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Feasibility study for meta-analysis of red-throated diver displacement

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Summary

The aim of this report is to assess the feasibility and levels of stakeholder interest in undertaking a meta-analysis of data on displacement of red-throated divers *Gavia stellata* by offshore wind farms (OWFs).

There may be considerable obstacles to undertaking a meta-analysis. These include:

- Willingness to collaborate and share data.
- Statistical difficulties regarding the type of meta-analysis and the feasibility of combining data sources.
- Buy-in from relevant stakeholders including the use of the outputs and their contribution to its delivery.

These issues could pose a risk to the meta-analysis being undertaken successfully and the work contracted by JNCC sought to evaluate and quantify the extent to which that may be the case. The objectives of the work were to:

1. Assess the amount of data that has been collected on red-throated diver abundance and distribution in relation to OWFs and the availability of that data for the proposed meta-analysis.
2. Consider which statistical approaches could feasibly be used in the meta-analysis, given the quality and quantity of data.
3. Assess levels of stakeholder interest in the outputs of the meta-analysis and willingness to contribute data and/or funds to the meta-analysis.

The amount of data that has been collected on red-throated diver in relation to OWFs was assessed through a literature review. The willingness of data holders to contribute data to the proposed meta-analysis and the potential support from a wider group of stakeholders was assessed through two questionnaires. The request for information through the questionnaires was predicated on an assurance of anonymity in the way that the responses were reported - the information obtained through the questionnaire is aggregated, categorised or simply not attributed to any individual or related to any individual OWF development. The consideration of statistical approaches was based on a literature review and the expertise held by Biomathematics and Statistics Scotland and the Centre for Ecology and Hydrology.

The conclusions drawn on the three objectives of the work were:

1 <u>Data availability</u>

The review of:

- the number and type of surveys that have been carried out at the pre-application, pre-construction, during construction and post construction stages of OWFs, and
- the number of sites at which red-throated diver have been found in numbers to enable their density to be calculated indicates that there is a potential wealth of data that has been acquired. Where sufficiently detailed information was obtained, it was identified that:
    - There are 43 operational OWFs from which there is the potential for data to be available to enable the meta-analysis.
    - Around three-quarters of OWF monitoring programmes were primarily based on boat transect surveys.
    - Around a fifth of OWF monitoring programmes were primarily based on aerial visual surveys.
    - There were three OWF monitoring programmes where aerial digital (stills or video) was identified as the primary technique applied.

- Information on red-throated diver density was located for around a half of the 43 operational OWFs (report access limitations means that this could be a significant underestimate).

The review identified that as time has passed since pre-application surveys have been carried out, the reports (primarily environmental statements) are increasingly becoming unavailable from publicly accessible sources. The public availability of pre-construction, during construction and post construction stage monitoring data, and reports on analyses of that data, varies considerably across the four countries studied (UK, Denmark, Germany, Netherlands). This has hindered, in the short time available to this project, identifying the precise number of studies that contain data, or aggregated data, on red-throated diver.

The limited existing publicly available red-throated diver data from OWF surveys across all of the four countries studied means that a meta-analysis is not practical without the co-operation of data-holders.

With respect to the questionnaire on data availability, the conclusions drawn were:

- Overall there was a reluctance to share raw data.
- Raw data would be forthcoming if it were prompted by a formal request from a regulator.
- There was more willingness to share secondary information in the form of monitoring reports and aggregated data.
- The willingness to share data varied by country - some willingness from the UK and the Netherlands and no willingness from Germany (data from Denmark is already available and as a result the measure of willingness is less relevant).
- Based on the responses received raw data could potentially be available for 12 OWFs for which there would be pre- and post-construction data on red-throated diver.

These conclusions are subject to the caveat that they are drawn from around a quarter of the potential participants who hold data.

2 Statistical approaches

Overall, the key modelling choice is between:

- running an aggregate data meta-analysis, using summary statistics from published studies, or
- running an “individual participant data” (IPD) meta-analysis in which the raw data from each study are re-analysed.

The technical, computational and time requirements for running an aggregate data meta-analysis would be substantially lower than for running an IPD meta-analyses. This would be the key advantage of the aggregate approach, along with the fact that the aggregate data meta-analysis does not require access to the raw data (and so would not be dependent upon obtaining data permissions). The key disadvantages of the aggregate approach are:

- That it relies upon being able to extract comparable summary statistics (estimated wind farm effects, and associated SEs) from all studies.
- That it relies upon the estimated wind farm effects from the different studies, and their associated SEs, being comparable.

The IPD meta-analysis approach would allow these issues to be dealt with, but would be a challenging exercise involving re-analysing data that have been obtained from different survey platforms, which are stored in different formats, and which have been subjected to varying levels of pre-processing.

The majority of studies that have combined data from different survey platforms for marine birds have used traditional boat-based and visual aerial transect methods. Results are mixed, but in general, these studies demonstrate that it is possible to combine data from these two platforms to better inform estimates of red-throated diver densities.

3 Stakeholder buy-in

The questionnaire to stakeholders produced a significantly higher level of response compared to that from data holders (48.7% compared to 23.3% respectively). There was a very high level of support for a meta-analysis (~95%). Interest was at around 75% in relation to the output parameters of:

- distance by which divers are displaced
- relative proportion of individuals displaced
- a displacement curve with distance
- the influence of anthropogenic and environmental covariates
- measures of uncertainty

The degree of support that was expressed was highest for that which did not require commitment of human and financial resources and lowest for that which required financial resources. Specifically support expressed was:

- ~75% by encouragement to others
- ~50% by providing data
- ~50% by providing technical assistance
- ~10% by providing funding

Recommendations

1. A meta-analysis does not proceed without the co-operation of data-holders.

2. The approach to a meta-analysis using published effect sizes is not applied.

3. The approach to the meta-analysis should be that either raw data from individual studies or relatively fine-scale aggregates of those raw data are used.

4. A meta-analysis does not proceed with the current likely availability of suitable data.

5. The support from stakeholders is used to encourage data holders to consider further their position on the release of raw, or relatively fine-scale aggregated, data such that a larger body of suitable data is made available for a meta-analysis of red-throated diver displacement by OWFs.

The work presented in this report was delivered by APEM Ltd as lead contractor, with Aarhus University, Biomathematics and Statistics Scotland, Centre for Ecology and Hydrology and Sjoerd Dirksen Ecology as sub-contractors. The team is grateful for the support of Sue O'Brien as JNCC project manager and the additional technical input made by Sophy Allen of Natural England.

Contents

1 Introduction

1.1 Aims

The aim of the contracted work that is reported in this document is to assess the feasibility and levels of stakeholder interest in undertaking a meta-analysis of data on displacement of red-throated divers *Gavia stellata* by offshore wind farms (OWFs).

1.2 Background

Red-throated divers winter around the North Sea, the Baltic Sea and the Irish Sea. Many OWFs have been constructed in these areas and there is evidence of red-throated divers being displaced from such developments (including a buffer around them), being displaced by activities associated with such developments and being displaced by other human activities in the marine environment (Dierschke *et al* 2016). Evidence to quantify the extent of displacement and what causes this response to vary among wind farms is sparse.

The effects of these developments on red-throated diver distribution are usually only considered in isolation and comparisons between multiple developments have not been previously undertaken. To produce a single consolidated assessment of the extent of displacement of red-throated divers at OWFs across Europe, ideally, all data from developments across the North Sea, Baltic Sea and Irish Sea would be combined in a single meta-analysis.

The results of such an analysis would help reduce future consent risk for individual OWFs through improving the evidence base on the extent of displacement of red-throated divers from OWFs. Such an analysis would also facilitate undertaking a cumulative effects assessment at the scale of the North Sea for this highly mobile migratory species. Additionally, the results may reduce the need for future post-consent monitoring, potentially freeing up resources for tackling other more strategic questions, such as obtaining an understanding of the consequences of displacement on red-throated diver populations.

However, there may be considerable obstacles to undertaking a meta-analysis. These include:

- Willingness to collaborate and share data: Obtaining commercially-sensitive data on abundance and distribution of birds in and around offshore wind farms can be challenging and developers and regulators are not always willing to share data.
- Statistical difficulties: How feasible would it be to combine data collected from different survey platforms and/or using different methods? Also, what types of analysis could be undertaken to best explain variance in diver distribution, both overall and in relation to offshore wind farms, and are the necessary environmental covariates available to undertake this work?
- Buy-in from relevant stakeholders: Would the statistical analyses actually provide useful results that would be of interest and benefit to the industry, regulators and their advisors in the UK, Denmark, Germany and the Netherlands? Would they use the outputs? What format would they like the outputs to be in, to be of most use? Would they also be interested in obtaining a revised population estimate of numbers of red-throated divers wintering in European waters? Would they be willing to provide data to enable the meta-analysis to be undertaken? Would they consider contributing funds towards the meta-analysis?

The issues listed above could pose a risk to the success of the meta-analysis. The work contracted by JNCC seeks to evaluate and quantify the extent to which that may be the case.

1.3 Objectives

To meet the overall aim of this project, the objectives are to:

1. Assess the amount of data that has been collected on red-throated diver abundance and distribution in relation to OWFs and the availability of that data for the proposed meta-analysis.
2. Consider which statistical approaches could feasibly be used in the meta-analysis, given the quality and quantity of data.
3. Assess levels of stakeholder interest in the outputs of the meta-analysis and willingness to contribute data and/or funds to the meta-analysis.

These three objectives determine the structure of this report, with each one addressed in a free-standing section.

Discussion of the issue of the population level consequences of displacement for red-throated divers is outside the scope of this project aim and objectives.

1.4 Objectives: Detailed tasks

1.4.1 Data availability

The tasks to be undertaken in relation to data availability are:

1. Identify and list the number of OWF across the North Sea, Baltic Sea and Irish Sea for which data exist on red-throated diver distribution and at which red-throated divers regularly occur at a sufficient density to be able to detect a change in response to the OWF.
2. For each OWF listed above, if possible, establish the quantity (no. of surveys/years) and quality (method of data collection) of data that was collected. If this information is not readily available, that will be noted instead.
3. For each OWF, where possible, contact those holding relevant data (industry/regulators) and assess their willingness to share their data. JNCC recognises that, given the time frame for delivering this project, contacting all data custodians may not be feasible or realistic. Where data custodians are not contacted, this will be noted and a reason given why.
4. For any data custodian that is unwilling to share their data for the meta-analysis, establish what, if anything, would need to change in order for them to be willing, e.g. spatial resolution at which data could be released, confidentiality statements, outputs in a different format from the meta-analysis.
5. Document the amount of data that has been collected on red-throated diver distribution around OWF and the proportion of that data that would be available for use in the meta-analysis.

1.4.2 Statistical analysis

The tasks to be undertaken in relation to statistical analysis are:

1. List the range of statistical approaches (from very basic to state-of-the-art) that would be feasible given the data that is likely to be available and list the pros and cons of each, including the ability of each to answer the key questions about extent of displacement of red-throated divers posed by regulators and advisors across Europe.

2. Assess and comment on the feasibility and limitations of combining survey platforms, including identifying studies that have already done this and briefly discussing their findings.
3. Consider which environmental covariates would be relevant to some of the statistical analyses and briefly report on the likely availability of these covariates at relevant spatial scales.

1.4.3 Stakeholder buy-in

The tasks to be undertaken in relation to stakeholder buy-in are:

1. Contact relevant stakeholders (e.g. offshore wind farm companies, regulators, their nature conservation advisors and bird NGOs) across Europe (Denmark, Germany, Netherlands, UK) and explore their level of interest and support for undertaking a meta-analysis.
2. Establish and list what types of outputs stakeholders would want to see for the meta-analysis to be considered a useful and worthwhile exercise.
3. Discuss whether they consider an updated population estimate of numbers of red-throated divers wintering in the North Sea, the Baltic and around the UK to be a key evidence need.
4. Explore whether they would be willing to assist with obtaining data and/or funding for the meta-analysis.
5. If not willing to contribute data and/or funds, to explore if this position would change if the scope or outputs of the meta-analysis were to change.

1.5 The team delivering the contract and their respective roles

The lead contractor for this project was APEM Ltd with the following sub-contractors (listed alphabetically):

- Aarhus University
- Biomathematics and Statistics Scotland
- Centre for Ecology and Hydrology
- Sjoerd Dirksen Ecology

The individuals working on this project and their roles were:

- APEM Ltd

Dr Mark Rehfisch: Project Director
Dr Timothy Coppack: Project Manager for continental Europe and lead on the preparation, issue and analysis of the questionnaires, sources of data and stakeholders relevant to German waters.
Dr Roger Buisson: Project Manager for UK and compiler of the overall report.
Dr Stephanie McGovern: Review of statistical components of the report.

- Aarhus University

Ib-Krag Petersen: Sources of data and stakeholders relevant to Danish waters.

- Biomathematics and Statistics Scotland

Dr Adam Butler: Statistical approaches and feasibility and limitations of combining survey platforms.

- Centre for Ecology and Hydrology

Dr Francis Daunt: Assessment of suitable environmental covariates and avian data sets.
Dr Kate Searle: Assessment of suitable environmental covariates and avian data sets.

- Sjoerd Dirksen Ecology

Sjoerd Dirksen: Sources of data and stakeholders relevant to Dutch waters.

1.6 The structure of the report

The report is structured in the same order as the specification of the work, provided by JNCC, that is:

Section 2: Assessing data availability for the proposed meta-analysis
Section 3: A consideration of the statistical approaches that could be used in the meta-analysis
Section 4: Assessing stakeholders on buy-in to the meta-analysis
Section 5: Conclusions and recommendations

Where appropriate some information has been presented in Appendices in order improve the flow and readability of the main text.

The request for information from individuals and organisations through the questionnaires was predicated on an assurance of anonymity in the way that the responses were reported. Accordingly, the information presented in this report is aggregated, categorised or simply not attributed to any individual or related to any individual OWF development. Where information in this report has been provided on any individual OWF development, then that information has been obtained from public sources and not from the questionnaire returns.

2 Data availability for the proposed meta-analysis

The objective of this section is to assess the amount of data that has been collected on red-throated diver abundance and distribution in relation to offshore wind farms and the availability of that data for the proposed meta-analysis.

2.1 OWFs for which data exist on red-throated diver distribution

2.1.1 Introduction

This sub-section seeks to identify those OWFs across the North Sea, Baltic Sea and Irish Sea for which data exist on red-throated diver presence/absence/density and where information on density is available if that might be sufficiently high to permit a detectable measure of change pre- and post-OWF construction.

2.1.2 Approach to data gathering and evaluation

Information on operational wind farms, a pre-requisite for post-construction data on red-throated diver presence/absence/density to be potentially available, was obtained from public sources (e.g. http://www.4coffshore.com/) and the knowledge held by the project team. Information on red-throated diver presence/absence/density at these operational wind farms was obtained from publications such as journal papers, conference proceedings, technical reports and literature published by the wind farm developers. Due to time constraints on delivering this project, it wasn't possible to approach developers or The Crown Estate Marine Data Exchange (http://www.marinedataexchange.co.uk/) to directly request reports and other information.

2.1.3 Results

Table 2.1 lists the operational wind farms in the relevant waters and the year in which the wind farm was fully commissioned (most likely to be equivalent to year 1 in any post-construction studies).

Table 2.1. Operational OWFs in the Baltic Sea, Irish Sea and North Sea.

OWF	Year fully commissioned
Baltic Sea: Danish waters	
Anholt	2013
Nysted 1	2003
Rødsand 2	2010
Baltic Sea: German waters	
EnBW Baltic 2 (Kriegers Flak)	2015
Irish Sea: UK waters	
Barrow	2006
Burbo Bank	2007
Gwynt y Mor	2015
North Hoyle	2004
Ormonde	2012
Rhyl Flats	2009
Robin Rigg	2010
Walney 1	2011
Walney 2	2012
West of Duddon Sands	2014
North Sea: Danish waters	
Horns Rev 1	2002

OWF	Year fully commissioned
Horns Rev 2	2010
North Sea: Dutch waters	
Egmond aan Zee (OWEZ)	2007
Eneco Luchterduinen	2015
Princess Amelia (PAWP)	2008
North Sea: German waters	
Alpha Ventus	2010
Amrumbank West	2015
BARD Offshore 1	2013
Borkum Riffgrund I	2015
Butendiek	2015
Dan Tysk	2015
Global Tech I	2015
Meerwind Süd/Ost	2014
Nordsee Ost	2015
Sandbank 24	2017
Trianel Windpark Borkum 1	2015
North Sea: UK waters	
Greater Gabbard	2013
Gunfleet Sands	2010
Humber Gateway	2015
Inner Dowsing	2009
Kentish Flats	2005
Kentish Flats Extension	2015
Lincs	2013
London Array	2013
Lynn	2009
Scroby Sands	2004
Sheringham Shoal	2013
Teesside	2014
Thanet	2010
Westermost Rough	2015

For more information on UK offshore wind farms see The Crown Estate (2017).

Table 2.2 provides for each of the operational wind farms identified above (divided in to the relevant waters) a quantitative or qualitative statement about any identified density of red-throated divers and the source of this information. Where quantitative information about red-throated diver density has been located then a figure from the pre-construction period is provided (e.g. as published in the environmental statement upon which the consent was based) where this is available. The surveys in this period are frequently of a wider area than the eventual operational footprint as they were part of the baseline characterisation for the impact assessment. Such baseline characterisation and also pre-construction baseline surveys also include a buffer around the location of the turbine array. Where the size of this buffer, if included in the determination of density, is known then that is stated. The density is expressed, where possible, as the peak (or mean peak) recorded. To place these figures in the context of existing protected areas the density for some examples of protected areas designated for red-throated diver, or wider areas around them, has been provided.

Table 2.2. Red-throated diver density identified in areas relevant to operational OWFs in the Baltic Sea, Irish Sea and North Sea.

OWF	Density of red-throated diver (birds/unit area)	Source with details of data [where available]
Baltic Sea: Danish waters		
Anholt	n/a	Currently unavailable but it is understood that sufficient data to calculate densities should be available (I.K. Petersen *pers comm*)
Nysted 1	0.06 birds/km^2	Petersen *et al* 2006 Maximum relative density [numbers considered too low to calculate absolute densities (I.K. Petersen *pers comm*)]
Rødsand 2	n/a	Currently unavailable and it is understood that numbers are too low to calculate densities (I.K. Petersen *pers comm*)
Baltic Sea: German waters		
EnBW Baltic 2 (Kriegers Flak)	n/a	Unknown
Irish Sea: UK waters		
Liverpool Bay SPA	0.58 birds/km^2	HiDef/WWT Consulting 2011 All diver spp peak density from aerial digital video surveys 2011
DTI/DECC survey zone NW5	1.69 birds/km^2	DONG Energy 2013a All diver spp peak density from aerial visual surveys 2001 - 2009
DTI/DECC survey zone NW6a	2.12 birds/km^2	DONG Energy 2013a All diver spp peak density from aerial visual surveys 2001 - 2009
Barrow	n/a	[ES not available on the BOWind, DONG or Tethys websites]
Burbo Bank	n/a	Casella Stanger 2002 No density stated in ES
Gwynt y Mor	n/a	[ES not available on the RWE, Innogy, Npower Renewables or Tethys websites]
North Hoyle	0.49 birds/km^2	RWE 2008 Peak count within OWF footprint pre-construction (no buffer) - Table 10.4
Ormonde	n/a	[ES not available on the Eclipse Energy, Vattenfall or Tethys websites]
Rhyl Flats	n/a	[ES not available on the RWE, Innogy, Npower Renewables or Tethys websites]
Robin Rigg	0.12 birds/km^2	Walls *et al* 2013 Modelled density within OWF footprint pre-construction (no buffer) from pre-construction survey peak numbers – Figure 6.16a.
Walney 1 & 2	n/a	[ES not available on the DONG, SSE or Tethys websites]
West of Duddon Sands	n/a	[ES not available on the DONG, Scottish Power or Tethys websites]
North Sea: Danish waters		
Horns Rev 1	0.22 birds/km^2	Petersen *et al* 2006 Maximum relative density [numbers considered too low to calculate absolute densities (I.K. Petersen *pers comm*)]
Horns Rev 2	1.33 birds/km^2	Christensen *et al* 2006 Maximum relative density

OWF	**Density of red-throated diver** (birds/unit area)	**Source with details of data** [where available]
North Sea: Dutch waters		
Egmond aan Zee	0.22 birds/km^2	Leopold *et al* 2011
Eneco Luchterduinen	n/a	Unknown
Princess Amelia	2.4 birds/km^2	Leopold *et al* 2011
North Sea: German waters		
Alpha Ventus	1.4 birds/km^2 0.51 birds/km^2	Welcker *et al* 2014 Maximum seasonal mean (spring) from aerial and boat based surveys respectively
Amrumbank West	n/a	Unknown
BARD Offshore 1	n/a	Currently unavailable
Borkum Riffgrund I	n/a	Unknown
Butendiek	1.9 birds/km^2	BioConsult 2002 Peak density
Dan Tysk	n/a	Currently unavailable
Global Tech I	n/a	Currently unavailable
Meerwind Süd/Ost	n/a	Unknown
Nordsee Ost	n/a	Unknown
Sandbank 24	1.17 birds/km^2	BioConsult 2003 Peak density
Trianel Windpark Borkum 1	n/a	Currently unavailable
North Sea: UK waters		
Greater Gabbard	n/a	GGOWLtd 2005 No density stated in ES
Gunfleet Sands	0.15 birds/km^2	GE Wind Energy 2002 ‘uncorrected density’ from aerial visual survey, derived from an unstated area of offshore waters
Humber Gateway	0.5 birds/km^2	E.ON 2005 Peak density
Inner Dowsing	n/a	[ES not available on the Centrica or Tethys websites]
Kentish Flats	3.5 birds/km^2	Percival 2010 Mean density within wind farm area (no buffer) from pre-construction surveys
Kentish Flats Extension	n/a	Vattenfall 2011 No density stated in ES
Lincs	n/a	[ES not available on the DONG, Centrica or Tethys websites]
London Array	20.8 birds/km^2	APEM 2011a Peak density in pre-construction year 2010-11 in ‘Zone 1’: the OWF plus a buffer of varying width (max = ~15km to NE)
Lynn	n/a	[ES not available on the Centrica or Tethys websites]
Scroby Sands	n/a	[ES not available on the E.ON or Tethys websites]
Sheringham Shoal	0.07 birds/km^2	Scira Offshore Energy Ltd 2006 Max density WF + 1.5km buffer
Teesside	n/a	EDF Energy Ltd 2004 No density stated in ES
Thanet	0.45 birds/km^2	Warwick Energy Ltd 2005 Peak density in OWF w/o buffer from boat survey data
Westermost Rough	n/a	RPS 2009 No density stated in ES

Note that information on red-throated diver densities from other offshore wind farm projects may have been accessible through The Crown Estate Marine Data Exchange and through contacting developers directly but this wasn’t feasible in the time available on this project.

The approach to surveys of wind farm development zones in the German exclusive economic zone (EEZ)

Offshore wind farms in the German EEZ are being developed in a series of clusters. There are currently 13 such clusters in the German EEZ of the North Sea (cf. “Bundesfachplan Offshore für die AWZ der Nordsee”: June 2015) and three such clusters in the German EEZ of the Baltic Sea (cf. “Bundesfachplan Offshore für die AWZ der Ostsee”: March 2014). Table 2.3 relates the operational wind farms identified above to their respective development ‘cluster’.

Bird surveys of neighbouring wind farm projects in these clusters are implemented as joint survey programmes in order to avoid parallel (competing) surveys in identical study areas. Data acquisition follows the current version the official Standard for Environmental Impact Assessment (StUK4), which requires 8 to 10 aerial digital surveys for marine mammals and birds per annual cycle and at least 12 monthly ship-based transect surveys for birds over at least two consecutive complete seasonal cycles prior to the start of construction, during construction, and over at least three years (up to five years if required) after construction. The result is that similar, if not identical, data sets should be available for OWFs in German waters within a cluster and that ‘baseline’ (i.e. pre-construction) figures on the densities of red-throated divers will be comparable and at, the ‘cluster’ scale, the same across that cluster. All data obtained from these surveys has to be provided to the Bundesamt für Seeschifffahrt und Hydrographie (BSH) [Federal Maritime and Hydrographic Agency] in a standard format. The data held by BSH remains the property of the wind farm developer or owner and are deemed confidential if not otherwise agreed by the developer.

Monitoring of wind farm clusters in the German North Sea (through aerial digital and ship-based wildlife surveys) has so far been organised by the BSH in to three monitoring clusters and one “coordinated transect design” area:

- Monitoring Cluster 1 “Westlich Sylt”
- Monitoring Cluster 2 “Nördlich Borkum”
- Monitoring Cluster 3 “Nördlich Helgoland”
- Coordinated transect design “Sylt Outer Reef” (both Monitoring Cluster 1 and 3)

These clusters and their respective operational wind farms are also listed in Table 2.3.

Table 2.3. Operational wind farms in the German EEZ and their respective development and monitoring ‘cluster’.

Operational wind farm	OWF development cluster	Wind farm priority area	Monitoring Cluster (BSH 2014)
North Sea			
Borkum Riffgrund I	1	“Nördlich Borkum”	Cluster (2) “Nördlich Borkum”
Trianel Windpark Borkum 1	2		
Alpha Ventus			
Borkum Riffgrund I			
Amrumbank West	4	“Südlich Amrumbank”	Cluster (3) “Nördlich Helgoland”
Nordsee Ost			
Meerwind Süd/Ost			
Butendiek	5	“Sylter Außenriff”	
Dan Tysk			Cluster 1 “Westlich Sylt”
Sandbank 24			
BARD Offshore 1	6	unnamed	unnamed

Operational wind farm	OWF development cluster	Wind farm priority area	Monitoring Cluster (BSH 2014)
Global Tech I	8	"Östlich Austerngrund"	unnamed
Baltic Sea			
Wikinger	1	"Westlich Adlergrund"	unnamed
EnBW Baltic 2	3	"Kriegers Flak"	unnamed

Table Notes: Cluster allocation based on BSH documents: "Bundesfachplan Offshore für die AWZ der Nordsee": June 2015; "Bundesfachplan Offshore für die AWZ der Ostsee": March 2014; official maps published by BSH (North Sea: January 01 2017; Baltic Sea: January 01 2017) and Koch *et al* 2014.

2.2 Evaluation of the data that exists on red-throated diver distribution

2.2.1 Introduction

This sub-section seeks to establish for the OWFs identified in Section 2.1 that have published figures on the density of red-throated diver, the quantity (that is number of surveys carried out and over how many years) and quality (that is the method of data collection) of data that was collected. Where this information has proven to be not readily available then that is noted.

2.2.2 Approach to evaluation of the data

Relevant survey and/or monitoring reports that relate to the specific OWFs identified above for which red-throated diver density was available were examined for the relevant information on the number of surveys carried out, how many years of survey and the data acquisition method.

2.2.3 Results

Table 2.4 provides for each of the operational wind farms identified above (divided in to the relevant waters) information on the surveys carried out. Where the information is available this is presented for the application i.e. as expressed in the environmental statement (ES), pre, during and post construction periods separately. Where the information is available, a finer level of detail is provided on the method used, the years in which that method was applied and the number of surveys carried out in specific years. Such a fine level of detail is not always readily available. For many of these developments, the passage of time and/or the change in ownership has meant that the developers have chosen not to continue to have the EIA and fepa/marine licence reports available on their websites. Given the very short timescale for this project, direct approaches were not made to developers to obtain documents that proved not to be available on a publicly accessible website.

Table 2.4. Summary information on surveys carried out at OWFs that might acquire red-throated diver density information.

OWF	Years of data collection	Method applied, year of survey and number of surveys carried out in specific years	Sources
Baltic Sea: Danish waters			
Anholt	n/a	Pre: [information not currently available]	
		During: [information not currently available]	
		Post: [information not currently available]	
Nysted 1	1999 - 2005	Pre: Aerial visual: 21 surveys Aug 1999 – Aug 2002	Petersen *et al* 2006

OWF	Years of data collection	Method applied, year of survey and number of surveys carried out in specific years	Sources
		During: Aerial visual: 3 surveys Jan – Aug 2003	Petersen *et al* 2006
		Post: Aerial visual: 8 surveys Jan 2003 – Nov 2005	Petersen *et al* 2006
Rødsand 2	n/a	Pre: [information not currently available]	
		During: [information not currently available]	
		Post: [information not currently available]	
Baltic Sea: German waters			
See Section 2.1.3 and Table 2.3 for information about surveys in the German EEZ			
Irish Sea: UK waters			
Barrow	2001 - 2008	ES: [no longer web accessible] Boat: 2001-02 [full info n/a] Aerial visual: [info n/a] Pre-con: Boat: 2004-05 [full info n/a] Aerial visual: 3 surveys May – Aug 2004.	Budgey & Ormston 2009
		During: Boat: 6 surveys May – Oct 2005; Aerial visual: Oct 2005 & Feb 2006.	Budgey & Ormston 2009
		Post: Aerial visual: Jan, Feb & Oct 2007; Feb 2008; Boat: Jul, Aug & Nov 2008.	BOWind 2008 BOWind 2009
Burbo Bank	2001 – 2008	ES: Boat: 3 surveys Dec 2001 – February 2002; Aerial visual: 6 surveys Nov 2001 – Apr 2002. Pre-con: Boat: 6 surveys Sep 2005 – Apr 2006 Aerial visual: None	Casella Stanger 2002 CMACS 2008 Budgey & Ormston 2009
		During: Boat: 13 surveys May 2006 – July 2007 Aerial visual: None	CMACS 2008 Budgey & Ormston 2009
		Post: Boat: 7 surveys Aug 2007 – Jul 2008; Aerial visual: None	Budgey & Ormston 2009
Gwynt y Mor	2003 - 2017	ES: Boat: 26 surveys Feb 2003 – March 2005; Aerial visual: 7 surveys Jul 2004 – May 2005. Pre-con: Boat: Aerial digital stills: 4 surveys Oct 2010 – Feb 2011.	Maclean *et al* 2009 APEM 2011b
		During: Boat: None Aerial digital stills: 5 surveys July 2012 – Feb 2013.	APEM 2014
		Post: Boat: None Aerial digital stills: [in progress 2016-17]	APEM *pers comm*
North Hoyle	2001 - 2007	ES: [no longer web accessible] Pre-con: Boat: 8 surveys Nov 2002 – Mar 2003; Aerial visual: 5 surveys Aug 2002 – Feb 2003; Radar: Pilot survey Mar 2003.	Budgey & Ormston 2009
		During: Boat: 11 surveys Feb 2003 – Feb 2004; Aerial visual: 4 surveys May 2003 – Mar 2004;	Budgey & Ormston 2009

OWF	Years of data collection	Method applied, year of survey and number of surveys carried out in specific years	Sources
		Post: Boat: 36 surveys Mar 2004 – Mar 2007; Aerial visual: 27 surveys May 2004 – Feb 2007	Budgey & Ormston 2009 RWE 2006 RWE 2007 RWE 2008
Ormonde	2004 - 2011	ES: [no longer web accessible, summary information from NTS] Boat: 12 surveys May 2004 – April 2005 Aerial visual surveys: 4+ surveys May 2004 – April 2005 Pre-con: n/a	Eclipse Energy 2005
		During: Boat: 4 surveys May, Jul, Aug & Sep 2010; Aerial visual and digital stills: Jan & Feb 2011.	RPS Energy 2012
		Post: [no reports located]	
Rhyl Flats	2005 - ?	ES: [no longer web accessible] Pre-con: Boat: 17 surveys Aug 2005 – Nov 2006; Aerial visual: 8 surveys May 2005 – Mar 2006.	Budgey & Ormston 2009
		During: [No web accessible fepa licence reports located]	
		Post: [No web accessible fepa licence reports located]	
Robin Rigg	2001 - 2013	ES: Boat: 22 surveys May 2001 – Apr 2002; Aerial: None. Pre-con: Boat: 21 surveys Apr 2003 – Jul 2007; Aerial: None.	Walls *et al* 2013
		During: Boat: 51 surveys Jan 2008 – Feb 2010; Aerial: None.	Walls *et al* 2013
		Post: Boat: 36 surveys Mar 2010 – Feb 2013 Aerial: None.	Canning *et al* 2013a and b
Walney 1 & 2	2008 - ?	ES: [no longer web accessible] Pre-con: Boat: Surveys in 2008 - 2009, no further details available.	DONG Energy 2013b
		During: Boat: Surveys in 2010 – 2011, no further details available.	DONG Energy 2013b
		Post: [No web accessible fepa / marine licence reports located] Radar: 3 weeks Oct 2010 [targeted at PFGoose]	DONG Energy 2013b
West of Duddon Sands	n/a	ES: [no longer web accessible] Pre-con: [No web accessible fepa / marine licence reports located]	
		During: [No web accessible fepa / marine licence reports located]	
		Post: [No web accessible fepa / marine licence reports located]	
North Sea: Danish waters			
Horns Rev 1	1999 - 2005	Pre: Aerial visual: 16 surveys Aug 1999 – Jan 2002	Petersen *et al* 2006

OWF	Years of data collection	Method applied, year of survey and number of surveys carried out in specific years	Sources
		During: Aerial visual: 3 surveys Mar – Aug 2002	Petersen *et al* 2006
		Post: Aerial visual: 15 surveys Jan 2003 – Nov 2005 Radar: Aug, Oct, Nov 2003; Mar, Apr, May, Aug, Sep 2004; Mar, Apr, May, Aug, Sep, Oct, Nov 2005	Petersen *et al* 2006
Horns Rev 2	2005 - 2013	ES: Aerial visual: 6 surveys Nov 2005 – May 2006 Pre: Aerial visual: 6 surveys Dec 2007 – Apr 2008	Christensen *et al* 2006 Skov *et al* 2008
		During: Aerial visual: [none]	
		Post: Aerial visual: 10 surveys Jan – Nov 2013	Dorsch *et al* 2014
North Sea: Dutch waters			
Egmond aan Zee (OWEZ)	2002 - 2010	Pre: Boat: 8 surveys Sep 2002 – Feb 2004 Visual: [none] Radar: [none]	Leopold *et al* 2011
		During: [none]	
		Post: Boat: 17 surveys Apr 2007 – Apr 2010 Visual: 61 visits Apr 2007 – Dec 2009 Radar: Continuous Apr 2007 – May 2010	Leopold *et al* 2011 Krijgsveld *et al* 2011
Eneco Luchterduinen	n/a	Pre: [information not available]	
		During: [information not available]	
		Post: [information not available]	
Princess Amelia (PAWP)	2002 - 2010	Pre: Boat: 8 surveys Sep 2002 – Feb 2004 Visual: [none] Radar: [none]	Leopold *et al* 2011
		During: Boat: 6 surveys Apr 2007 – Jan 2008 Visual: [none] Radar: [none]	Leopold *et al* 2011 Krijgsveld *et al* 2011
		Post: Boat: 11 surveys Apr 2008 – Apr 2010 Visual: [none] Radar: [none]	Leopold *et al* 2011 Krijgsveld *et al* 2011
North Sea: German waters			
See Section 2.1.3 and Table 2.3 for information about surveys in the German EEZ			
North Sea: UK waters			
Greater Gabbard	2004 - ?	ES: Boat: 13 surveys Feb 2004 – March 2005; Aerial visual: 4 surveys Nov 2004 – Feb 2005. Pre-con: [No web accessible fepa licence reports located]	GGOW Ltd 2005
		During: [No web accessible fepa licence reports located]	
		Post: [No web accessible fepa licence reports located]	

OWF	Years of data collection	Method applied, year of survey and number of surveys carried out in specific years	Sources
Gunfleet Sands	2001 - ?	ES: Boat: 23 surveys Oct 2001 – Jul 2002; Aerial visual: 2 surveys Jan & Mar 2002. Pre-con: Boat: 9 surveys Oct 2007 – Mar 2008; Aerial visual: 4 surveys Nov 2007 – Mar 2008.	GE Wind Energy 2002 Budgey & Ormston 2009
		During: Boat: 1st winter?; 2nd winter 10 surveys Oct 2009 – Mar 2010. Aerial: 1st winter & 2nd winter – none.	Percival 2010a
		Post: [No web accessible fepa licence reports located for the post-construction phase]	
Humber Gateway	2003 - ?	ES: Boat: 30 surveys Sep 2003 – Dec 2005; Aerial visual: 18 surveys Oct 2003 – Nov 2005; Radar: Oct 2004. Pre-con: [No web accessible marine licence monitoring reports located]	E.ON 2005
		During: [No web accessible marine licence monitoring reports located]	
		Post: [No web accessible marine licence monitoring reports located]	
Inner Dowsing	2002 - 2010	ES: [no longer web accessible] Pre-con: Boat: 14 surveys Nov 2002 – Mar 2005; Aerial visual: 4 surveys Nov 2002 – Mar 2005.	Budgey & Ormston 2009
		During: Boat: 8 surveys Apr – Dec 2007; Aerial visual: [no information available] Radar: Sep – Nov 2007 [targeted at PFGoose]	Budgey & Ormston 2009 Plonczkier & Simms 2012
		Post: [No web accessible post construction monitoring reports located] Radar: Sep – Nov 2008 – 2010 [targeted at PFGoose]	Plonczkier & Simms 2012
Kentish Flats	2001 - 2013	ES: [no longer web accessible] Pre-con: Boat: 40 surveys Oct 2001 – Nov 2003; Aerial visual: 5 surveys Jan 2002 – Nov 2003.	Vattenfall 2009 Budgey & Ormston 2009
		During: Boat: 18 surveys Aug 2004 – Aug 2005 Aerial visual: 6 surveys Oct 2004 – Jul 2005.	Vattenfall 2009 Budgey & Ormston 2009 Gill *et al* 2008
		Post: Boat: 35 surveys Aug 2005 – Jul 2007; 6 surveys Nov 2009 – Feb 2010; 10 surveys Oct 2011 – Mar 2012; 12 surveys Oct 2012 – Mar 2013. Aerial visual: 10 surveys Aug 2005 – Jul 2007.	Vattenfall 2009 Gill *et al* 2008 Percival 2010b Percival 2014
Kentish Flats Extension	2009 - ?	ES: Boat: 18 surveys Nov 2009 – March 2011; Aerial digital stills: 4 surveys Nov 2010 – Feb 2011. Pre-con: [No web accessible marine licence monitoring reports located]	Vattenfall 2011
		During: [No web accessible marine licence monitoring reports located]	

OWF	Years of data collection	Method applied, year of survey and number of surveys carried out in specific years	Sources
		Post: [No web accessible marine licence monitoring reports located]	
Lincs	2004 - 2016	ES: [no longer web accessible] Boat: [No web accessible report located on these surveys]; Aerial visual: [reported in total for pre-construction aerial surveys below]. Pre-con: Boat: [No web accessible report located on these surveys]; Aerial: 22 visual surveys and 4 digital video surveys Nov 2004 – Mar 2010.	Webb *et al* 2017
		During: Boat: [No web accessible report located on these surveys]; Aerial digital video: 14 surveys Nov 2010 – Feb 2013.	Webb *et al* 2017
		Post: Boat: [No web accessible report located on these surveys] Aerial digital video: 66 surveys Apr 2013 –Mar 2016.	Webb *et al* 2017
London Array	2001 - 2016	ES: [no longer web accessible] Boat: [known to have taken place, details no longer web accessible] Aerial: [known to have taken place, details no longer web accessible] Pre-con: Boat: [None] Aerial digital stills: 4 surveys Nov 2010 – Feb 2011.	APEM 2017
		During: Boat: None Aerial digital stills: 8 surveys, 4 in each of the winters 2011/12 and 2012/13 over the months Nov - Feb.	APEM 2017
		Post: Boat: None Aerial digital stills: 12 surveys, 4 in each of the winters 2013/14 to 2015/16 over the months Nov - Feb.	APEM 2017
Lynn	2002-2010	ES: [no longer web accessible] Pre-con: Boat: 14 surveys Nov 2002 – Mar 2005; Aerial visual: 4 surveys Nov 2002 – Mar 2005.	Budgey & Ormston 2009
		During: [No web accessible during construction monitoring reports located] Radar: Sep – Nov 2007 [targeted at PFGoose]	Plonczkier & Simms 2012
		Post: [No web accessible post construction monitoring reports located] Radar: Sep – Nov 2008 – 2010 [targeted at PFGoose]	Plonczkier & Simms 2012
Scroby Sands	n/a	ES: [no longer web accessible] Pre-con: [No web accessible fepa licence monitoring reports located]	

OWF	Years of data collection	Method applied, year of survey and number of surveys carried out in specific years	Sources
		During: [No web accessible fepa licence monitoring reports located] Boat: [tracking study of little tern provided no data on red-throated diver]	Perrow *et al* 2006
		Post: [No web accessible fepa licence monitoring reports located] Boat: [tracking study of little tern provided no data on red-throated diver]	Perrow *et al* 2006
Sheringham Shoal	2004 - ?	ES: Boat: 29 surveys Mar 2004 – Feb 2006; Aerial visual: 7 surveys Nov 2004 – Aug 2005; Radar: 6 days Oct 2004 & 4 days Sep 2005. Pre-con: [No web accessible licence condition monitoring reports located] Boat: [visual tracking study of Sandwich tern provided no data on red-throated diver]	Scira Offshore Energy Ltd 2006 Harwood *et al* 2017
		During: [No web accessible licence condition monitoring reports located] Boat: [visual tracking study of Sandwich tern provided no data on red-throated diver]	Harwood *et al* 2017
		Post: [No web accessible licence condition monitoring reports located]	
Teesside	2002 - ?	ES: Boat: 24 surveys Jul 2002 – Jul 2003; Aerial visual: 4 surveys Nov 2002 – Aug 2003; Shore based visual: 24 surveys Jul 2002 – Jul 2003. Pre-con: [No web accessible fepa licence monitoring reports located]	EDF Energy Ltd 2004
		During: [No web accessible fepa licence monitoring reports located]	
		Post: [No web accessible fepa licence monitoring reports located]	
Thanet	2004 - 2012	ES: Boat: 12 surveys Nov 2004 – Oct 2005; Aerial visual: 4 surveys Nov 2004 – Mar 2005. Pre-con: [no additional surveys to those reported in the ES]	Warwick Energy Ltd 2005
		During: Boat: 15 surveys Feb 2009 – Mar 2010.	Percival 2013
		Post: Boat: 36 surveys Oct 2010 – Mar 2013.	Percival 2013
Westermost Rough	2004 - ?	ES: Boat: 24 surveys Aug 2004 -Jul 2006; Aerial visual: 14 surveys Sep 2004 – Jun 2006. Pre-con: [No web accessible licence condition monitoring reports located]	RPS 2009
		During: [No web accessible licence condition monitoring reports located]	
		Post: [No web accessible licence condition monitoring reports located]	

2.3 Questionnaire to data holders on their willingness to share their data

2.3.1 Introduction

A questionnaire survey approach was used to contact representatives from the wind industry and their regulators holding relevant data and to assess their willingness to share these data for a Europe-wide meta-analysis of red-throated diver displacement. The questionnaire survey also intended to establish the conditions under which data custodians would be more likely to share their data.

2.3.2 The identification of data holders

A list of data holders across Europe was compiled based on a list of operational offshore wind farm developments for which relevant data are known to exist. The list of questionnaire recipients was established by consulting experts from UK, Germany, The Netherlands and Denmark and by collecting current information on the status of individual wind farm developments from internet sources, available scientific publications and EIA reports.

Table 2.5 provides a summary of the types of individuals who were sent a copy of the questionnaire to data holders. Existing knowledge of how OWF survey data was held in each country meant that the approach made varied by country.

Table 2.5. Types of individuals who were data holder questionnaire recipients.

Category	Class	Number of recipients
Country	Denmark	2
	Germany	16
	The Netherlands	5
	United Kingdom	7
Role	Owner/operator of OWF	24
	Statutory / regulatory organisation	4
	Researcher	1
	Consultant	1

2.3.3 Questionnaire of data holders

An invitation was sent by email on 24th February 2017 to the identified representatives of data holders, as listed in Section 2.3.2.

A copy of the text of this email is reproduced in the box below:

Subject: Europe-wide analysis of displacement of Red-throated Diver from offshore wind farms – assessment of data availability

Dear Mr/Mrs…,

Wintering Red-throated Divers are known to be displaced by offshore wind farms across Europe but evidence for the extent of displacement and what causes this response to vary among wind farms is lacking. Displacement effects are usually only considered in isolation and comparisons between multiple developments have not been previously undertaken. Ideally, all data from developments across the North Sea, Baltic Sea and Irish Sea would be combined in a single meta-analysis that would give a single consolidated assessment of the extent of displacement of Red-throated Divers at offshore wind farms across Europe.

This could bring multiple benefits to the industry including increased statistical power and consequent improved confidence in evidence on the extent of displacement. An improved evidence-base would help reduce uncertainty in future ecological assessments for the consenting of offshore windfarms

However, the success of such an analysis depends on availability of relevant data. Prior to initiating a meta-analysis, JNCC wishes to ascertain the extent to which post-consent monitoring data would be available for such a study.

APEM has been contracted by JNCC to manage this assessment of data availability. We would like to invite you on behalf of JNCC to participate in a brief ***online questionnaire****, which will take only 5 minutes to complete.*

Please click the link below to go to the survey web site (or copy and paste the link into your internet browser).

https://www.surveymonkey.co.uk/r/APEMJNCCDA

Please complete and submit the questionnaire online by ***March 3 2017****.*

If you are unable to participate we would be grateful if you could forward our request to an appropriate colleague within your organisation.

[If you are unwilling to participate simply reply to this email with “NO” in the subject line.]

PLEASE NOTE: *At this stage, we are only assessing the quantity of suitable data and the possibilities of obtaining these data for future collaborative research.* ***You are not committing to providing data by answering this questionnaire.***

Confidentiality

JNCC (http://jncc.defra.gov.uk) is the statutory adviser to the UK Government and devolved administrations on UK and international nature conservation. Any data and information provided will be treated as strictly confidential and will not be transferred to any third parties. Any report derived from the results of this questionnaire will include no development-specific information.

We look forward to receiving your response. Thank you for your support!

With kind regards,

On behalf of JNCC

Tim Coppack

After five working days the following reminder was sent out by email:

Subject: QUESTIONNAIRE 01: Red-throated Divers and offshore wind farms – assessment of data availability

Dear participants,

We would like to thank you for the valuable input that has reached us so far.

If you have not yet submitted the questionnaire, *please use the link below to go to the survey web site (or copy and paste the link into your internet browser).*

It will take only 5 minutes to complete.

https://www.surveymonkey.co.uk/r/APEMJNCCDA

Please also remember tomorrow’s deadline - ***March 3 2017 (23:59 CET)!***

If you are unable to participate we would be grateful if you could forward the link to an appropriate colleague within your organisation.

[If you are unwilling to participate simply reply to this email with “NO” in the subject line.]

PLEASE NOTE: *At this stage, we are only assessing the quantity of suitable data and the possibilities of obtaining these data for future collaborative research.* ***You are not committing to providing data by answering this questionnaire.***

Confidentiality

JNCC (http://jncc.defra.gov.uk) is the statutory adviser to the UK Government and devolved administrations on UK and international nature conservation. Any data and information provided will be treated as strictly confidential *and will not be transferred to any third parties. Any report derived from the results of this questionnaire will include no development-specific information.*

We look forward to receiving your response.

Thank you for your support!

With kind regards,

On behalf of JNCC

Tim Coppack

The questionnaire was designed and run using the web-based application "SurveyMonkey". The questionnaire was accessible via an internet link in the email to the survey website. The questionnaire link was IP-sensitive preventing individuals from participating more than once. Participants had the opportunity to review their entries and to revisit the questionnaire website until finalizing the response by clicking the button "Done" at the end of the webpage.

The questionnaire, as viewed by recipients when they accessed the link, is illustrated in the set of screenshots reproduced in the Appendix. There were eight questions to answer that are illustrated in the Appendix with the respective response options in their original format.

2.3.4 Results of the questionnaire to data holders

The questionnaire to data holders was answered by seven (23.3%) out of the 30 potential participants. A 'potential participant' was categorised as an email contact to which the invitation and reminder were successfully delivered by email both on 24th February 2017 and on 3rd March 2017, respectively.

It was known from the 'recipient tracking' information relayed by Microsoft Outlook that 14 (46.7%) of the 30 potential participants confirmed to have read the invitation and/or the reminding email.

Only one potential participant actively refused to participate by answering "NO" to the reminding email.

The following Tables 2.6 to 2.13 presents a summary of the results for each of the eight questions sent to data holders.

Table 2.6. Responses of data holders to Question 1.

Does your organisation or business hold seabird survey data that contains information on the distribution and abundance of Red-throated Divers (*Gavia stellata*)?		
Answer Options	Response Percent	Response Count
yes	100.0%	7
no	0.0%	0
unknown	0.0%	0
answered question		*7*
skipped question		*0*

Table 2.7. Responses of data holders to Question 2.

Are these data currently kept confidential or shared publicly?		
Answer Options	Response Percent	Response Count
confidential	57.1%	4
publicly accessible from a website	0.0%	0
publicly accessible on request	42.9%	3
Other (please specify)		3
answered question		*7*
skipped question		*0*

Response Date	**Other (please specify)**
March 3 2017	"some confidential, others accessible on request"
March 2 2017	"available on request or through TCE where post-consent data not commercially sensitive"
February 27 2017	"The report of all bird surveys is available on internet and the data on request. It will be available eventually on a website of the government."

Table 2.8. Responses of data holders to Question 3.

Would you be interested in sharing your raw post-consent monitoring data to enable the meta-analysis described above to take place?		
Answer Options	Response Percent	Response Count
yes	71.4%	5
no	28.6%	2
answered question		*7*
skipped question		*0*

Table 2.9. Responses of data holders to Question 4.

Do you think your work or business would benefit from a Europe-wide meta-analysis of Red-throated Diver displacement?		
Answer Options	Response Percent	Response Count
yes	57.1%	4
no	14.3%	1
depends on outcome	28.6%	2
answered question		*7*
skipped question		*0*

Table 2.10. Responses of data holders to Question 5.

If you are unable to provide raw data, what processed product would you be able to share?		
Answer Options	Response Percent	Response Count
original monitoring reports	42.9%	3
post-consent EIA documents	14.3%	1
none	42.9%	3
Other (please specify)		4
answered question		*7*
skipped question		*0*

Response Date	**Other (please specify)**
March 3 2017	"For the wind farms we are not able to share raw data, we may be able to share interim monitoring reports."
March 3 2017	"It might be possible to support by delivering aggregated (processed) data in 10x10km raster (the way needed for assessments in MSFD context)."
March 2 2017	"monitoring reports signed off by MMO"

Table 2.11. Responses of data holders to Question 6.

If you are unable to share raw data, then what would make you more likely to consider sharing your data?		
Answer Options	Response Percent	Response Count
a confidentiality agreement and presentation of outputs in a form that does not convey confidential information	28.6%	2
raw data requested at an aggregated scale, e.g. mean densities at a coarse spatial resolution	14.3%	1
data requested on behalf of the regulator or nature conservation advisor	57.1%	4
Other (please specify)		4
answered question		*7*
skipped question		*0*

Response Date	**Other (please specify)**
March 3 2017	"We will not be able to share raw data from sites with uncompleted monitoring programmes, or sites/areas with commercial aspects to the data."
March 3 2017	"A common understanding on an aggregation level of processed data, like 10x10km raster."
March 2 2017	"Clear information on the study itself including questions to be addressed in study."

Table 2.12. Responses of data holders to Question 7.

For how many windfarm sites could you provide post-construction survey data? Please could you name each individual development and indicate clearly whether you are willing to share data for that development (yes/no)	
	Response Count
	7
answered question	*7*
skipped question	*0*
March 3 2017	"14 offshore wind farms"
March 2 2017	"two or three"

Table 2.13. Responses of data holders to Question 8.

Please provide any other information you think would be helpful for JNCC to know	
	Response Count
	3
answered question	*3*
skipped question	*4*
Response Date	**Response Text**
March 3 2017	"Are you sure it is worth the effort/hassle to collect and re-analyse raw data? To the extent can be shared, will most likely be from completed and reported monitoring programmes."
March 3 2017	"We may consider the possibility to support with aggregated (processed) data. The aggregation and quality assurance has been assured by independent research institutes on behalf of the licensing authorities."
February 27 2017	"We have information about divers, but in general there are no large numbers of divers. They are found mainly in the coastal zone, outside the zone where the windfarms are."

2.3.5 Interpretation of the questionnaire returns from data holders

The majority of the emails sent out to potential participants, all of whom were data holders, did not elicit a response (23 out of 30; 76.7%). Although it is known that the emails were received by an active email in-box, the reasons and motivations as to why no response was made remains unknown.

The respondents answered all the questions completely (i.e. none were skipped) except for the optional Question 8 that was on any additional information that could be helpful to JNCC. The response to Question 1 clearly shows that all participants came from organisations or businesses that currently hold seabird survey data with information on the distribution and abundance of red-throated divers. Thus, the responses to the remaining questions represent those from this group of potential data providers. All self-response questionnaires are potentially subject to the bias that those individuals who respond are more interested in being involved in the issue that is the subject of the questionnaire. In this case that could mean that those individuals more interested in gaining answers to the potential scale of impacts on marine birds are more likely to respond.

In the majority of cases, the responses indicated that relevant data are kept confidential and raw data may only be accessed on request and potentially, with approval of the relevant regulator. There were no indications that raw data may be available from internet sources. Five of the seven data holders said that they would be interested to share their data and four of them responded that their work or business would benefit from a Europe-wide meta-analysis of red-throated diver displacement. However, the mixed responses to Question 5 indicate that most data holders within the wind farm industry may find it hard to share raw data. Some could provide secondary information in the form of monitoring reports and aggregated data. There was only one reference to an available pre-construction report which contains data on red-throated diver distribution.

There was a clear tendency for participants to be more willing to share their raw data if requested by a regulator or nature conservation advisor (Question 6). Thus, it seems currently unlikely that data holders will share their commercially sensitive data from completed or uncompleted monitoring programmes without having to do so.

Only one participant stated explicitly that he or she could share raw data. Sharing aggregated data currently seems more promising, with a greater number of respondents indicating that could be the case. To achieve this, a level of aggregation would have to be established that met the specific aims of the intended meta-analysis.

The responses to Question 7 provided an indication as to the minimum number of OWFs for which suitable post-construction raw data could potentially be made available but should be treated with caution due to the low response rate to the questionnaire. This provides an indication of the minimum amount of data that could be available should an option be pursued for a meta-analysis using raw data (see the next Section for the discussion of statistical approaches). Table 2.14 summarises the potential availability of raw data by country.

Table 2.14. Minimum number of OWFs by country for which raw data could potentially be available, based on responses to a questionnaire.

Country	**Number of OWFs**
Denmark	4
Germany	0
The Netherlands	4
United Kingdom	4

Finally, Question 8 was answered by only three participants and provided little helpful information on how raw data availability could be improved.

2.4 Summary of data availability

There are 43 operational OWFs in the marine waters that are the subject of this review and from which there is the potential for data to be available to enable the meta-analysis.

Of those OWFs it is judged that all will have post-construction data, although there is some uncertainty as access to many of the reports proved impossible using only web sources. There is the possibility, that was not possible to verify without access to the reports and it was outside the scope of this project, that the nature of the surveys meant that they could not contribute data to any meta-analysis. Of the OWF monitoring programmes (i.e. excluding baseline information gathering reported in the ES) where detailed information had been obtained on the survey programme, around three-quarters were primarily based on boat transect surveys and around a fifth primarily based on aerial visual surveys (there was a small number where there was an extensive programme of both boat and aerial visual surveys). The preponderance of these methods is the result of the timing of when the surveys were carried out (i.e. before the advent of digital techniques) and/or the decision to continue post construction surveys using the technique applied in the baseline or pre-construction period. There were three OWF monitoring programmes where aerial digital (stills or video) was identified as the primary technique applied.

Of those OWFs, information on red-throated diver density was located for around a half of them. The limitation of access to reports being sought through web sources added uncertainty and this was to the extent that it could be a significant underestimate of the actual body of information available on red-throated diver density.

With the passage of time since pre-application surveys have been carried out, the reports (primarily environmental statements) are increasingly becoming unavailable from publicly accessible sources. However, given more time, it would be possible to access more reports by approaching developers directly and through The Crown Estate Marine Data Exchange.

The public availability of pre-construction, during construction and post construction stage monitoring data, and reports on analyses of that data, varies considerably across the four countries studied. None of the countries has procedures by which the reports generated by monitoring studies are automatically placed on a public access website.

Notwithstanding the above limitations, it is considered that there is a potential wealth of relevant data that has been acquired that could be applied in a meta-analysis.

With respect to the questionnaire on data availability the responses were received from only seven out of the 30 potential participants. Those who did respond were all data holders. Overall there was a reluctance to share raw data, although that would be forthcoming if it were prompted by a formal request from a regulator. There was more willingness to share secondary information in the form of monitoring reports and aggregated data. With regard to the distribution by country of a willingness to supply data, there was some willingness expressed by respondents from the UK and the Netherlands. Data from Denmark is already available. There was no willingness to share data expressed by the respondents from Germany. Based on the responses received raw data could potentially be available for a minimum of 12 OWFs.

3 Statistical approaches that could be used in the meta-analysis

The objective of this section is to consider which statistical approaches could feasibly be used in the meta-analysis, given the quality and quantity of data.

3.1 Overview of statistical approaches

This project is concerned with the feasibility of running a meta-analysis to determine the impact of offshore wind farms upon the displacement of red-throated divers (RTDs). We outline the range of statistical approaches that are available, their disadvantages and advantages, and the feasibility of using these approaches within the context of this species.

In order to assess the data and the set of published effects that are likely to be available (which can be used in place of raw data within some forms of meta-analysis), we reviewed the available literature. We found, and were able to access, sixteen individual studies spanning the period 2006-2016 (publication dates), several of which encompassed more than one wind farm. The key features of these studies are summarised and compared in Table 3.1. All studies were identified using published reviews (Dierschke *et al* 2016; Furness 2013), ISI Web of Science searches, Google Scholar searches, and expert knowledge from project participants.

Table 3.1. Description of the survey methodologies used in each of the sixteen previous studies assessing the impact of offshore wind farms upon red-throated divers.

OWF	Reference	Assessment periods	Platform(s) used	Years of data collection
Robin Rigg	Canning *et al* 2013b	Before, during and after construction	Boat-based line transect survey	2001-2013
Kentish Flats	Gill *et al* 2008	Before, during and after construction	Boat-based line transect survey	2001-2007
			Aerial visual line transect survey	2001-2007
Kentish Flats	Rexstad *et al* 2012	Before and after construction, but not during	Boat-based line transect survey	2001-2010 (2001-2005 only used in this study)
Kentish Flats	Percival 2014	Before, during and after construction	Boat-based line transect survey	2001-2013
Outer Thames	Banks *et al* 2011	Before, during and after construction	Boat-based line transect survey	2001-2010
			Aerial visual line transect survey	2002-2007 and 2009-2010
			Aerial high resolution digital still imagery	2009-2010
Outer Thames	McGovern *et al* 2016	Before, during and after construction	Aerial high resolution digital still imagery	2009-2014
Thanet	Percival 2013	Before, during and after construction	Boat-based line transect survey	2004-2012
Lincs	Webb *et al* 2017	Before, during and after construction	Boat-based, radar and aerial seabird surveys	2007-2016
Egmond aan Zee	Krijgsveld *et al* 2011	Post- construction (this study) but there was monitoring before and during construction	Radar	2007-2010
PAWP and OWEZ	Leopold *et al* 2013	Before, during and after construction	Boat-based line transect survey	2002-2009

OWF	Reference	Assessment periods	Platform(s) used	Years of data collection
Alpha Ventus	Welcker & Nehls 2016	After construction (post-operational)	Boat-based line transect survey	2010-2013
North Hoyle	RWE 2007 & RWE 2008	Before, during and after construction	Boat-based line transect survey Aerial visual line transect survey	2001-2007 2000-2006
Horns Rev 1	Petersen & Fox 2007	Post construction comparison of encounter rates within and on periphery of wind farm	Aerial visual line transect surveys	2004-2007
Horns Rev 1 and Nysted	Petersen *et al* 2006	Before and after construction comparison of flight behaviour	Radar	1995-2005
Horns Rev 1 and Nysted	Topping & Petersen 2011	Agent based model to assess RTD habitat use and displacement	Aerial visual line transect surveys	1999-2007
Horns Rev 2	Petersen *et al* 2014	Before and after construction	Aerial visual line transect surveys	2005-2012

In order to list the set of possible statistical approaches, we categorise these in terms of three elements of the analysis:

a) the choice of outcome measure;
b) the approach that is used to analyse data for a single wind farm;
c) the "meta-analysis" approach that is used to evaluate the overall effect of wind farms, combining data across multiple wind farms / studies.

Within this report we regard a statistical approach as involving a combination of choices for each of these three elements: a particular outcome measure, a particular methodology for analysing the data for a single wind farm, and a particular methodology for combining results across wind farms. These elements are distinct, even if not entirely separate, so we present and discuss each of these elements in turn.

3.2 Possible outcome measures

The "outcome measure" refers to the quantity that is used in evaluating the impact of the wind farm upon displacement of the species.

All of the studies that we reviewed for red-throated divers used the same basic design – a "BACI" (Before-After, Control-Intervention) design. This design involves collecting data within the wind farm footprint, and at a control site, both before and after construction of the wind farm. Many (but not all; Rexstad & Buckland 2012) studies also collected data during construction, whilst one study only collected post-construction data (Welcker & Nehls 2016). The studies differ in the size and location of the control site.

The effects of displacement are quantified by estimating the spatial distribution of birds within and outwith the wind farm footprint (at the control site, and in the vicinity of the footprint), for each of the periods under consideration. A range of different specific metrics have then been used to quantify the effects of displacement based upon these estimated distributions.

One widely used metric for quantifying the displacement effect of the wind farm within this design involves looking at the ratio between the change in relative abundance from the "before" to "after" period at the treated site (i.e. within the wind farm footprint) and comparing this against the equivalent change at the control site. More specifically, if $\mathrm{y_{ij}}$ denotes an abundance metric for area i (1 = control, 2 = wind farm) in period j (1 = before, 2 = after) then the effect of the wind farm is quantified to be:

$$\frac{y_{22}/y_{21}}{y_{12}/y_{11}}$$

[Equation 1]

If this ratio is equal to one, the change in (relative) abundance is identical for both sites. A value greater than one for the ratio implies that abundance within the wind farm has, in relative terms, increased more rapidly between the pre- and post-construction periods than abundance in the control area. A value of less than one for the ratio implies that abundance within the wind farm has decreased relative to the control area, and (if significant) would be taken as evidence that the wind farm has had a negative impact upon the population of the species. Some studies quantify abundance using summed raw counts, whereas others consider densities (e.g. count divided by survey area).

It is standard to use the log transformation of the ratio, rather than the ratio itself, for testing the existence of a displacement effect. The log transformation is primarily used because the ratio in Equation 1 can only take positive values (or zero), and so cannot be normally distributed (as a normal distribution would imply that negative as well as positive values are possible). The log-transformation therefore allows standard statistical methods which assume normality, such as ANOVA, to be used. On a log scale, a value of zero corresponds to the absence of any wind farm effect; negative values represent a decrease in the values within the wind farm relative to the control (i.e. the existence of a displacement effect).

Testing whether the log-ratio is equal to zero is equivalent to testing for an interaction between "phase" (before / after) and zone (wind farm / control) within a model (most commonly an ANOVA model) that has log(abundance) as the response variable.

A range of other possible metrics have also been considered. The Jabob's Selectivity Index (e.g. Petersen 2006) provides an alternative metric for comparing the overall abundance of birds within the footprint against those within the wider study area. Other metrics directly consider the spatial scale at which displacement operates, rather than simply focusing on a binary effect (wind farm vs control, or wind farm vs wider study area): a number of studies used a "gradient" approach (Percival 2013, 2014; Welcker & Nehls 2016) in which the strength of the "distance from centre of wind farm" metric within both the post-construction period and pre-construction period is estimated as part of the statistical modelling; the difference between these is assumed to represent the displacement effect. Petersen *et al* (2006) use the "cumulative distance frequency distribution" as a metric; this is conceptually similar to the gradient analysis approach, but considers the cumulative distribution rather than the probability density, and uses "distance to nearest turbine" rather than "distance to centre of wind farm". Other studies do not explicitly consider a single outcome measure, but rather estimate the spatial map for the change in distribution across the entire area in and surrounding the footprint (and test at each location to see whether this distribution has changed significantly between pre- and post-construction periods). We have not been able to review all relevant studies within this project, so it is likely that additional metrics have also been considered.

3.3 Possible statistical approaches to assessing the impact of a single wind farm

The studies that we have reviewed for red-throated divers use a range of different approaches to assess the impact of a single wind farm. Most studies break this analysis down into three stages:

a) a “pre-processing” stage, in which biases relating to the data collection are quantified and accounted for;
b) a “spatial modelling” stage, which is used to quantity the abundance of birds within each of the areas of interest (e.g. wind farm, control) within each of the periods of interest (e.g. before, during, after construction); and
c) a “hypothesis testing” stage, in which the outcome measure is calculated and the statistical significance of this metric is evaluated.

3.3.1 Pre-processing stage

The pre-processing stage involves attempting to convert the observed counts of birds into the actual abundance of birds, by adjusting for the characteristics of the data collection process.

The key element of this stage is the correction for non-detection: not all birds that are present within the transect will actually be observed during the survey, and the probability of non-detection will tend to increase as the distance to the transect line (for bird-based or traditional aerial surveys) or observation point (for radar surveys) increases. The “detection function”, which quantifies the relationship between distance to observer and the probability of non-detection, can be estimated empirically. In practice, three approaches have so far been used within analyses of red-throated divers, with varying levels of complexity, to deal with the issue of non-detection:

(i) ignore non-detection (which is equivalent to assuming that non-detection does not exist: i.e. assuming that the detection probability is always one; although all studies reviewed here dropped data from the outer distance bands of surveys if non-detection methods were not applied to the data);
(ii) account for non-detection by using existing, published, correction factors; or
(iii) estimate the detection function empirically using data for the wind farm of interest.

Different red-throated diver studies have used each of these three approaches e.g. Canning *et al* (2013b) used approach (i); Gill *et al* (2008) used approach (ii); Rexstad *et al* (2012), Banks *et al* (2011) and Leopold *et al* (2013) all used approach (iii). The first approach, (i), is clearly the simplest, but the second approach, (ii), is also straightforward to apply in situations where existing correction factors are available e.g. for boat-based surveys that have been conducted using standard data collection protocols (Camphuysen *et al* 2004). The third approach, (iii), is the most time-consuming approach to implement, but is also likely to provide the most accurate way of calculating the actual (corrected) counts, because it allows for differences in non-detection probabilities between sites.

The first approach, (i), appears to have the lowest defensibility, because it is clearly unrealistic to assume that all birds have been detected with equal probability, even if data from the furthest distance bands have been dropped from the analysis. The justification for using (i), however, is that the focus in testing for displacement is solely on looking for an interaction between spatial and temporal effects – so if the probability of non-detection is fairly homogeneous in either time or space then failing to account for non-detection should not lead to bias (i.e. between the wind farm area and control area). If the detection probabilities vary across both time and space, however, this approach is likely to lead to biased results (e.g. due to surveys in different areas being undertaken in different weather conditions, or because of large variation in bird numbers over space). This issue also applies to approach (ii), since published correction factors do not account for spatial and temporal differences in detectability.

3.3.2 Spatial modelling stage

The second stage involves calculating the spatial distribution of birds within the wind farm, and within the control area. The simplest approach to this stage involves simply summing abundance across spatial locations and/or years, to obtain a total estimate of abundance for each analysis unit. The “analysis unit” varies between studies, but often constitutes the combination of gridded sections of transects (or whole transects) and period (pre, during and post construction) – this is the unit that will be used for the final stage of analysis in a single wind farm study (hypothesis testing).

Alternative, more sophisticated approaches, involve modelling abundance as a function of covariates and/or spatial coordinates, in order to obtain predicted densities for each analysis unit. This approach removes some of the noise that is included in the summed counts, by smoothing the relationship across geographical and/or environmental space, and allows for a quantification of uncertainty. A range of different modelling approaches have been used in the different studies of red-throated divers, including generalized linear models (GLMs; Banks *et al* 2011), generalized additive models (GAMs; Rexstad *et al* 2012), generalized additive mixed models (GAMMs; Canning *et al* 2013b) and zero-inflated generalized additive mixed models (ZI-GAMMs; Leopold *et al* 2013).

3.3.3 Hypothesis testing stage

The final stage involves calculating the outcome measure, and evaluating the significance of this metric. In studies where the metric is log abundance (density or count) for each of the analysis units, then testing for a period (before/during/after) by area (wind farm / control) effect typically uses a standard ANOVA analysis. Note that the ANOVA also includes main effects for “area” and “period”, so it is concerned with assessing whether the “period” effect is different in the wind farm area and control area. Studies sometimes (e.g. Percival 2014) replace a standard (parametric) ANOVA with the non-parametric equivalent – the Kruskal-Wallis test – which is less powerful than a standard ANOVA but which also relies upon weaker assumptions.

Alternative metrics are tested using a range of different approaches, with the approach taken depending largely upon the statistical properties of the outcome measure being considered. The cumulative frequency distribution approach of Petersen *et al* (2006), for example, involves the non-parametric estimation of two curves (the cumulative distribution curves for the pre- and post-construction periods), and the hypothesis testing step is therefore based upon the Kolmogorov-Smirnov test.

3.3.4 Potential to combine the stages

One study (Leopold *et al* 2013) combines the final two stages – spatial modelling and hypothesis testing - within a single model. None of the studies that were reviewed here combined the pre-processing stage, (a), with either of the other two stages, although this would in principle be possible. The key advantage of combining multiple stages into a single analysis is that this should enable a more complete and unified assessment of uncertainty. Combining the approaches into a single model will typically increase the technical and computational complexity of the modelling, often substantially, and it will usually mean that the analyses can no longer be implemented using standard off-the-shelf software. The MRSea package though (developed within the R statistical programming environment) does allow the hypothesis testing and spatial modelling parts of the analysis to be combined, along with the key pre-processing step (the adjustment for non-detection)

3.4 Possible statistical approaches to meta-analysis

The term “meta-analysis” covers the full range of statistical methodologies that are concerned with combining, in a quantitative way that accounts properly for uncertainty, the results obtained from multiple individual studies. Meta-analyses are conducted because they may be much more powerful than any of the individual studies included within them – it is possible for a meta-analysis to detect a significant effect even if none of the individual studies that were included within it did so. Meta-analyses will tend to be particularly important in situations where a relatively large number of studies exist, but where the sample sizes within each study are relatively small.

Meta-analyses are typically conducted as part of a systematic review of the available literature, although not all systematic reviews include a meta-analysis. Meta-analysis methods are used in a wide range of disciplines, but the most widely-known and established application of these methods is within the context of clinical trials (Haidich 2010). Meta-analyses of clinical trial results are routinely undertaken, via an established protocol - the Cochrane Review process (Higgins & Green 2011) - and the results feed directly into health policy (e.g. the results of Cochrane Reviews are used by the National Institute for Health and Clinical Excellence [NICE] in producing clinical guidelines for the National Health Service [NHS] in England and Wales). Meta-analysis methods have also been used in ecology but their use in this discipline is not yet routine and where meta-analyses have been conducted they often use simpler and less defensible methods than those deployed in other disciplines (Stewart 2010).

Three different broad types of meta-analysis are possible (Riley *et al* 2010): aggregate data meta-analysis, and two forms of individual participant data (IPD) meta-analysis. These approaches differ in terms of whether they analyse the raw data from each study (one-step IPD and two-step IPD approaches) or analyse published/reported summary statistics from the existing analyses within each study (aggregate data approach), and in whether they assess a separate effect for each wind farm and then combine these (one-step IPD and aggregate data approaches) or directly assess the overall effect of wind farms by pooling data across all studies (two-step IPD approach).

We discuss the advantages and limitations of each of these three types. Each of the approaches is very broad, and we also discuss the more detailed methodological choices that need to be made within each approach. In order to assess whether a meta-analysis is feasible – not only in the sense that it can be conducted, but also that the results will be defensible - it is necessary to consider a number of different elements, and we consider each of these in the context of red-throated diver. Some of these elements are only relevant for particular types of meta-analysis, whilst others are relevant for all three types. Note that all three types of meta-analysis impose assumptions upon the comparability of the data collection process that was used within each study – and this issue is considered in more detail in the section on combining survey platforms.

3.4.1 Aggregate data meta-analysis

The traditional approach to meta-analysis, especially in the context of clinical trials, involves running an “aggregate data” (AGD) meta-analysis – extracting relevant summary statistics from the reported results of the analysis within each study, and then analysing these summary statistics. The process is summarised in Figure 1.

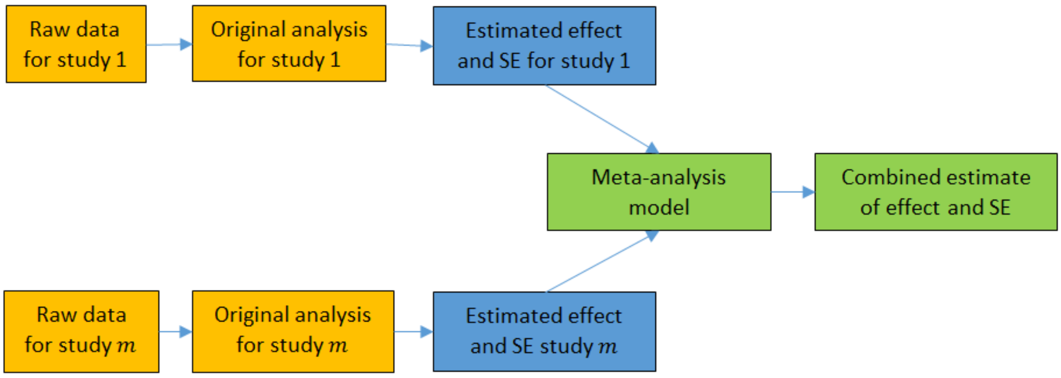

Figure 1. *Flow chart to illustrate how the aggregate data meta-analysis approach operates. Green boxes denote elements that involve work within the meta-analysis; blue boxes denote inputs to the meta-analysis; orange boxes denote work that is done separately from the meta-analysis. SE refers to Standard Error of the effect estimate.*

The key summary statistics that are typically used in meta-analyses of clinical trials are the estimated effect of the treatment (e.g. the estimate for the mean difference in an outcome measure between treated and control groups) and the standard error associated with this estimated effect (SE).

The key general advantages of an aggregate data meta-analysis are that this approach is relatively straightforward and quick to implement, in comparison to the possible alternatives, and that it does not require access to the raw data for each study. The latter characteristic is crucial in many applications, because it means that it is the only viable approach in situations where it is impossible for the person conducting the meta-analysis to gain access to the raw data for each study (e.g. because the data holders are unable or unwilling to release the data; this may be for legal, commercial or logistical reasons).

A key general disadvantage of the aggregate data meta-analysis is that it relies on making a strong assumption – that the estimates and standard errors obtained from the studies are directly comparable - which will often be impossible to test without access to the raw data of each individual study. More fundamentally, however, an aggregate data meta-analysis will only be defensible if:

a) the different studies under consideration all utilise the same outcome measures (summary statistics);
b) the different studies all report the summary statistics; and
c) these summary statistics are derived from the raw data using identical, or at least comparable, methods of analysis.

These requirements are potentially problematic in the context of red-throated divers. We saw from Section 3.3 that the statistical methods used to assess the impacts of individual wind farms vary substantially between studies – in terms of the choice of statistical test to use in assessing significance, in terms of the statistical modelling approach that is used to estimate the abundance of birds within and outside the wind farm, and in terms of the pre-processing methods that are applied to raw data prior to the statistical modelling. Note that these differences occur not only between studies that use different survey platforms, but also between studies that use the same platform (including between studies that use comparable data collection methods, such as standard boat-based line transect approaches). All of the studies appear to use the same outcome measure (Section 3.2), but this would need to be checked carefully before an aggregate-data meta-analysis could be undertaken.

The possible specific ways of implementing an aggregate data meta-analysis for red-throated diver would be identical to the ways in which the second stage of the two-step IPD meta-analysis could be conducted, and these are discussed in the next section.

3.4.2 Two-step IPD meta-analysis

The alternative approaches to meta-analysis both assume that the researcher conducting the meta-analysis does have access to the raw data of every individual study – these approaches are referred to as “individual participant data” (IPD) meta-analyses in the clinical trials literature, and we continue to use this terminology here (although it is important to note that this terminology does not imply that we have data relating to individual birds: the “individual” refers, in the context of ecological surveys, to individual *observations*, rather than individual *birds*).

The simplest variant of IPD meta-analysis is the “two-step” approach. This involves:

a) estimating the key summary statistics of interest separately for each study, using the raw IPD data; and then
b) analysing the resulting statistics using the standard approaches for aggregate data meta-analysis.

The process is summarised in Figure 2; this figure illustrates that the approach is similar, in many ways, to aggregate data meta-analysis, and the second step (b) utilises statistical methods that were developed in the context of aggregate data meta-analysis. The key difference lies in the fact that the two steps of analysis are conducted by the same researcher.

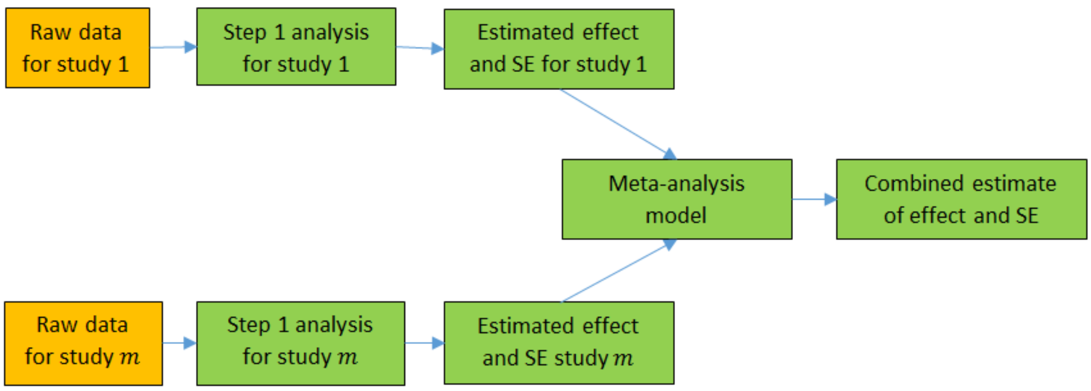

Figure 2. *Flow chart to illustrate how the two-step IPD meta-analysis approach operates. Colour scheme is as in Figure 1. SE refers to the Standard Error of the estimated effect.*

The general advantage of the two-step IPD approach over the aggregate data approach is that it is able to evaluate the validity of the assumptions that underpin the second stage of the meta-analysis, and potentially to refine the methodology that is used for the first step of the analysis in order to ensure that the assumptions underpinning the second step are fulfilled. Critically, the approach can ensure that the same outcome measures (summary statistics) are calculated and reported for each study. In the context of red-throated divers, this should be a major advantage over the aggregate data approach - it allows the methodology and choice of outcome measure to be standardised.

The key disadvantage of the two-stage IPD approach is that it is time consuming and resource intensive: it is necessary to run a separate new analysis using the data for each individual study. The approach is also only feasible if the data collection processes within the different studies are directly comparable. For red-throated divers it is likely to be reasonable to assume that data collected from the same platform (e.g. data collected using standard boat-based line transect techniques) are comparable, but it is less clear that data collected using different platforms will be comparable – this is discussed further in Section 3.5. This approach also requires the data to be made available in a format that enables similar or identical analyses to be applied to each dataset – this means that, in practice, the approach will be much more defensible if the raw data, rather than pre-processed data, from each study are obtained, and if the pre-processing steps as well as the modelling itself is standardised.

Within the context of two-step IPD meta-analysis a range of different specific methodologies are possible, for each of the two stages of the analysis. The first stage of analysis involves analysing the data for each study separately. The set of methods that are available for the first step are therefore the set of methods that are available for analysing the impact of wind farms upon displacement for a single wind farm (Section 3.3). The second stage of analysis involves combining the estimated effects that have been obtained for each individual study. A number of methodologies for this second stage have been developed.

Probably the simplest possible strategy involves calculating the proportion of studies that find a significant negative effect – “vote counting”. This very crude approach, however, fails to allow for the fact that the magnitude of effect may vary between studies, and fails to quantify the overall magnitude of the effect. According to the Cochrane Handbook (Higgins & Green 2011, Section 9.4.11), which sets out the standard protocols for performing meta-analyses in the context of clinical trials, “vote counting might be considered as a last resort in situations when standard meta-analytical methods cannot be applied (such as when there is no consistent outcome measure)”.

Another simple strategy involves taking a straightforward average (e.g. arithmetic mean) of the estimates obtained from each study. This approach is generally not defensible, however, because it fails to account for the fact that studies vary in terms of the sample size and level of unexplained variation – it is desirable to assign more weight to studies with low uncertainty (e.g. high sample size and/or low levels of unexplained variation), and less weight to studies with high uncertainty (e.g. low sample size and/or high levels of unexplained variation).

The simplest approach that accounts for this is the “inverse-variance method” (Higgins & Green 2011, Section 9.4.3.0), and this approach is very widely used. If $\mathrm{y_i}$ denotes the estimated effect for each of the $\mathrm{i} = 1.,,,.\mathrm{m}$ individual studies, and $\mathrm{s_i}$ denotes the standard error associated with this estimate, then the overall estimate of effect is calculated to be a weighted average of the effect estimates from the individual studies:

$$z = \frac{\sum_{i=1}^{m} w_i \, y_i}{\sum_{i=1}^{m} w_i}$$

[Equation 1]

where the weights are equal to the inverse of the squared standard errors:

$$w_i = \frac{1}{s_i^2}$$

[Equation 2]

The weighting factor has the effect of assigning more weight to studies with low uncertainty (e.g. those with large sample sizes) than to those with high uncertainty (e.g. those with small sample sizes) when calculating the estimate for the overall effect. It is also possible to calculate the standard error for the combined estimate. The inverse-variance approach can probably be regarded as the simplest possible approach to meta-analysis that is (at least in some situations) statistically defensible. This approach can be implemented within R using the **lm** function, via the use of the **weighting** argument.

The most basic version of the inverse-variance approach fails to account for the fact that the intervention effect (e.g., in our context, the effect of the wind farm) may genuinely vary between studies – i.e. to account for the fact that there may be genuine variation between studies in the true magnitude of the effect. An extension of the inverse-variance approach (DerSimonian & Laird 1986) uses a “study” random effect to account for this heterogeneity; within this approach the analyses are therefore based on linear mixed models (LMMs; e.g. as implemented in R using the **lme4** and **nlme** packages).

3.4.3 One-step IPD meta-analysis

The final type of meta-analysis also assumes that raw (IPD) data are available. This approach (which is illustrated in Figure 3) models the overall outcome measure directly in terms of the raw data, within the context of a single unified statistical model – the individual studies are not analysed separately. Variation between study is nonetheless, accounted for – the simplest way of doing this is by including “study” as a random effect within the statistical model, but more sophisticated approaches will often be necessary.

The one-step IPD approach can generally be used in situations similar to those used for the two-step IPD approach, and both have identical requirements in terms of data availability.

The key advantage of the one-step approach is that it can potentially provide more efficient (precise) estimates for the overall effect, by allowing some information to be pooled between studies within the analysis. The approach is extremely flexible, and conceptually simple, since it involves fitting a single model – this makes it easier to understand the assumptions of the model, and hence potentially to interpret the results of the analysis. Finally, the use of a single model means that the quantification of uncertainty will occur naturally as part of the modelling, and means that model selection and goodness-of-fit assessment can be conducting using standard statistical approaches (e.g. AIC/BIC/DIC criterion for model selection).

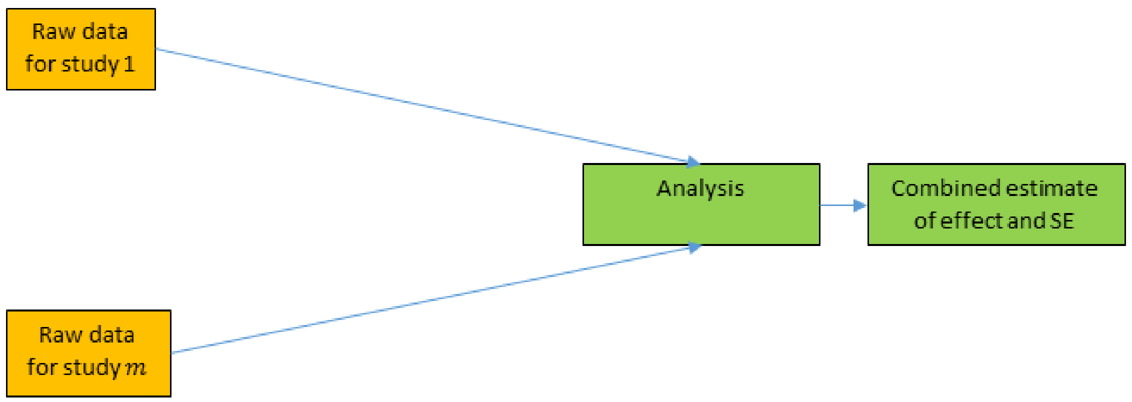

Figure 3. Flow chart to illustrate how the one-step IPD meta-analysis approach operates. Colour scheme is as in Figure 1. SE refers to the Standard Error of the estimated effect.

The key disadvantage of the one-step IPD approach is that the technical and computational complexity will generally be greater than for the two-step IPD approach, and standard software will typically not be available to implement the one-step approach – it is likely to be necessary to implement this using flexible statistical modelling software such as WinBUGS/JAGS, which requires the user to have a high-level of technical knowledge. The intellectual challenge of formulating an appropriate model will also typically be higher, since it will be necessary to explicitly make assumptions not only regarding the characteristics of data within the study, but also concerning variation between studies. If parameters are incorrectly pooled between studies, or if study-to-study variation is incorrectly included in the model, then this may lead to bias in the estimation of the overall effect.

3.4.4 Summary

The various aspects of the modelling, and the advantages and disadvantages associated with the choices at each stage, are summarised in Table 3.2. Overall, the key modelling choice is between running an aggregate data meta-analysis – using summary statistics from published studies – or running an IPD meta-analysis in which the raw data from each study are re-analysed.

Table 3.2. Summary of the main possible approaches to the key elements of the statistical analysis, and the advantage and disadvantages of each.

Analysis stage	**Possible options**	**Advantages**	**Disadvantages**
Pre-processing to adjust for non-detection	No adjustment made	Very straightforward to use. Defensible if probability of non-detection is fairly homogeneous	Relies upon an assumption of perfect detection that is unlikely to be realistic. Bias may arise if probability of non-detection varies over time and space.
	Adjustment using published correction factors	Straightforward to use. Adjusts for the under-estimation of abundance that results from non-detection (albeit crudely).	Published factors not always available (e.g. for aerial survey data).

Analysis stage	Possible options		Advantages	Disadvantages
	Adjustment by fitting detection functions to empirical data for this wind farm		Adjusts for the under-estimation of abundance that results from non-detection. Allows for spatial variations in non-detection.	Relatively complicated to use. Many not be feasible if sample sizes are small.
Spatial modelling and/or aggregation of abundance data (within each study)	Summing up observed counts/densities		Very straightforward to use.	Underlying differences between the control and wind farm areas (e.g. in terms of differences in covariates) cannot be accounted for. Difficult to formulate a reliable assessment of uncertainty.
	Generalised linear model (GLM)		Relatively straightforward to use. Covariates can be included in the analysis. Uncertainty can be quantified.	Less flexible than mixed models or GAMs, so the assumptions underlying the GLMs may not always be reasonable.
	Generalised additive model (GAM)		Covariates can be included. Uncertainty can be quantified. Covariates and spatial location can be accounted for in a more flexible way than is possible using GLMs.	Technical complexity is moderate (standard software exist, but there are technical complications that make use and interpretation harder than for GLMs).
	Generalized additive mixed model (GAMM)		As for GAMs, but can also account for residual spatial autocorrelation.	Technical complexity is fairly high.
	Zero-inflated generalized additive mixed model (ZI-GAMM)		As for GAMMs, but also accounts for zero inflation.	Technical complexity is high.
Combining results from different studies via meta-analysis	Two-step meta-analysis (either aggregate data meta-analysis or two-stage IPD meta-analysis)	Vote counting (e.g. looking at sign of estimated effect in each study)	Very straightforward to use.	Does not provide any estimate for overall magnitude. Makes only very partial use of data
		Calculation of simple (unweighted) arithmetic mean of estimated effects.	Straightforward to use.	Fails to account for differences in sample size and levels of unexplained variation within studies.
		Standard (fixed effect) inverse-variance method	Fairly straightforward to use. Accounts for differences in sample size between studies, and differences in levels of unexplained variation.	Moderate level of technical complexity.
		Random effect inverse-variance method	Allows for the fact that the true effect may vary between studies.	Relatively high technical complexity.

Analysis stage	Possible options		Advantages	Disadvantages
	One-stage IPD meta-analysis	Various – this is an extremely flexible approach, so a wide range of possible model formulations are possible.	Extremely flexible approach. Allows some information to be pooled between studies, where appropriate. Allows for full quantification of uncertainty.	High level of technical complexity (compared to two-stage approach)

The technical, computational and time requirements for running an aggregate data meta-analysis would be substantially lower than for running an IPD meta-analyses. This would be the key advantage of the aggregate approach, along with the fact that the aggregate data meta-analysis does not require access to the raw data (and so would not be dependent upon obtaining data permissions). The key disadvantages of the aggregate approach are:

a) that it relies upon being able to extract comparable summary statistics (estimated wind farm effects, and associated SEs) from all studies. We expect from our literature review that this is likely to be possible, because most studies do ultimately, use comparable outcome measures, but it is nonetheless a non-trivial task: the studies differ considerably in the way that they report their results, and in the level of detail that is provided;
b) that it relies upon the estimated wind farm effects from the different studies, and their associated SEs, being comparable. There are substantial differences in the analysis methodologies used by the different studies, as well as in the survey platforms used, so it is not clear that the study-species estimates – and, especially, the SEs associated with them – would be comparable.

The IPD meta-analysis approach would allow these issues to be dealt with, but would be a challenging exercise involving re-analysing data that have been obtained from different survey platforms, which are stored in different formats, and which have been subjected to varying levels of pre-processing.

3.4.5 Possibility of running a meta-analysis using data aggregated by the data holder

The results of the questionnaire suggest that some data holders may be willing to release data that have been aggregated to a crude spatial scale even when they are not willing to release the corresponding raw data. Would it be feasible to use such data within a meta-analysis? There are two key general points to consider here, regardless of the precise method used to aggregate:

1) The meta-analysis would only be feasible if a consistent approach to data aggregation were used for all studies.
2) The aggregate data would necessarily have been pre-processed (e.g. to deal with non-detection), and, unless the data holders could be persuaded to re-run the pre-processing steps using a standardised approach (which would be time consuming for them), there would be considerable differences in the way this was done within different studies. This approach would therefore have many of the same drawbacks as an aggregate data meta-analysis (Section 3.4.1), although the final parts of the analysis could be standardised to an extent that is not possible if the meta-analysis relies solely upon published summary statistics.

The exact form of aggregation is also important. We consider two basic possibilities here, because these appear to be the most likely ways in which aggregate data might be made available.

The first approach assumes that data holders aggregate their data onto a spatial grid, and that all data holders use the same spatial resolution (e.g. 10x10km). If this approach used a fine spatial grid (e.g. 1 x 1km) then this approach would be relatively defensible, and would, in many ways, be similar to an IPD meta-analysis (albeit with the pre-processing steps already having been undertaken, so that the methodology would not be as standardised as in an IPD meta-analysis). If the grid has a coarse resolution, relative to the size of a wind farm, then the defensibility of the approach is reduced. It would be difficult to calculate the number of birds within the wind farm and control area with any accuracy because this would have to be done using interpolation. If the grid is very coarse i.e. the grid cells are large enough that it is difficult to define any individual cell as being within or outwith the wind farm then this approach is not only less defensible than the an aggregate data meta-analysis (Section 3.4.1) but probably also less defensible than an IPD meta-analysis (Sections 3.4.2 and 3.4.3).

The second approach assumes that data holders aggregate their data up to spatial units that are related to the wind farm itself, for instance to provide mean densities within the WF and control areas, in both pre- and post-construction periods. This would be in many ways similar to the inputs and methodology used for an aggregate data meta-analysis (Section 3.4.1), although the inputs here would be provided by the data holder rather than derived by the analyst from published reports. The drawbacks of this are similar to those described in Section 3.4.1, with one exception: the lack of standardisation in reporting could be avoided if the data holders provide the aggregate data directly. It would be essential, however, for the data holders to provide quantification of uncertainty (e.g. standard errors) alongside mean densities, in order for the analysis to have any level of defensibility.

3.5 Possible statistical approaches when it is required to combine survey platforms

3.5.1 Requirements on data collection in order to conduct a meta-analysis

For all three types of meta-analysis it is necessary that:

a) all studies included within the meta-analysis clearly report and describe the data collection methodology that was used;
b) all studies included within the meta-analysis utilise data collection methods that are defensible and robust; and
c) all studies use *comparable* data collection methods i.e. they use similar data collection methods, or else the differences between the data collection methods can be quantified.

These requirements are the same regardless of whether the same platform is used for data collection in all studies, or whether a range of different platforms are used, especially because there will be variations in the precise protocol used for data collection even within the context of a single platform (e.g. variations in the height of the observer above sea level, and variations in the number of observers). Displacement effects on red-throated diver are assessed by comparing the spatial distribution of birds within and out-with the wind farm footprint, and assessing how this spatial distribution changes over time, so in order to combine data from multiple studies it is necessary that they are each capable of estimating these spatial distributions reliably. In practice, this means that data collected using different methods (e.g. from different platforms, or from the same platform using different protocols) can be defensibly combined within a single analysis only if:

a. the magnitude of any systematic under or over-estimation of the true number of birds present at each location and time (e.g. due to non-detection or flushing) can be quantified, and hence accounted for within the analysis; and

b. standard errors associated with these numbers can be calculated in a reliable way.

In other words, each data collection platform needs to be accurate (lacking in systematic bias), and to have an accurately quantified measure of precision. Note that it is not necessary for the level of precision to be high, or for the level of precision to be the same for all platforms, since differences in precision between platforms can be automatically accounted for within the meta-analysis, the key thing is that the precision can be accurately quantified.

3.5.2 Descriptions of possible survey platforms

Within the sixteen studies listed in Section 3.1 a total of six different platforms were used for data collection – boat-based visual surveys, aerial visual surveys, aerial high-resolution digital stills photography, aerial high-resolution digital video photography, radar and bird-borne tracking devices. The key characteristics of these platforms are summarised in Table 3.3.

Table 3.3. Description of each data collection platform.

Platform	Non-detection?	Non-classification of species?	Behaviour identified?	Area covered
Boat-based visual survey	Yes	Group or species level	Yes – on-sea and in flight, distance band	Line transects
Aerial visual survey	Yes	Typically group level (species level is rare)	Yes – number, behaviour, distance band	Line transects
Aerial digital still photography	No	Group or species level	Yes – on sea vs in flight	Matched to aerial survey transects (for RTD study)
Aerial digital video photography	No	Group or species level	Yes – on sea vs in flight	Matched to aerial survey transects (for RTD study)
Radar	Yes – accounted for using intensive pre-processing of raw data in relation to weather, wave activity, noise, etc	Radar data typically do not distinguish between species. Additional monthly surveys are used to estimate proportion of birds that belong to each species. Some species identified using flight patterns	Flight only – position, angle and speed	Fixed point location (for the two RTD studies to use radar)

Platform	Non-detection?	Non-classification of species?	Behaviour identified?	Area covered
Bird-borne tracking devices: GLS GPS	GLS: Standard methods result in no locations during equinoxes, but analyses available to fill these gaps using temperature data GPS: standard methods based on short-term attachment methods are focussed on summer distributions only, one study (Zydelis *et al* unpublished) used GPS tags implanted in the abdominal cavity which results in long-term attachment	No	Yes – can get information on activity	Individual range; for GLS, individual fixes have average error of ca. 180km, with possibility for improved accuracy using spatial modelling

i *Boat-based transect surveys*

One of the more common platforms used for data collection in the context of displacement by wind farms is the boat-based visual survey. A standard survey methodology exists (Tasker *et al* 1984; Camphuysen *et al* 2004), and all of the studies that used this platform followed this protocol (although some studies adapted methods to match this protocol partway through the study). All approaches tend to encounter the same general issues, namely repeat counting of birds, imperfect detection ability, attraction versus repulsion of birds, and non-random sampling (for review see BirdLife International 2010). A particular issue concerns ‘flushing’ of birds as vessels approach flocks. Schwemmer *et al* (2011) estimated the flushing distance of diving bird species (not including red-throated divers) during boat-based visual surveys and found birds took flight between 200m and 800m from the approaching vessel, although there was wide variation around these values for the four species assessed indicative of considerable individual-level variation. Importantly, flush distances for three of the diving bird species in this study were positively related to flock size, indicating that interactions between overall bird density and flock size will affect the extent to which boat-based visual surveys are affected by this issue (Schwemmer *et al* 2011). Moreover, sea state was found to have a strong influence on flush distance with most species flushing at shorter distances with increasing sea state (Schwemmer *et al* 2011). A handful of other studies have assessed flushing distances using radar (Kaiser *et al* 2006; Bellebaum *et al* 2006) and reported greater flushing distances for some species than those reported by Schwemmer *et al* (2011); however, in all cases it was noted that the influence of ambient environmental conditions will likely have affected the behavioural response and therefore it will be difficult to compare and compensate for varying flushing distances across studies where conditions have not been recorded in sufficient detail to account for statistically.

Several studies have employed methods to deal with flushing of divers during boat-based visual surveys. These methods typically involve observers periodically scanning far ahead of the boat to identify flocks and individuals at risk of flushing before they are encompassed by the furthest distance band being used in the survey. However, an additional observer has not been employed in all studies.

Note that the same comments described here in relation to flushing of birds during boat-based visual surveys also apply to aerial visual surveys.

ii Aerial visual transect surveys

The second most common method was traditional aerial visual transect or strip surveys, used in five of the thirteen studies. Aerial surveys can be particularly useful for surveying large areas in short periods of time, and are therefore useful in determining seabird distribution over greater scales than vessel-based surveys. Aerial visual surveys often follow the same collection approaches as boat-based visual surveys, although fewer potential biases may be involved. In particular, it is not necessary to employ a snapshot methodology to deal with birds in flight because observation flight speeds are faster than those of the birds, neither is it necessary to consider birds from the forward half of the platform only because, unlike boats, aircraft do not attract birds (although they may flush birds depending on the height above sea level). Typically, aerial visual surveys employ a continuous-strip survey where any birds sighted are recorded, and are then analysed using standard distance transect methodology (see BirdLife International 2010 for a review). Several studies using this method were able to identify a proportion of sighted divers to the species level i.e. red-throated diver (e.g. Webb *et al* 2017).

iii Aerial digital still photography

Aerial digital stills photography surveys were used in one study, although this study was a comprehensive review of data on red-throated divers in the Outer Thames Estuary, so encompassed five different planned or operational wind farms (APEM 2011c). This method tends to apply the same transect methodology as traditional aerial visual surveys, but surveys are typically flown at much greater heights above sea level, thereby avoiding issues with flushing of red-throated divers. Digital stills imagery typically had a resolution of 3cm Ground Sampling Distance (GSD) for aerial bird surveys but has now moved to the higher resolution of 2cm GSD for most surveys, with each image covering an area of approximately 31,000m^2, and whilst some species may only reliably be identified to group level (e.g. auk, diver, seaduck) other species such as red-throated divers may be identified to species level (Knights *et al* 2010; APEM 2011c). It has been found that during periods of high red-throated diver abundance, digital stills can produce greater estimates of abundance than the traditional aerial visual methodology (Goodship *et al* 2015), most likely attributable to the ability to enumerate large numbers of birds post-hoc using the digital method, a procedure which is not possible for visual surveys (Knights *et al* 2010). However, when densities are very low, the traditional aerial visual survey method has a higher relative encounter rate than the digital method (Knights *et al* 2010). Finally, because digital stills can be archived there is a much greater opportunity for quality assurance procedures and post-hoc reviewing of survey data than is available in visual aerial or boat-based surveys.

iv Aerial digital video photography

Digital aerial video surveys typically fly a series of transects, spaced over the survey area to achieve the % coverage sought. Four video cameras are mounted on the aircraft, each sampling a specific strip width, separated by a gap (e.g. Webb *et al* 2017). Surveys are flown at a constant altitude of around 550 - 600m above sea level and speed of approximately 230 km/h, with cameras set to resolve a distance on the ground of 2cm x 2cm (referred to as 2cm ground sample distance ("GSD")) for each camera pixel. The cameras are angled 30° in front of or behind the aircraft to ensure that they are pointing away from any sun glare on the sea surface. GPS position data for the aircraft is captured enabling a

1m precision for the positions, and recording updates in location at one second intervals for later matching to bird observations. Aircraft flight height is set to ensure that there is no risk of flushing species which have been proven to be easily disturbed by aircraft noise. However, this survey method (and that using aerial digital stills) suffers more from availability bias for diving species in comparison to boat-based visual surveys (the bias caused by diving animals while they are underwater at the time of the survey) because of the very short time frame when animals are visible (Webb *et al* 2014). This can be corrected using known diving rates of animals, but these tend to be collected during the breeding season using breeding adults under considerably different energetic and behavioural constraints than individuals in the post-breeding period.

Video data are first viewed by trained reviewers to mark any objects in the footage as requiring further analysis, determining which are birds, marine mammals, other vertebrates or inanimate objects such as ships, buoys or other objects of interest. For quality assurance, an additional “blind” review of a proportion of the raw data is also conducted. Objects were only recorded if they crossed a reference line which defined the true transect width for each camera. By excluding objects that do not cross the red line, biases to abundance estimates caused by flux (movement of objects in the video footage relative to the aircraft, such as ’wing wobble’) are eliminated. Images are then reviewed by specialist ornithologists for identification to the lowest taxonomic level possible and for assessment of the approximate age and the sex of each animal and any behaviour traits visible from the imagery, again with an external quality assurance process. All objects were assigned a species group and where possible, each of these was identified to species level. Red-throated divers are typically identified to species level using this method (e.g. Webb *et al* 2017). The species identifications were given a confidence rating of possible, probable or definite. Ornithologists also noted their behaviour, flying direction, and where possible, age, plumage and sex. The height above sea for flying birds is also determined using standard methodology. Furthermore, flight directions can be used to determine if the wind farm is acting as a barrier to movement. Although not strictly displacement, and therefore not in the scope of this report, it is an important additional mechanism whereby wind farms can adversely affect marine birds such as red-throated diver. However, it is not clear how this can be included in a meta-analysis of data from multiple platforms, the majority of which do not measure barrier effects/macro-avoidance. Finally, all survey data is archived and is therefore available for review.

v Radar

Radar observations (Studies: LIN and Egmond aan Zee) have been used to estimate displacement and barrier effects from wind farms to red-throated diver and other marine birds by comparing bird use of wind farm areas before and after construction, or post-construction only. Radar uses both a horizontal radar to measure flight paths, and a vertical radar to measure fluxes and flight altitudes. In the most detailed instance of radar as a survey platform in relation to displacement from wind farms for red-throated divers (Krijgsveld *et al* 2010), flight patterns in relation to the wind farm were quantified using a combination of automated and visual observation techniques. From the metmast in the area (the metmast is positioned south-west of the wind farm, at a distance of c. 500m from the nearest turbines), visual observations were carried out, as well as radar observations with both a vertical radar and a horizontal radar. Visual observations gave insight into species composition and species distribution in the area, as well as species-specific information on flight patterns. Radar observations were carried out around the clock, each day, all year, giving insight into overall flight patterns in the area.

Using radar, observations of flight paths are done using horizontal marine surveillance radar (S-band). This is a standard radar as used on ships, which scans the area in the horizontal plane around the radar. With this radar, flight paths of birds flying through the radar beam are tracked and flight speeds and directions recorded, as well as other flight characteristics. Observations of bird fluxes and flight altitudes is done using a comparable type of radar (X-band), which is tilted to rotate vertically, and thus scans the air vertically rather than horizontally. Using a radar in the relatively short X-band frequencies allows high-resolution target identification and information. In this way, bird flux can be quantified by counting the number of birds that crossed the radar beam during a fixed amount of time, and flight altitude of birds can be measured by recording the vertical distance of the bird to the sea surface.

Not all tracks recorded by radar are tracks of birds or bird groups, but are erroneously recorded tracks originating from clutter such as the movement of insects, turbine rotors, the sea surface (waves) or interference from other radars. To be able to remove these data from the database, a series of tests and experiments are typically done to identify and discriminate between records of birds and clutter.

To depict flight directions and flight intensities in the wind farm area, a virtual grid is placed over the wind farm area, typically consisting of cells of 1 x 1km. Within each of these cells, the average flight direction is calculated, as well as the total number of tracks recorded.

Radar data are not recorded to species level. Additional visual and auditory observations were therefore carried out at the location of the wind farm on approximately one day each month; the visual and auditory observations were used to determine the proportion of birds that belonged to each species, and the visual observations were used to determine flight patterns. These additional data were then used, in combination with the radar data, to calculate the number of birds belonging to each species (or species group). In the one instance of using radar methodology to assess displacement of red-throated divers, radar flight information was determined at the species level.

vi Bird-borne geolocation and GPS tracking devices

Quantifying barrier effects from GPS tracks is achieved by examining directions of flight lines directly. Quantifying displacement from GPS tracks is more challenging because birds may fly directly to the displacement location so the track would not exhibit any detectable deviation away from the wind farm location. Such tracks of displaced individuals are hard to distinguish from those of individuals that instead had an initial preference for the location to which other birds were displaced. Analysts may resort to the main assumption adopted in at-sea based surveys, whereby the relative difference inside and outside the footprint before and after construction is assumed to result from displacement. Alternatively, the problem can be addressed using two approaches: a) BACI analysis, using a nearby colony as a control; b) gradient analysis at a single colony, where the difference in distribution before and after construction is quantified in relation to distance to the wind farm, thereby attributing changes in distribution to the wind farm and not to some other potential cause.

3.5.3 The pros and cons of different methods at quantifying displacement

There are two main challenges associated with quantifying displacement: empirical estimation and detection.

With respect to the first, all methods face the same challenge that displacement is unlikely to be recorded directly. Birds are likely to travel directly to displacement locations, so even those approaches that record flight lines accurately (tracking, radar) are likely to need to use indirect methods (though this is untested; it is possible that individuals show a detectable deviation in flight path when being displaced). As such, all survey methods must work with the distribution of birds before and after construction. All methods have the potential to apply BACI or gradient analyses to test statistically for the effects of displacement. Tagging has the additional advantage of controlling for individual-level effects (which are likely to be substantial) by deploying devices on the same individuals before and after construction.

With respect to the second, methods vary in detection probability. Aerial digital and GPS tracking data have an advantage in this respect over visual surveys (boat-based or aerial) or radar. Bird-borne devices have the additional advantage over other methods of providing data in all weather conditions. However, these advantages are set against high cost in the case of aerial digital and logistical constraints and the potential for device effects on bird behaviour in the case of bird-borne devices. Furthermore, these methods were not widely available in earlier work which has made comparison between pre- and post-construction challenging.

After construction, at-sea based surveys methods are subject to non-random placement of transects with respect to turbines. There are safety concerns with aerial visual surveys post-construction that are overcome with digital methods that are able to fly at a safe height above the turbines and collect images that allow species identification.

3.5.4 Feasibility of combining data from different platforms

We performed ISI Web of Science and Google Scholar searches, and along with expert knowledge from project participants and the project steering group we identified eleven published or confidential studies that have estimated seabird spatial distributions and abundance by combining data from different survey platforms. Of these publications, three addressed combining boat-based survey data with GPS tracking data (Louzao *et al* 2009; Arcos *et al* 2012; Perrow *et al* 2015), although none of these related directly to red-throated divers. We are aware of no studies on red-throated diver that have attempted to combine GPS or telemetry data with those from another survey platform, although red-throated diver distributions have been assessed using telemetry methods (e.g. Žydelis *et al* 2016). Whilst difficult, it should be noted that it is possible to use advanced statistical methods to combine data from aerial or vessel-based surveys with those from tracking studies. Therefore, should more such data become available for red-throated divers in the future, they could potentially be combined with data arising from more traditional methods to better inform bird habitat usage, distribution and abundance at-sea. However, we do not discuss the methods in detail in this report.

Of the remaining studies that were identified in the literature search, four compared or combined boat-based and aerial transect surveys (Briggs *et al* 1985; Ford *et al* 2004; Henkel *et al* 2006; Winiarski *et al* 2014); two combined boat-based transect surveys with aerial digital videography surveys (Webb *et al* 2014; Hostetter *et al* 2015); and one combined boat-based transect surveys, aerial observer transect surveys and aerial digital still surveys (APEM 2011c).

i Combining vessel-based and visual aerial transect surveys

This sub-section considers combining vessel-based and visual aerial transect surveys; discussion of the additional aerial survey techniques using digital stills and digital video cameras combined with vessel-based surveys follows this sub-section.

Studies on species other than red-throated divers have indicated boat-based and visual aerial surveys are, in general, comparable in terms of estimating abundance. Ford *et al* (2004) compared density estimates of common guillemots *Uria aalge* and phalaropes *Phalaropus* spp. from aerial and boat-based surveys off central California, conducted during the same season but on different days. This study reported the density of common guillemots was similar between survey platforms; whilst density of phalaropes was greater from aerial surveys (Ford *et al* 2004). Importantly, for both taxa, zero counts within 10’ x 10’ (degrees latitude/longitude) cells were more common on boat-based surveys than aerial surveys; and aerial surveys detected more large flocks of phalaropes (Ford *et al* 2004). This has implications for analyses done on presence/absence data, and for studies looking at clustering or flock sizes of birds.

Similarly, Piatt *et al* (1991, unpublished; reported in Henkel *et al* 2006) compared data from simultaneous aerial and boat-based surveys for marbled murrelets *Brachyramphus marmoratus* in south-east Alaska and found no statistical difference between density estimates based on the two techniques. However, in contrast to these studies, Nysewander *et al* (unpublished report 2005; reported in Henkel *et al* 2006) conducted several studies using simultaneous aerial and boat-based surveys in Puget Sound and found that for most species aerial surveys resulted in density estimates less than 50% of those from boat-based surveys, although aerial density estimates for sea ducks were proportionally higher than for other species. These results were similar to other studies comparing aerial and ground or boat-based surveys for waterfowl, in which aerial surveys resulted in lower density estimates (Stott & Olson 1972 – ground-based surveys; Conant *et al* 1988 – boat-based surveys, reported in Henkel *et al* 2006).

However, contrasting results have been reported in two more recent studies where data from simultaneous aerial and boat-based surveys of diver species (Pacific diver *Gavia pacifica*; great northern diver, *G. immer*; and red-throated diver) were used to compare density estimates from each method (Henkel *et al* 2006; Winiarski *et al* 2015). One of the studies reported that density estimates of all divers combined (including red-throated divers) were significantly greater based on aerial surveys than in boat-based surveys (California; Henkel *et al* 2006), and it was postulated that this difference may have been due to boat avoidance leading to biased density estimates from boat-based surveys (Henkel *et al* 2006). Density estimates from boat-based surveys were significantly less than those from aerial surveys in which data from the glare side of the plane were excluded; however regression analysis indicated that aerial survey density estimates were quite similar to those from boat-based surveys when densities were greater than 2 birds/km^2, with the expected 1:1 ratio falling within 95% confidence intervals above this threshold density (Henkel *et al* 2006). However, the authors caution that for diver species, the data were highly variable, and the relationship should be viewed with caution (Henkel *et al* 2006).

In conclusion, the authors noted that the greater densities estimated from aerial surveys were likely based on avoidance of the boat or different detectability between the two platforms (Henkel *et al* 2006). Because of the high speed of the aerial surveys, birds generally have very little time to react to the approaching plane; in contrast, animals may avoid a relatively slow moving boat and divers were observed taking off from the water several hundred meters in advance of the approaching boat (Henkel *et al* 2006; Schwemmer *et al* 2011). Briggs *et al* (1985b) also noted divers avoiding the research boat in a study in California.

A common theme in several of these studies is that although density estimates for divers tended to be greater from aerial surveys in comparison to boat-based surveys, these differences may be relatively unimportant with respect to natural variability in abundance of these species and variability of density estimates from either platform based on the clumped distribution of these species. Indeed, two other studies (Briggs *et al* 1985; Ford *et al* 2004) noted that while density estimates derived from the two different methods may vary, the differences between the density estimates on a regional scale may be small relative to variability from other sources, such as season or location. For instance, Briggs *et al* (1985) compared density estimates of seabirds (including divers) from simultaneous aerial and ship-based surveys found that whilst local estimates of densities from aerial surveys were three to four times greater than those from ship-based surveys (California; Briggs *et al* 1985), additional comparisons conducted on a regional scale revealed no significant difference between density estimates from the two platforms, although this regional analysis did not include diver species due to low numbers observed across the entire region (Briggs *et al* 1985).

The most recent study to compare these two survey methods used density surface models (DSMs) to predict the distribution and abundance of great northern divers using aerial strip transect surveys and boat-based line surveys during winter 2009–2010 in a 3,800km^2 study area off the coast of Rhode Island, USA (Winiarski *et al* 2015). Before combining the two sets of survey data, compatibility of the two types of survey data was assessed in areas where the two surveys overlapped. This study found that great northern diver densities were compatible by platform, although at least one ship-based segment with much higher diver abundance was estimated than found with the aerial surveys; however, a Kolmogorov-Smirnov 2-sample test indicated that the two sets of densities could have come from the same distribution (Winiarski *et al* 2015). The DSMs were then used to account for three factors that could affect great northern diver abundance estimates: (1) by using a detection function to account for imperfect detection probabilities in the ship-based line transect survey data; (2) by using an availability bias correction to account for diver diving behaviour when surveyed with aerial-based strip transects; and (3) by using a spatially explicit model with environmental covariates to account for non-uniform distribution of divers across the study area (Winiarski *et al* 2015). The DSMs incorporated spatially explicit environmental covariates (water depth and latitude) to provide predictions of the spatial distribution and abundance of wintering great northern divers (for flying individuals only), and it was found that the combined-platform model (boat-based + aerial surveys) offered substantial improvement in the precision of abundance estimates from the ship-platform model, and modest improvement in the precision of the aerial-platform model, although it had relatively low predictive power (Winiarski *et al* 2015).

In summary, these studies demonstrate that it is possible to combine data from boat-based and aerial transect surveys to estimate densities, but that there appear to be inherent biases in the raw counts these two methods produce for diver species such as the red-throated diver. Aerial transect studies tend to produce greater density estimates for this species, or other diver species, in comparison to boat-based surveys due to differences in bird behavioural reactions to boats versus planes, and in differences in detection probabilities between the two survey platforms. However, given the considerable spatial and temporal variation in bird densities across areas, these survey-based discrepancies are likely to be relatively minor. If sufficient details exist on the detection probabilities and methods used in aerial and boat-based transect surveys, it does therefore seem possible that data from these two methods can be combined within a single analysis to produce better estimates of red-throated diver density. However, this exercise is not trivial and should ideally involve environmental covariates to attempt to account for the overriding natural variation in bird densities that exists in isolation from any effect of offshore renewables, and in how the relationships between bird density and environmental covariates changes seasonally and over time. Moreover, methods that combine these two data types appear to have low predictive power, therefore any application should be restricted to the area from which the survey data derives, rather than extrapolating more widely to different regions.

ii Combining boat-based transect surveys and digital video aerial surveys

A small number of studies have compared data collected via traditional methods (boat-based visual surveys) and with newer technologies (aerial digital video photography).

In one study, predictions of marine bird abundance and distribution (including divers, which were analysed as a group comprising great northern divers, red-throated divers and all unidentified diver observations), were jointly informed by aerial surveys, which encompassed a large geographic area, and boat surveys, which allowed for estimation of detection probability (Hostetter *et al* 2015).

The study developed an approach to combine shipboard and digital video aerial survey data to produce a single prediction of marine bird abundance and distribution, in essence creating a covariate based on the data from the digital video aerial surveys to be included as a predictor variable in the boat surveys. Models were then compared with and without the aerial covariate to evaluate the model performance and determine the best method for predicting bird abundance and distribution (Hostetter *et al* 2015).

The results showed that integrated and boat-only models predicted similar total abundance across the study area, but that distributions and hotspot locations often varied between approaches; notably divers showed strong associations between aerial and boat data, which led to concentrated hotspots (Hotstetter *et al* 2015). Model evaluation indicated that integrated models outperformed models that only used boat data when predicting back to the same boat and aerial data used for the analysis, but boat-only models were better at predicting distributions from separate surveys, i.e. boat and aerial surveys conducted in the same season but during a different month than the data used in the analysis (Hostetter *et al* 2015).

In summary, the integrated model used in this study had noticeable improvements in predicting local hotspots and marine bird distribution relative to models that only included boat-based data; however, it had relatively low predictive power to independent surveys which was likely a consequence of inter-seasonal variation in local hotspots, changes in habitat covariates, and possibly changes in the relationships with those covariates (Hostetter *et al* 2015). Integrated models improved the identification of abundance hotspots and areas of lower than expected abundances, and the authors note that developing new joint modelling approaches can improve identification of important habitat use areas (particularly local dynamic hotspots) and provides a framework to compare historical and new sources of data (Hostetter *et al* 2015). Finally, the authors note that this type of integrated model could potentially estimate species-specific abundances where not available, by accounting for birds that were not identified to species (in the aerial dataset) using information from the boat surveys to inform species identification in the aerial survey, although they note this is by no means trivial (Hostetter *et al* 2015).

A second study (Webb *et al* 2014) compared bird densities estimated by boat-based and aerial digital video surveys to consider differences between more recent data and that collected historically under the ESAS program. During this work, an additional aim was to assess the bird density derived from digital video aerial surveys and boat-based visual survey data captured simultaneously. The goal was to assess if a scaling factor could be applied to the raw data collected using one of the survey platforms and thus allow regression models to use data derived from both data platforms together to better estimate bird densities (Webb *et al* 2014). The study focused this analysis on the six most common species (guillemot *Uria aalge*, kittiwake *Rissa tridactyla*, northern gannet *Morus bassanus*, razorbill *Alca torda*, fulmar *Fulmarus glacialis* and puffin *Fratercula arctica*) and so the applicability to red-throated divers remains untested. Of these six species, it was found that two (kittiwake and razorbill) had statistically different median density predictions arising from the two survey platforms, with both species having greater densities estimated by the boat-based visual surveys than the aerial digital video surveys (Webb *et al* 2014). It was suggested these differences may have resulted in differences in environmental conditions or behaviours over the timing of the surveys (although surveys were conducted on the same day they were conducted sequentially). This work then assessed how different model formulations including data from single or both survey platforms performed in predicting observed densities (boat-based visual surveys only; boat-based visual data + digital video aerial surveys; boat-based visual data + digital video aerial surveys with a scaling factor applied for kittiwakes and razorbills). In all models the addition of aerial digital video survey data increased over-dispersion scores and weakened the strength of evidence in the data for the model, as did adding scaling factors for models for kittiwakes and razorbills (Webb *et al* 2014). Importantly, all fitted models had low predictive power, which was attributed to the lack of predictive power in the environmental covariates used in model fitting (Webb *et al* 2014).

iii Combining visual aerial survey data with aerial digital imagery

One study was identified that developed methodology for combining historic visual data (from aerial transect surveys) with state of the art high resolution digital still imagery data from aerial surveys (APEM 2011c). The study acquired all available data for five planned or operational wind farms within the Outer Thames Estuary; Greater Gabbard, Gunfleet Sands, Kentish Flats, London Array and Thanet, and estimated changes in their abundance and distribution over the period 2001 – 2010, representing a comprehensive review of red-throated diver data for this period in the Outer Thames Estuary area (APEM 2011c). The study undertook a calibration exercise at one of the wind farms (the London Array offshore wind farm site) and estimated a statistical relationship between red-throated diver density estimated by traditional visual survey and high resolution digital still surveys to produce a long-term trend incorporating both methods. The integration of the two types of survey data was limited to the London Array wind farm, although the authors note the derived relationship is potentially applicable to other offshore sites, but its suitability for application in new areas would require a more thorough understanding of site-specific environmental conditions and differences (APEM 2011c). The approach was used to estimate a historical trend based on data collected by traditional visual aerial survey method and data collected by high resolution digital stills, via a calibration exercise that produced a significant relationship between standard visual survey estimates and those from high resolution digital stills (APEM 2011). The equation describing that relationship was then applied to standard visual survey data to estimate a trend for the abundance of red-throated divers in the London Array OWF site by combining the two types of data (APEM 2011c).

A second study (Webb *et al* 2017) compared abundance estimates for diver species as a group using digital video imagery versus visual aerial survey platforms at the Lincs offshore wind farm. This study highlighted the differences in the efficiency of different survey platforms, particularly in relation to digital methods tending to result in higher densities of some species, including red-throated divers due to flushing or disturbance of this species by low-flying aircraft (Webb & Garthe 2013). The calibration in this study (Webb *et al* 2017) used data from five surveys from the German North Sea around the Alpha Ventus and the Amrumbank wind farms. Distance analysis was used to correct for imperfect detection from the visual aerial survey methods at greater distances from the transect line. It was found that for most species and species groups (including divers), there was no significant difference in the overall abundance estimates between the two methods once corrected for distance (assessed using a paired parametric test on the mean estimates deriving from each method).

iv Combining different types of digital aerial survey data

One study compared bird density estimates arising from aerial digital stills (of two resolutions) and aerial digital video over 19 transects covering 1,211km^2, although red-throated divers were not included in the analysis (Mendel *et al* 2016). Raster maps were created to visualise the data arising from the three survey datasets, and for every raster cell a density value was calculated from the number of individuals spotted and the sum of the mapped surface area. Distribution maps were created for the most common bird species -- northern gannets, lesser black-backed gulls *Larus fuscus*, kittiwakes, Sandwich terns *Sterna sandvicensis*, common / Arctic terns *Sterna hirundo* / *paradisaea*, and guillemots. A generalised mixed model with Poisson distribution as a method of error distribution was used to assess differences in bird density between datasets. The study found that the digital video method and the digital still method using a 2cm resolution recorded higher densities of animals than the other digital still method using a 3cm resolution, with the 3cm resolution method only recording half as large a population as the digital video survey (Mendel *et al* 2016). The first two methods (digital video and the digital still survey using a 2cm resolution) did not differ from one another statistically for the species examined. It was postulated that the difference in resolution of the digital stills method resulted in lower numbers of birds being identified, and this was shown explicitly in relation to flying and swimming guillemots, which were seen much less often in the lower resolution survey (Mendel *et al* 2016). It should be noted that currently most aerial digital still surveys use the finer 2cm resolution cameras, and therefore the differences seen in this study are likely to have been nullified by the advance in technological capability.

v Combining boat-based transect surveys, aerial transect surveys and tracking data

Our review identified one study that combined three different survey platforms (Thiers *et al* 2014). This study developed species distribution models (SDMs) for frigatebirds, terns and boobies in the Mozambique channel by combining data collected using tracking technologies and classical aerial and at-sea surveys. These datasets were temporally matched and standardised at the coarsest resolution of all datasets (including environmental variables; 0.25º) and aggregated over this standard grid with a temporal resolution of one month (Thiers *et al* 2014). For tracking data of breeding birds, the filtered locations of each foraging trip were assigned on corresponding cells of the standard grid and time spent per unit area was used to define presence cells; because these types of data provided only presence records, pseudo-absence data were also generated for bird tracks (Thiers *et al* 2014). Densities from boat-based and aerial surveys were converted to binary presence/ absence, indicative of whether at least one individual was recorded within a given 0.25° cell (Thiers *et al* 2014). The study found consistent results between the three different data sources used in the SDMs, and also noted that they were able to assess the correspondence between the distributions of breeders and non-breeders from tracking data and observations at sea (Thiers *et al* 2014).

3.5.5 Summary

The majority of studies that have combined data from different survey platforms for marine birds have used traditional boat-based and visual aerial transect methods. Results are mixed, but in general, these studies demonstrate that it is possible to combine data from these two platforms to better inform estimates of red-throated diver densities, but that in so doing several important caveats must be considered, notably the biases associated with the two methods (e.g. extent of flushing or disturbance of birds in boat-based and visual aerial surveys versus digital aerial surveys), differing levels of detectability associated with different platforms, and the considerable spatial and temporal variation arising from environmental and seasonal variation in surveyed areas which make extrapolation of calibration relationships between platforms to new areas difficult. The same can also be said for combining traditional aerial visual transect methods with digital aerial stills, or combining traditional boat-based surveys with digital videography. Finally, we were unable to find any examples of radar survey data being combined with another survey platform type. However, we anticipate that integrating radar data with other types will be inherently challenging due to the specificities of this type of data and the considerable amount of pre-processing that is required to result in density estimates of flying birds. No previous study appears to have combined data from all four platforms, and this is likely to be a considerable challenge. In general, comparisons between survey platforms have tended to show low power for detecting differences in bird densities between techniques due to very highly variable numbers of some species in space and time. Given the logistical difficulties in running simultaneous surveys with precise spatial and temporal matching it remains difficult to carry out effective and fair comparisons between survey techniques, and more opportunities are needed to investigate the differences between alternative platforms under a range of conditions (Webb *et al* 2014).

3.6 Possible environmental covariates relevant to some of the statistical analyses

In the marine environment, the abundance and distribution of higher predators is strongly affected by bottom-up processes whereby changes in climate affect the oceanography, which in turn causes changes that propagate up the food chain from phytoplankton to zooplankton, forage fish and higher predators (Miller 2004; Frank *et al* 2007). One of the best studied predator groups is marine birds, and numerous studies have undertaken analyses of physical and biological drivers of their distribution at sea (reviewed in Grémillet & Boulinier 2009; Tremblay *et al* 2009; Wakefield *et al* 2009). These studies have linked at-sea distributions to a wide range of oceanographic variables such as bathymetry, distance to coast, temperature, chlorophyll, productivity and tidal or upwelling features (e.g. Hunt *et al* 1999; Daunt *et al* 2006; Pinaud & Weimerskirch 2007; Burthe *et al* 2014; Carroll *et al* 2015; Wakefield *et al* 2015). In summer, intrinsic mechanisms associated with central-place foraging, in particular the constraints on foraging range and the enhanced intraspecific competition for food, are also important factors driving at-sea distribution (Orians & Pearson 1979; Lewis *et al* 2001; Wakefield *et al* 2013). Whilst the majority of research has been on seabirds, other studies have been undertaken on predatory fish, turtles and marine mammals, demonstrating important correlations between oceanography/primary production and predator distribution (Boyd & Arnbom 1991; Polovina *et al* 2004; Bailleul *et al* 2005; Zainuddin *et al* 2006).

There are two perennial challenges associated with ecological studies of marine top predators. First, diet data are often limited, particularly outside the breeding season (Barrett *et al* 2007). Second, there is a lack of data on the distribution of key prey species at the appropriate temporal and spatial scale for use in analysis of space use or preference, in particular for piscivorous predators (Fauchald 2009). Analyses that relate oceanography or primary production to top predator distribution must consider that a comprehensive description of the food web including marine bird diet is not always available, that there can be up to four intermediate trophic levels between primary production and top predators (Barnes & Hughes 2008), and that these trophic levels may be mismatched spatially or temporally leading to discrepancies between oceanography, primary production and marine top predator distribution (Grémillet *et al* 2008). Nonetheless, such analyses represent a pragmatic solution to a difficult problem and can, if interpreted with care, prove useful in understanding the drivers of marine bird distribution.

Red-throated divers that winter in UK waters are a typical example of this. Diet studies are few and restricted to a few locations (Madsen 1957; Zydelis 2002; Guse *et al* 2009; Morkune *et al* 2016). These studies have shown that they feed on a broad range of pelagic fish in winter. In the absence of appropriate data on the distribution of these prey items, studies have focussed on environmental indicators of prey distribution (Skov & Prins 2001; Skov *et al* 2016). These studies have identified the position of estuarine fronts as being the prime environmental determinant of red-throated diver distribution, which the authors interpret are due to the predictability of food sources at these locations (Skov & Prins 2001; Skov *et al* 2016). Salinity, slope, sediment type and shipping activity have also been correlated with the at-sea distribution of this species (e.g. Skov *et al* 2016). These studies provide useful pointers as to the environmental covariates that would be most appropriate to include in a meta-analysis. In short, we recommend those a) for which we already have permissions in place and b) that have been shown in past studies to be significant predictors of the distribution of red-throated divers in particular (Skov & Prins 2001; Skov *et al* 2016), and piscivorous UK marine birds in general (Daunt *et al* 2006; Burthe *et al* 2014; Carroll *et al* 2015; Wakefield *et al* 2015; McGovern *et al* 2016):

- Distance to coast
- Bathymetry (ETOPO)
- Seabed slope (ETOPO)
- Sediment (sand/gravel/mud ratios; EDINA)
- Chlorophyll A (MODIS)
- Sea Surface Temperature (MODIS)
- Salinity (MODIS)
- Thermal front gradient density (NEODAAS)
- Potential energy anomaly (PEA), which quantifies the intensity of thermohaline stratification (MyOcean)
- Proportion of time for which the water column was stratified (UK Met FOAM AMM reanalysis; http://marine.copernicus.eu/)
- Shipping activity

All the above data sets are available for all likely marine regions of interest, with the exception of sediment, which is only available in UK waters. However, the spatial and temporal resolution of covariates must be assessed for suitability in any analysis of habitat association (Skov *et al* 2016). For example, if variables are spatially coarse (e.g. 10km x 10km), they may still be useful if bird data are only available at that scale, but only if the underlying habitat associations continue to hold at this scale. Since many of the key variables relating to seabird foraging are spatially heterogeneous we anticipate that relationships are likely to be much weaker once data are aggregated to a coarse spatial scale, and the statistical power to detect a relationship is therefore likely to be much reduced. It would be impossible to know whether this was the case without actually running the analysis, however. An additional challenge is that environmental data may be unavailable or unreliable adjacent to the coast. We also recommend that a comprehensive exploration of fish prey distribution data is undertaken to assess potential suitability for inclusion in a meta-analysis, in particular from winter ICES International Bottom Trawl Survey (IBTS) surveys.

4 Questionnaire to stakeholders on buy-in to the meta-analysis

4.1 Introduction

The objective of the second questionnaire was to assess the level of stakeholder interest in the outputs of the meta-analysis and any willingness to contribute data and/or funds to a meta-analysis of red-throated diver displacement across Europe.

4.2 The identification of stakeholders

A list of stakeholders involved in the offshore wind sector across Europe was established by consulting experts from UK, Germany, The Netherlands and Denmark and by collecting supplementary information from internet sources, available scientific sources and EIA reports.

Table 4.1 provides a summary of the types of individuals who were sent a copy of the questionnaire to stakeholders.

Table 4.1. Types of individuals who were stakeholder questionnaire recipients.

Category	Class	Number of recipients
Country	Denmark	10
	Germany	16
	The Netherlands	5
	United Kingdom	45
Role	Owner/operator of OWF	15
	Statutory / regulatory organisation	15
	NGO	13
	Researcher	8
	Consultant	25

4.3 Questionnaire to stakeholders

An invitation was sent by email on 24th February 2017 to the individual stakeholders whose affiliations and country are summarised in Section 4.2 above.

A copy of the text of this email is reproduced in the box below:

Subject: Europe-wide analysis of Red-throated Diver distribution near offshore wind farms – Stakeholders' interests

Dear Mr/Mrs…,

Wintering Red-throated Divers are known to be displaced by offshore wind farms across Europe but evidence for the extent of displacement and what causes this response to vary among wind farms is lacking. Displacement effects are usually only considered in isolation and comparisons between multiple developments have not been previously undertaken. Ideally, all data from developments across the North Sea, Baltic Sea and Irish Sea would be combined in a single meta-analysis that would give a single consolidated assessment of the extent of displacement of Red-throated Divers at offshore wind farms across Europe.

This could bring multiple benefits to the industry including increased statistical power and consequent improved confidence in evidence on the extent of displacement. An improved evidence-base would help reduce uncertainty in future ecological assessments for the consenting of offshore windfarms

*The success of such a meta-analysis relies on the **support and 'buy-in' from stakeholders** across Europe. Consequently, JNCC wishes to assess the levels of stakeholder interest in undertaking a Europe-wide meta-analysis on displacement of Red-throated Divers from offshore wind farms.*

*APEM has been contracted by JNCC to manage this assessment of stakeholder interest. We would like to invite you on behalf of JNCC to participate in a brief **online questionnaire**, which will take only 5 minutes to complete.*

Please click the link below to go to the survey web site (or copy and paste the link into your internet browser).

https://www.surveymonkey.co.uk/r/APEMJNCCSI

*Please complete and submit the questionnaire online by **March 03 2017**.*

If you are unable to participate we would be grateful if you could forward our request to an appropriate colleague within your organisation.

[If you are unwilling to participate simply reply to this email with "NO" in the subject line.]

PLEASE NOTE:** At this stage, we are only assessing stakeholders' interests in a potential meta-analysis of red-throated diver displacement. **By answering this questionnaire, you are not committing your organisation to contributing data, financial support or anything else to the meta-analysis.

Confidentiality

JNCC (http://jncc.defra.gov.uk) is the statutory adviser to the UK Government and devolved administrations on UK and international nature conservation. Any information provided will be treated as strictly confidential and will not be transferred to any third parties. Any report derived from the results of this questionnaire will NOT have organisation-specific information in it.

We look forward to receiving your response. Thank you for your support!

With kind regards,

On behalf of JNCC

Tim Coppack

After five working days the following reminder was sent out by email:

Subject: QUESTIONNAIRE 02: Red-throated Divers and offshore wind farms – stakeholders' interests

Dear participants,

We would like to thank you for the valuable input that has reached us so far.

If you have not yet submitted the questionnaire, please use the link below to go to the survey web site (or copy and paste the link into your internet browser).

It will take only 5 minutes to complete.

https://www.surveymonkey.co.uk/r/APEMJNCCSI

Please also remember tomorrow's deadline - March 3 2017 (23:59 CET)!

If you are unable to participate we would be grateful if you could forward the link to an appropriate colleague within your organisation.

[If you are unwilling to participate simply reply to this email with "NO" in the subject line.]

PLEASE NOTE: At this stage, we are only assessing stakeholders' interests in a potential meta-analysis of red-throated diver displacement. By answering this questionnaire, you are not committing your organisation to contributing data, financial support or anything else to the meta-analysis.

Confidentiality

JNCC (http://jncc.defra.gov.uk) is the statutory adviser to the UK Government and devolved administrations on UK and international nature conservation. Any data and information provided will be treated as strictly confidential and will not be transferred to any third parties. Any report derived from the results of this questionnaire will include no development-specific information.

We look forward to receiving your response.

Thank you for your support!

With kind regards,

On behalf of JNCC

Tim Coppack

In the same manner as the questionnaire to data holders, the questionnaire was designed and run using the web-based application “SurveyMonkey”. The questionnaire was accessible via an internet link in the email to the survey website. The questionnaire link was IP-sensitive preventing individuals from participating more than once. Participants had the opportunity to review their entries and to revisit the questionnaire website until finalizing the response by clicking the button “Done” at the end of the webpage.

The questionnaire, as viewed by recipients when they accessed the link, is illustrated in the set of screenshots reproduced in the Appendix. There were five questions to answer that are illustrated in the Appendix with the respective response options in their original format.

4.4 Results of the questionnaire to stakeholders

The questionnaire to stakeholders was answered by 37 (48.7%) out of the 76 potential participants. A ‘potential participant’ was categorised as an email contact to which the invitation and reminder were successfully delivered by email both on 24th February 2017 and on 3rd March 2017, respectively.

It was known from the ‘recipient tracking’ information relayed by Microsoft Outlook that 33 (43.4%) of the 76 potential participants confirmed to have read the invitation and/or reminding email.

None of the potential participants actively refused to participate by answering “NO” to the invitation and reminding email.

The following Tables 4.2 to 4.6 present the results for each of the five questions sent to stakeholders.

Table 4.2. Responses of stakeholders to Question 1.

In principle, are you supportive of a meta-analysis of displacement of red-throated diver data obtained from offshore wind farms across Europe?		
Answer Options	Response Percent	Response Count
yes	94.6%	35
no	0.0%	0
This is not relevant for my work	5.4%	2
Other (please specify)		1
answered question		*37*
skipped question		*0*

Response Date	**Other (please specify)**
March 3 2017	“Whilst of interest, this is not a priority for Scotland.”

Table 4.3. Responses of stakeholders to Question 2.

Of the following list, which information would you find useful or believe would be of benefit to the offshore renewable sector? Please consider that this information may also help in developing mitigation strategies to reduce displacement from existing or future wind farm sites. Please tick as many boxes as are relevant to you.		
Answer Options	Response Percent	Response Count
the average distance by which Red-throated Divers are displaced	75.7%	28
the average proportion of displaced individuals relative to overall population size	70.3%	26
a displacement curve from which the proportion of Red-throated Divers displaced at defined distances could be identified	75.7%	28
the magnitude of uncertainty around displacement measures	75.7%	28
the influence of covariates such as vessel traffic and size, number and layout of turbines on among-site variation in diver distribution and abundance	78.4%	29
the influence of environmental covariates (e.g. time of year, water depth, distance to coast) on variation in diver distribution and abundance across northern Europe	78.4%	29
none of the above	2.7%	1
Other (please specify)		11
answered question		*37*
skipped question		*0*

Note, the 11 participants selecting ‘other’ chose not to provide any further information in the free text box.

Table 4.4. Responses of stakeholders to Question 3.

[OPTIONAL] How would you support a Europe-wide analysis of Red-throated Diver displacement? Please tick any boxes that apply to you.		
Answer Options	Response Percent	Response Count
by providing data	40.6%	13
by providing technical expertise	53.1%	17
by providing funding	9.4%	3
by encouraging others to participate	78.1%	25
Other (please specify)		8
answered question		*32*
skipped question		*5*

Table 4.5. Responses of stakeholders to Question 4.

[OPTIONAL] If you are currently unable to provide support, what would make you more likely to consider supporting a Europe-wide analysis of Red-throated Diver displacement?	
	Response Count
	2
answered question	*2*
skipped question	*35*
Response Date	**Response Text**
March 3 2017	"A common understanding on the kind of data needed to answer the questions stated above. Due to the trade secret on the majority of monitoring data it might be useful to define levels of aggregated data to be used for analyses. This might be the 10x10km raster as needed for assessments in MSFD context."
February 24 2017	"If Dutch offshore wind development abandoned their current focus on offshore waters farther away than 10nm offshore and start including more inshore waters, red-throated diver issues are more likely to come into the picture for environmental impact analyses and we will be even harder pressed for this Europe-wide analysis of diver displacement."

Table 4.6. Responses of stakeholders to Question 5.

Please provide any other information you think would be helpful for JNCC to know.	
	Response Count
	9
answered question	*9*
skipped question	*28*
Response Date	**Response Text**
March 3 2017	"This study may link in with another initiative for strategic environmental monitoring currently being discussed by industry and stakeholders and therefore it would be good to align with this work."
March 2 2017	"Is the area in question wide enough - tagging studies are showing some species to be incredibly wide ranging - can we discount the likely increase of offshore wind farms on the Eastern seaboard of the USA on populations in Europe."
February 24 2017	"In the Netherlands a similar approach is being undertaken for common guillemot; this will likely lead to a peer-reviewed paper on the amount of displacement of guillemots by offshore wind farms and its dependence on wind farm characteristics; general principles of this approach can (and will) be shared."

4.5 Interpretation of the questionnaire returns

The response rate of the stakeholders to the questionnaire (48.7%) was significantly higher than that of the data holders' responses to that specific questionnaire (23.3%). This suggests that the majority of stakeholders are currently more interested in a Europe-wide meta-analysis of red-throated diver displacement than the potential data providers. This indicates a potential conflict of interests that may prevent any proposed meta-analysis from being undertaken successfully.

The stakeholders' responses to the questionnaire reflect the diversity of the participants that came from a variety of different organisations and countries (see Table 4.1 above). That diversity means that the stakeholder questionnaire has to be interpreted in the light of this difference.

The response to Question 1 clearly showed a high level of stakeholder interest in a meta-analysis of red-throated diver data obtained from offshore wind farms across Europe. Only two participants found this to be irrelevant to their work.

The participants gave a very balanced answer to Question 2 concerning the detailed requirements for the meta-analysis. All six parameters recommended for a meta-analysis (distance of displacement, relative proportion of individuals displaced, a displacement curve, influence of anthropogenic and environmental covariates, measures of uncertainty) were found to be useful or beneficial for the offshore renewable sector by 70% to 78% of the participants. Only one of the respondents found none of the mentioned parameters helpful. 11 out of 37 participants chose the category “other” in Question 2 but when presented with the option to elaborate on their view in the free text box, none of them mentioned any special requirement.

Question 3 was optional, and five of the 37 participants skipped this question. According to the remaining responses, the majority of stakeholders (78%) would support a Europe-wide meta-analysis by encouraging others to participate, while only 9% signalled willingness to provide funds. This result probably reflects that potential funding bodies (developers and statutory / regulatory organisations) invited to participate in the survey made up ~20% of the respondents. Thus, it seems that most stakeholders are currently not willing to fund a meta-analysis of red-throated diver displacement despite the overall interest and willingness of stakeholders to provide data and technical expertise.

Only two of the 37 participants responded to the optional Question 4 by explicitly stating what would increase the likelihood of supporting a Europe-wide analysis of red-throated diver displacement. One of the respondents emphasised the importance of defining levels of aggregated data to enable the use of available aggregated data in published reports (since raw data are often treated as commercially confidential). A respondent from The Netherlands pointed at the importance of including data from near-shore areas due the increasing number of wind farm developments in those regions. This issue is also relevant to current near-shore developments in the German Baltic territorial waters; survey data from within the 12 nautical mile zone are not being stored centrally at BSH as their responsibility is for the EEZ only.

In Question 5, nine of the 37 participants provided additional information of potential interest to informing the feasibility of the meta-analysis. These responses were generally supportive of a Europe-wide meta-analysis or pointed out potential synergies with other initiatives. Responses, apparently from the UK, referred to initiatives including a recent OWF industry workshop, action by RenewableUK, Natural England funded projects and statistical work by a particular researcher. One response from The Netherlands stated that a similar approach including meta-analysis is being taken to guillemot displacement and one response from Germany confirmed that data is being kept at BSH and is owned by the industry. Finally, one participant questioned whether the spatial scale of the intended meta-analysis is sufficient to account for potential carry-over effects of anthropogenic stressors that act elsewhere within the annual cycle of this migrant diver species.

4.6 Summary of stakeholder interest

The questionnaire to stakeholders produced responses from 27 of the 76 potential participants. Almost all the responses (94.6%) were supportive of a meta-analysis. With respect to the output parameters of the meta-analysis, interest was at a similar high level of around 75% for the options of distance by which displaced, relative proportion of individuals displaced, a displacement curve with distance, the influence of anthropogenic and environmental covariates and measures of uncertainty. With respect to support that could be provided, there was a high level of support (around 75%) by encouragement to others, a moderate level of support (around 50%) by providing data and technical assistance but a low level of support (around 10%) by providing funding.

5 Conclusions and recommendations

The conclusions and recommendations of this study are set out below.

5.1 Conclusions

The conclusions are ordered by the three components that formed the overall programme of work.

5.1.1 Data availability

The review of:

- the number and type of surveys that have been carried out at the pre-application, pre-construction, during construction and post construction stages of OWFs, and
- the number of sites at which red-throated diver have been found in numbers to enable their density to be calculated indicates that there is a potential wealth of data that has been acquired.

This project identified that as time has passed since pre-application surveys have been carried out, the reports (primarily environmental statements) are increasingly becoming unavailable from websites. However, other reports may be available through The Crown Estate Marine Data Exchange and/or through directly contact with developers. The public availability of pre-construction, during construction and post construction stage monitoring data, and reports on analyses of that data, varies considerably across the four countries studied. None of the countries has procedures by which the reports generated by monitoring studies are automatically placed on a public access website, although most reports in the UK are available through the Marine Data Exchange. This has hindered, in the short time available to this project, identifying the precise number of studies that contain data, or aggregated data, on red-throated diver.

This project found indications that existing publicly available raw red-throated diver data from OWF surveys across all of the four countries is limited. This means that a meta-analysis is not practical without the co-operation of data-holders.

With respect to the questionnaire on data availability, noting that the responses were received from only seven out of the 30 potential participants but those who did respond were all data holders, the conclusions drawn were:

- Overall there was a reluctance to share raw data.
- Raw data would be forthcoming if it were prompted by a formal request from a regulator.
- There was more willingness to share secondary information in the form of monitoring reports and aggregated data.
- The willingness to share data varied by country - some willingness from the UK and the Netherlands and no willingness from Germany (data from Denmark is already available and as a result the measure of willingness is less relevant).
- Based on the responses received raw data could potentially be available for a minimum of 12 OWFs for which there would be pre and post-construction data on red-throated diver.

These conclusions are subject to the caveat that they are drawn from around a quarter of the potential participants who hold data and also the lack of time on this project to fully explore data availability, e.g. potential to obtain raw data through confidentiality agreements.

5.1.2 Statistical approaches

Overall, the key modelling choice is between:

- running an aggregate data meta-analysis, using summary statistics from published studies, or
- running an IPD meta-analysis in which the raw data from each study are re-analysed.

The technical, computational and time requirements for running an aggregate data meta-analysis would be substantially lower than for running an IPD meta-analyses. This would be the key advantage of the aggregate approach, along with the fact that the aggregate data meta-analysis does not require access to the raw data (and so would not be dependent upon obtaining data permissions). The key disadvantages of the aggregate approach are:

- That it relies upon being able to extract comparable summary statistics (estimated wind farm effects, and associated SEs) from all studies. It is expected, based on the literature review, that this is likely to be possible, because most studies do ultimately use comparable outcome measures. It is nonetheless a non-trivial task as the studies differ considerably in the way that they report their results and in the level of detail that is provided.
- That it relies upon the estimated wind farm effects from the different studies, and their associated SEs, being comparable. There are substantial differences in the analysis methodologies used by the different studies, as well as in the survey platforms used, so it is not clear that the study-species estimates – and, especially, the SEs associated with them – would be comparable.

The IPD meta-analysis approach would allow these issues to be dealt with, but would be a challenging exercise involving re-analysing data that have been obtained from different survey platforms, which are stored in different formats, and which have been subjected to varying levels of pre-processing.

The majority of studies that have combined data from different survey platforms for marine birds have used traditional boat-based and visual aerial transect methods. Results are mixed, but in general, these studies demonstrate that it is possible to combine data from these two platforms to better inform estimates of red-throated diver densities. In so doing several important caveats must be considered, notably the biases associated with the two methods (e.g. extent of flushing or disturbance of birds in boat-based and visual aerial surveys versus digital aerial surveys), differing levels of detectability associated with different platforms, and the considerable spatial and temporal variation arising from environmental and seasonal variation in surveyed areas which make extrapolation of calibration relationships between platforms to new areas difficult. The same can also be said for combining traditional aerial visual transect methods with aerial digital stills, or combining traditional boat-based surveys with aerial digital videography. No examples were found of radar survey data being combined with another survey platform type. However, it is anticipated that integrating radar data with other types will be inherently challenging due to the specificities of this type of data and the considerable amount of pre-processing that is required to result in density estimates of flying birds. No previous study appears to have combined data from all four platforms, and this is likely to be a considerable challenge.

5.1.3 Stakeholder buy-in

The questionnaire to stakeholders produced a significantly higher level of response compared to that from data holders (48.7% compared to 23.3% respectively). There was a very high level of support for a meta-analysis (~95%). Interest was at around 75% in relation to the output parameters of:

- distance by which divers are displaced
- relative proportion of individuals displaced
- a displacement curve with distance
- the influence of anthropogenic and environmental covariates
- measures of uncertainty

The degree of support that was expressed was highest for that which did not require commitment of human and financial resources and lowest for that which required financial resources. Specifically support expressed was:

- ~75% by encouragement to others
- ~50% by providing data
- ~50% by providing technical assistance
- ~10% by providing funding

5.2 Recommendations

Given the restricted number of studies from which data on red-throated diver, even in aggregated form, is publicly accessible, **it is recommended that a meta-analysis does not proceed without the co-operation of data-holders**.

With regards to the three approaches to conducting a meta-analysis:

1. Using published effect sizes
2. Using the raw data from each study
3. Using aggregate data from each study

The following forms the basis of specific recommendations:

Approach 1: Using published effect sizes, without any access to the underlying data for each study, within a two-stage meta-analysis.

The approach to a meta-analysis using published effect sizes is not recommended for two reasons:

a. the lack of consistent reporting of effect sizes (and particularly associated measures of uncertainty) between studies means that it would be difficult to collate the information required to conduct such an analysis;
b. more fundamentally, differences in the metrics used to assess wind farm effects, differences in pre-processing methods, and differences in the statistical approaches to analysis used within different studies all mean that the results of any such meta-analysis would lack statistical defensibility.

Approach 2: Using the raw data from each study, within either a one-stage or two-stage meta-analysis

This approach would be statistically defensible and technically possible, albeit a time-consuming task that would require a high level of technical skill and clear documentation of the raw data for each study. Fundamentally, it relies upon having access to the raw data for all relevant individual studies so if this is not forthcoming the approach is unfeasible.

Approach 3: Using aggregate data from each study.

The feasibility of this approach is the hardest to assess, because it depends upon exactly which data were made available. The approach would be viable and probably reasonably defensible if the aggregate data from different projects could be made available in a consistent way, and if the data were aggregated to a scale that is relatively fine compared to the size of a wind farm. If the data are only available at a coarse scale, however, this approach is not considered to be viable. It would suffer from essentially the same issues as those involved in using published effect sizes (Approach 1) and may even be less defensible than using published effect sizes if the data are aggregated to a grid that is so coarse it is difficult to reliably determine which grid cells relate to the wind farm and which do not.

A meta-analysis is likely to be feasible, in the sense of being not only possible but also defensible, if either the raw data from individual studies or relatively fine-scale aggregates of those raw data are available. **The recommended statistical approach to the meta-analysis should be that either raw data from individual studies or relatively fine-scale aggregates of those raw data are used.**

Both of these approaches require access to data that can only be obtained with the co-operation of the data-holders. The review of the current willingness of data holders to make raw or fine scale aggregated data available indicates that there is little appetite for such an action. Currently it is likely that suitable data for the recommended approach to the meta-analysis would only be forthcoming from a minimum of 12 OWFs. **It is recommended that a meta-analysis does not proceed with the current likely availability of suitable data.**

The review of the position of a wider stakeholder group for a meta-analysis is that there is a very high level of support for a meta-analysis. **It is recommended that the support from stakeholders is used to encourage data holders to consider further their position on the release of raw, or relatively fine-scale aggregated, data such that a larger body of suitable data is made available for a meta-analysis of red-throated diver displacement by OWFs.**

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Appendix: A screenshot copy of each of the questionnaires sent out.

Questionnaire to data holders

JNCC Questionnaire 01

QUESTIONNAIRE

Feasibility study for a Europe-wide meta-analysis of Red-throated Diver distribution near offshore wind farms

- Data availability -

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JNCC Questionnaire 01

Red-throated Divers winter around the North Sea, the Baltic Sea and the Irish Sea. Many offshore wind farms have been constructed in these areas and there is evidence of Red-throated Divers being displaced from some of these developments (for review see Dierschke et al. 2016, Seabirds and offshore wind farms in European waters: Avoidance and attraction. Biological Conservation, 202, 59-68).

The effects of offshore wind farms on Red-throated Diver distribution are usually only considered in isolation and comparisons between multiple developments have not been previously undertaken. Ideally, all data from developments across the North Sea, Baltic Sea and Irish Sea would be combined in a single meta-analysis that would give a single consolidated assessment of the extent of displacement of Red-throated Divers at offshore wind farms across Europe.

Such a meta-analysis has the potential to bring multiple benefits to the offshore wind industry:

- An analysis using data from multiple wind farms would have greater statistical power compared with analysis of data from individual wind farms alone.
- The results would help reduce uncertainty in future ecological assessments for the consenting of offshore windfarms.
- Improved understanding of what drives variation in the extent of displacement among offshore wind farms (e.g. turbine size and layout, local vessel activity, etc.) would assist with identifying feasible mitigation measures.

However, the success of such a joint analysis depends on availability of relevant data. Prior to initiating a meta-analysis, JNCC wishes to ascertain the extent to which post-consent monitoring data would be available for such a study.

The aim of this questionnaire is to quantify the availability of suitable data for a potential meta-analysis of Red-throated Diver displacement across the UK, Germany, Denmark and The Netherlands.

Please complete the below questionnaire by placing mark or writing in the space provided [queries marked by asterisks (*) are required].

* 1. Does your organisation or business hold seabird survey data that contains information on the distribution and abundance of Red-throated Divers (Gavia stellata)?

- ○ yes
- ○ no
- ○ unknown

* 2. Are these data currently kept confidential or shared publicly?

- ◯ confidential
- ◯ publicly accessible from a website
- ◯ publicly accessible on request

Other (please specify)

* 3. Would you be interested in sharing your raw post-consent monitoring data to enable the meta-analysis described above to take place?

- ◯ yes
- ◯ no

4. Do you think your work or business would benefit from a Europe-wide meta-analysis of Red-throated Diver displacement?

- ◯ yes
- ◯ no
- ◯ depends on outcome

* 5. If you are unable to provide raw data, what processed product would you be able to share?

- ◯ original monitoring reports
- ◯ post-consent EIA documents
- ◯ none

Other (please specify)

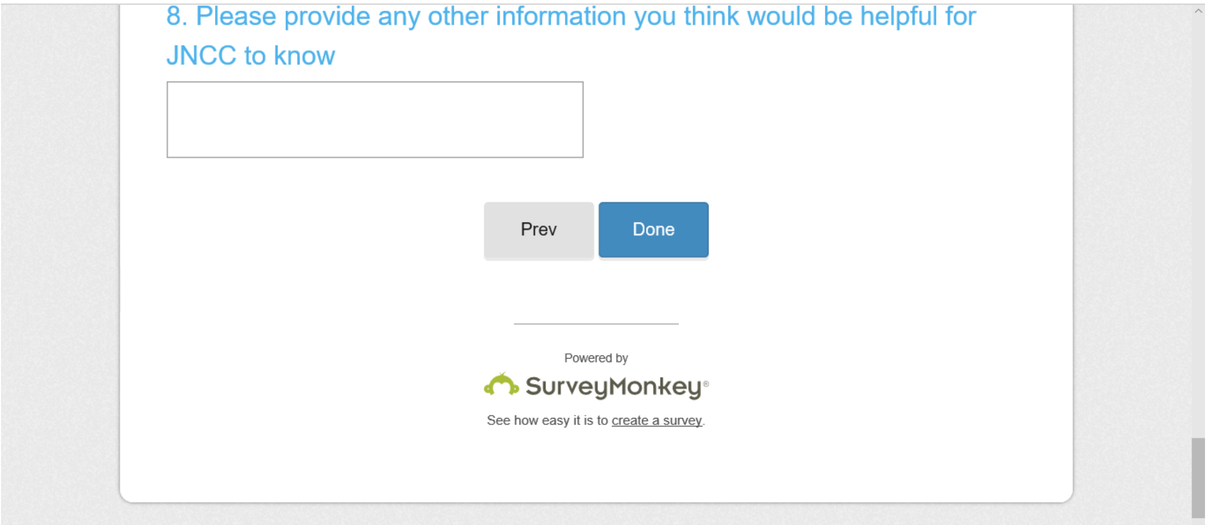
* 6. If you are unable to share raw data, then what would make you more likely to consider sharing your data?

- ◯ a confidentiality agreement and presentation of outputs in a form that does not convey confidential information
- ◯ raw data requested at an aggregated scale, e.g. mean densities at a coarse spatial resolution
- ◯ data requested on behalf of the regulator or nature conservation advisor

Other (please specify)

7. For how many windfarm sites could you provide post-construction survey data?

Please could you name each individual development and indicate clearly whether you are willing to share data for that development (yes/no)


8. Please provide any other information you think would be helpful for JNCC to know
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Done
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Questionnaire to stakeholders

JNCC QUESTIONNAIRE 02

QUESTIONNAIRE

Feasibility study for a Europe-wide meta-analysis of Red-throated Diver distribution near offshore wind farms

- Stakeholders' interests -

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JNCC QUESTIONNAIRE 02

Red-throated Divers winter around the North Sea, the Baltic Sea and the Irish Sea. Many offshore wind farms have been constructed in these areas and there is evidence of Red-throated Divers being displaced from some of these developments (for review see Dierschke et al. 2016, Seabirds and offshore wind farms in European waters: Avoidance and attraction. Biological Conservation, 202, 59-68).

The effects of offshore wind farms on Red-Throated Diver distribution are usually only considered in isolation and comparisons between multiple developments have not been previously undertaken. Ideally, all data from developments across the North Sea, Baltic Sea and Irish Sea would be combined in a single meta-analysis that would give a single consolidated assessment of the extent of displacement of Red-throated Divers at offshore wind farms across Europe.

Such a meta-analysis has the potential to bring multiple benefits to the offshore wind industry:

- An analysis using data from multiple wind farms would have greater statistical power compared with analysis of data from individual wind farms alone.
- The results would help reduce uncertainty in future ecological assessments for the consenting of offshore windfarms.
- Improved understanding of what drives variation in the extent of displacement among offshore wind farms (e.g. turbine size and layout, local vessel activity, etc.) would assist with identifying feasible mitigation measures.

The aim of this questionnaire is to assess levels of stakeholder interest in such a meta-analysis of Red-throated Diver displacement across the UK, Germany, Denmark and The Netherlands.

Please complete the below questionnaire by placing mark or writing in the space provided [queries marked by asterisks (*) are required].

* 1. In principle, are you supportive of a meta-analysis of displacement of red-throated diver data obtained from offshore wind farms across Europe?

○ yes

○ no

○ This is not relevant for my work

Other (please specify)

* 2. Of the following list, which information would you find useful or believe would be of benefit to the offshore renewable sector?

Please consider that this information may also help in developing mitigation strategies to reduce displacement from existing or future wind farm sites. Please tick as many boxes as are relevant to you.

- [ ] the average distance by which Red-throated Divers are displaced
- [ ] the average proportion of displaced individuals relative to overall population size
- [ ] a displacement curve from which the proportion of Red-throated Divers displaced at defined distances could be identified
- [ ] the magnitude of uncertainty around displacement measures
- [ ] the influence of covariates such as vessel traffic and size, number and layout of turbines on among-site variation in diver distribution and abundance
- [ ] the influence of environmental covariates (e.g. time of year, water depth, distance to coast) on variation in diver distribution and abundance across northern Europe
- [ ] none of the above

Other (please specify)

3. [OPTIONAL] How would you support a Europe-wide analysis of Red-throated Diver discplacement?

Please tick any boxes that apply to you.

- [ ] by providing data
- [ ] by providing technical expertise
- [ ] by providing funding
- [ ] by encouraging others to participate

Other (please specify)

4. [OPTIONAL] If you are currently unable to provide support, what would make you more likely to consider supporting a Europe-wide analysis of Red-throated Diver displacement?

5. Please provide any other information you think would be helpful for JNCC to know.

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