 90% (136) of the records.

The remaining 15 records were screened in their entirety (i.e. full text) and relevant information was recorded. We additionally recorded information on the type of management action that was tested and the vessel type. Due to the limited evidence on the topic, our aim was to identify studies that measured the effect of at-sea disturbance on seabirds or waterbirds. We excluded studies that did not measure the effect of disturbance, studies that exclusively detected at-sea threat hotspots for seabirds and those that did not provide new evidence on the matter, broad reviews on the subject. We retained 8 records for final assessment.

Additionally, we identified three key references that were presumed highly relevant to this topic: Abdulla and Linden (2008), Furness et al. (2013b), and MMO (2018), and searched references within to identify relevant literature that may have been overlooked during the systematic literature search. We additionally searched for studies that were identified during the 'reduction of disturbance (at colony)' literature search. We identified, read the full-text, and extracted relevant information from six references. From this process, we retained three records for final assessment. Overall, 11 references were included for the final review.

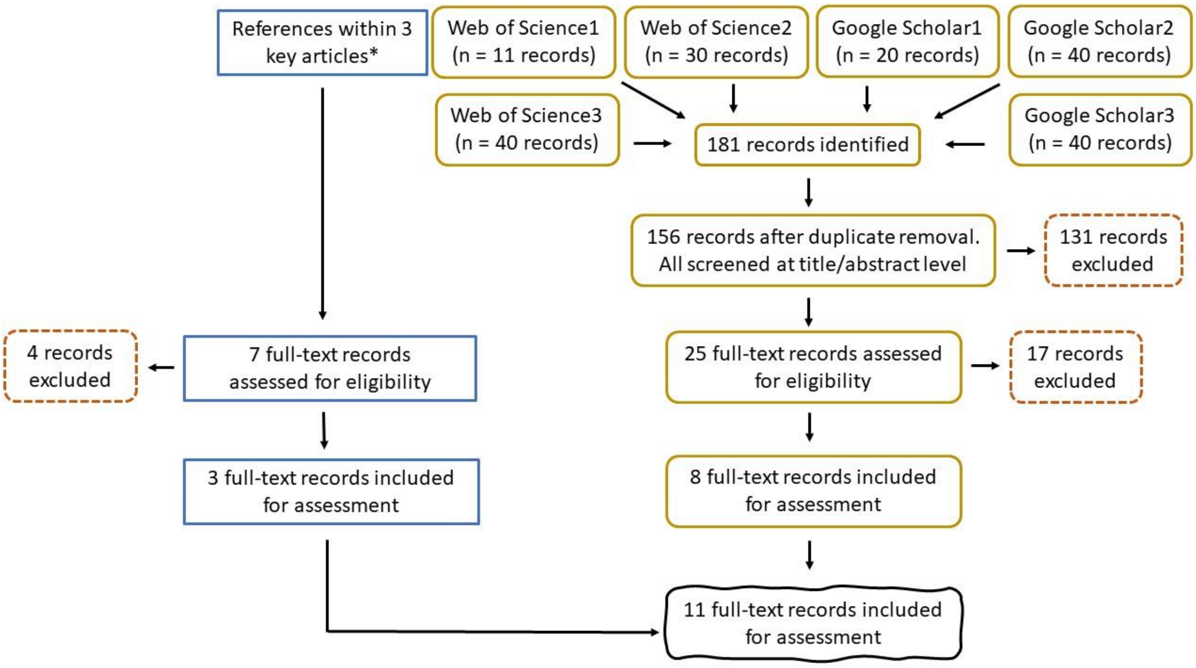


Figure 39. Flow diagram depicting the study selection process for the systematic review on reducing disturbance at sea. Results from the study selection using search engines are within yellow rounded polygons, while additional references are highlighted within blue rectangles. Excluded records are presented in dashed red polygons. The total full-text records are given within the undulating black polygon. *Key articles are: Abdulla and Linden (2008), Furness et al. (2013b), and MMO (2018).

Information on the complete reference list obtained during the literature search, and the level at which each reference was eliminated can be found in Annex 3.

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