Nova Innovation Limited

Shetland Tidal Array Monitoring Report
April 2022 to July 2023

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1 Introduction

This report is provided in support of discharge of conditions attached to the following licences for Nova Innovation's Shetland Tidal Array in Bluemull Sound:

1. Marine Licence MS-00009110, issued by Marine Scotland Licensing Operations Team on behalf of the Scottish Ministers, under the Marine (Scotland) Act 2020.
2. Shetland Islands Council (SIC) Works Licence 2022/015/WL, issued by Shetland Islands Council under the Zetland County Council Act 1974.

In the reporting period covered by this report (April 2022 to July 2023), the programme of environmental monitoring for the Shetland Tidal Array comprised the following two key activities:

1. Land-based diving bird and marine mammal observation surveys in Bluemull Sound.
2. Subsea monitoring using turbine-mounted optical video cameras.

Combined, these methods gather data to understand the likely nature and consequences of any nearfield interactions between turbines in the array and marine wildlife, with a focus on mammals and diving birds, due to their protected status.

This report builds on previous monitoring reports produced by Nova for the Shetland Tidal Array (Nova Innovation, 2017; 2021a; 2021b; 2022b; 2022c). It presents the results from analysis of environmental monitoring data gathered between April 2022 and July 2023 (the 'reporting period'). This includes analysis of data gathered during 108 hours of land-based surveys and around 40 GB of subsea video footage from subsea monitoring using turbine-mounted cameras.

A key focus of effort during this reporting period has been exploring the development of tools to automate processing and analysis of subsea video, which to date has required resource intensive and time-consuming manual review. A study to develop a model based on machine learning for processing and analysing the subsea video data is presented in this report, as well as ongoing work to refine the model and apply it to Nova's subsea video data.

2 The Shetland Tidal Array

2.1 Location

The Shetland Tidal Array is situated in Bluemull Sound, between the islands of Unst and Yell, just offshore from the Ness of Cullivoe, as illustrated in Figure 2-1.

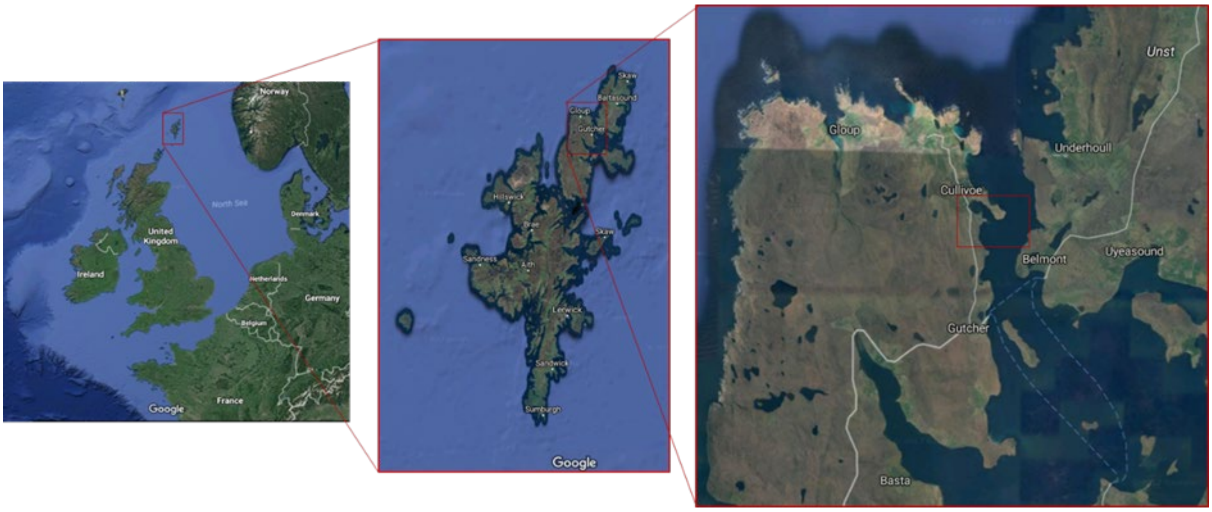

Figure 2-1 Location of the Shetland Tidal Array in Bluemull Sound, Shetland.

2.2 Project details

In April 2022, at the start of the current reporting period, the Shetland Tidal Array comprised four Nova 100 kW tidal turbines. These included three Nova M100 geared turbines (T1 to T3) and one of Nova's next generation M100-D direct drive turbine (T4), shown in Figure 2-2.

Figure 2-2 The Nova M100-D turbine. *Source: Nova Innovation 2018*

In January 2023, two further M100-D turbines were installed (T5 and T6), increasing the total capacity of the array to 600 KW. In April 2023, the three original geared M100 turbines (T1 to T3) were decommissioned, reducing the array capacity to 300 kW[1]. The three turbines M100-D (T4 to T6) are expected to remain in Bluemull Sound until the end of their operational life[2].

All turbines in the Shetland Tidal Array are or were installed subsea at a depth of 30-40m. Figure 2-3 shows the 'as installed' position of all six turbines and infrastructure in the Shetland Tidal Array following installation of T5 and T6 in January 2023.

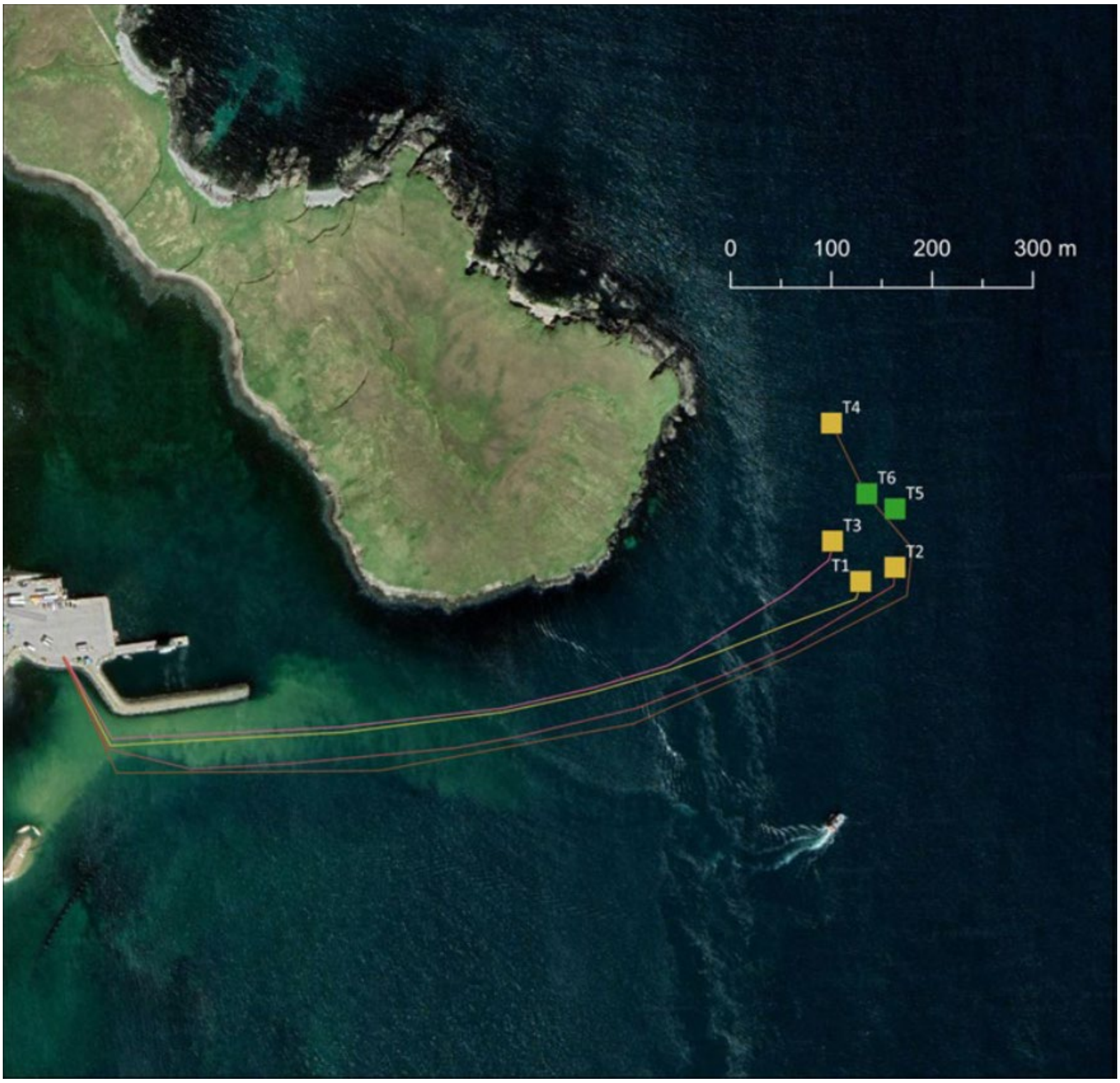

Figure 2-3 STA 6-turbine installed layout and export cables. T1 to T3 and their export cables have now been fully decommissioned. *Source: Nova Innovation, 2023*

[1] The steel substructure of T1 remained in Bluemull Sound until it was decommissioned in October 2023.

[2] The Marine Licence for the Shetland Tidal Array (MS-00009110) remains in force until 1 April 2038.

3 Monitoring activity April 2022 to July 2023

3.1 Overview

The Project Environmental Monitoring Plan (Nova Innovation, 2022a) provides comprehensive details of all environmental monitoring activities associated with the Shetland Tidal Array. This report provides details of three key activities carried out between April 2022 and July 2023[3] to understand the likely nature and consequences of any nearfield interactions between turbines in the array and marine wildlife, as follows:

1. Land-based diving bird and marine mammal observation surveys in Bluemull Sound.
2. Subsea monitoring using turbine-mounted optical video cameras.
3. Exploration of the potential application of Artificial Intelligence (AI) and machine learning to assist with video data processing, analysis and reporting.

Further details of the land-based surveys and subsea video monitoring carried out by Nova between April 2022 and July 2023 are provided in Section 3.2 and 3.3.

The use of tools based on AI or machine learning could enable analysis of a greater proportion of the Shetland Tidal Array video dataset, whilst also reducing the size of data storage. These are widely acknowledged monitoring challenges for tidal energy projects, requiring focused effort to resolve (Copping and Hemery, 2020).

To explore the use of machine learning to automate analysis of the subsea video data, Nova partnered with CGG, a global technology and High Performance Computing leader. The collaborative study used 'training' datasets of video that had been manually analysed by Nova and presented in previous monitoring reports. The study represents "the most significant progress to date in the automation of analysis of subsea video from marine energy developments" (Andrea Copping, OES-Environmental pers. comm.).

The study is presented as a standalone piece of work in Section 4 of this report. The tool has also been further refined based on video footage from the current reporting period. The results from this are presented in Section 7.

3.2 Land-based surveys

All land-based surveys between April 2022 and July 2023 were conducted from a vantage point approximately 10m above sea level on the Ness of Cullivoe, shown in Figure 3-1. The vantage point provides good coverage and uninterrupted views of the survey area (just under 20 hectares in total), while avoiding disturbance to otters on the shoreline of the Ness of Cullivoe.

[3] Details of other monitoring activities such as surveillance for European Protected Species and basking shark are provided in reports provided separately to MD-LOT.

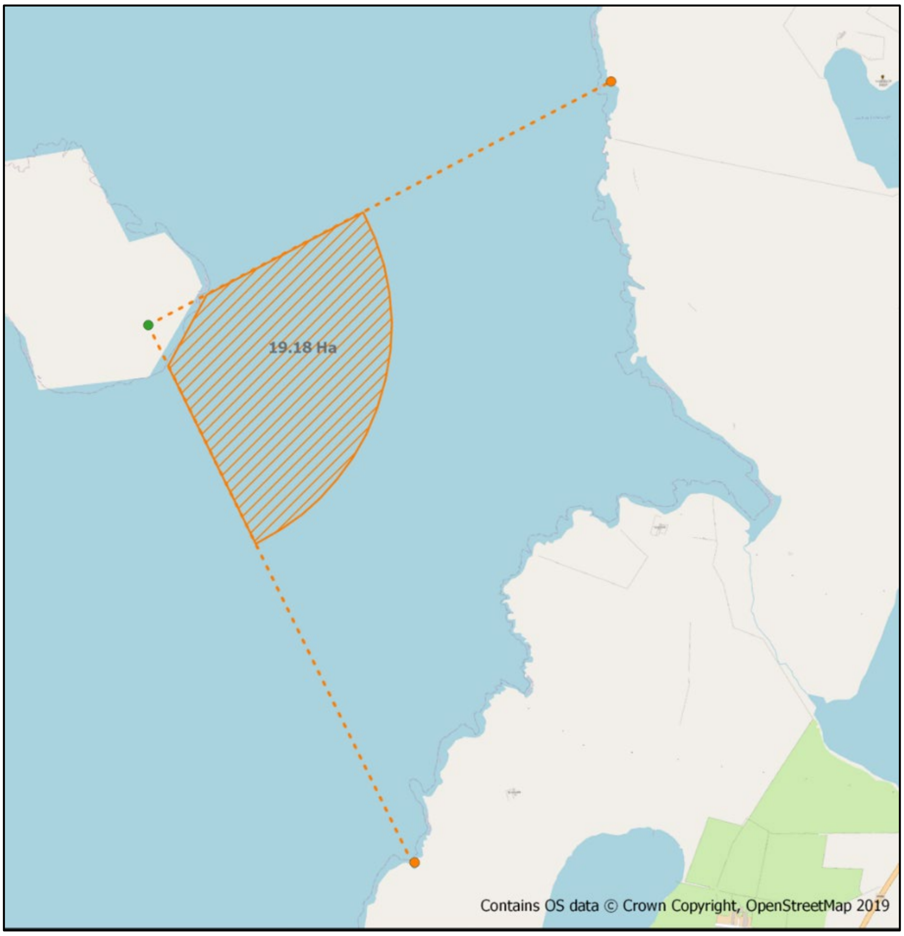

Figure 3-1 Land-based survey area in Bluemull Sound showing vantage point on the Ness of Cullivoe and sight lines to landmarks on Yell delineating the survey area.

Land-based surveys were carried out across the full tidal cycle, which was divided into six 2-hour periods. These six tidal periods were defined according to local conditions in Bluemull Sound derived from Nova's tidal model for the site, shown in Figure 3-2. The six tidal periods for land-based surveys are detailed in Table 3-1.

	HIGH WATER						LOW WATER						HIGH WATER	
Time after HW/LW	6th hr	1st hr	2nd hr	3rd hr	4th hr	5th hr	6th hr	1st hr	2nd hr	3rd hr	4th hr	5th hr	6th hr	1st hr
Bluemull slacks			HW SLACK						LW SLACK					
Simplified slacks			HW SLACK						LW SLACK					
Relative speed (R.O. Twelfths)	3	2	1	1	2	3	3	2	1	1	2	3	3	2
Direction	FLOODING			EBBING						FLOODING				
Tidal Periods	**MF**	**Decreasing Flood**		**Increasing Ebb**		**Maximum Ebb**		**Decreasing Ebb**		**Increasing Flood**		**Maximum Flood**		**DF**

Figure 3-2 Bluemull Sound hydrodynamic model detailing the tidal cycle.

Table 3-1 The six tidal periods during which land-based surveys were undertaken.

Tidal period	Details
1: Increasing flood	2-4 hours after low water (LW), starts immediately after LW slack in Bluemull Sound.
2: Maximum flood	4-6 hours after LW.
3: Decreasing flood	0-2 hours after high water (HW), starts 1.5 hours before and straddles HW slack in Bluemull Sound.
4: Increasing ebb	2-4 hours after HW, starts around 30 minutes after HW slack in Bluemull Sound.
5: Maximum ebb	4-6 hours after HW.
6: Decreasing ebb	0-2 hours after LW, starts 2 hours before LW slack in Bluemull Sound.

Surveys were also carried out across four annual periods, detailed in Table 3-2, which take account of key annual stages for diving birds, cetaceans[4] and grey and common seals.

Table 3-2 The four annual periods during which land-based surveys were undertaken.

Annual period	Details
1: April to July	Breeding season (birds), common seal pupping, grey seal moulting, harbour porpoise birth period.
2: August to mid-September	Post-breeding/moult (birds, common seal), harbour porpoise breeding season, gannet fledging.
3: Mid-September to October	Autumn (start of grey seal pupping).
4: November to March	Winter (grey seal pupping).

All land-based surveys between April 2022 and July 2023 were carried out in sea state 2 or less and during periods of good visibility to assure good quality data.

A total of fifty-four 2-hour land-based surveys were carried out between April 2022 to July 2023, representing a total survey effort of 108 hours. Table 3-3 details survey effort for the four annual and six tidal periods between April 2022 and July 2023.

Table 3-3 Total surveys across a) annual period and b) tidal period for the reporting period.

a) Annual period

	Number of surveys	Survey effort (hours)
Annual period 1 (April to July)*	24	48
Annual period 2 (August to mid-September)	12	24
Annual period 3 (Mid-September to October)	12	24
Annual period 4 (November to March)**	6	12

* Survey effort for annual period 1 reflects reporting period which spans April 2022 to July 2023 inclusive.
** Survey effort for annual period 4 reflects the asymmetric survey design which is constrained by limited daylight hours during winter in Shetland.

[4] Key stages for harbour porpoise included, as the most common cetacean recorded in surveys to date.

b) Tidal period

	Number of surveys	Survey effort (hours)
Tidal period 1 (Increasing flood)	9	18
Tidal period 2 (Maximum flood)	9	18
Tidal period 3 (Decreasing flood)	9	18
Tidal period 4 (Increasing ebb)	9	18
Tidal period 5 (Maximum ebb)	9	18
Tidal period 6 (Decreasing flood)	9	18

3.3 Subsea video

All turbines in the Shetland Tidal Array between April 2022 and July 2023 were equipped with high definition subsea cameras to monitor nearfield interactions with marine wildlife. The three original turbines (T1, T2 and T3) each had cameras each with a horizontal field of view in water of 70^0, a sensitivity LUX rating of 0.001 and a resolution of 412,000 pixels. The camera configuration for T1 to T3 is illustrated in Figure 3-3.

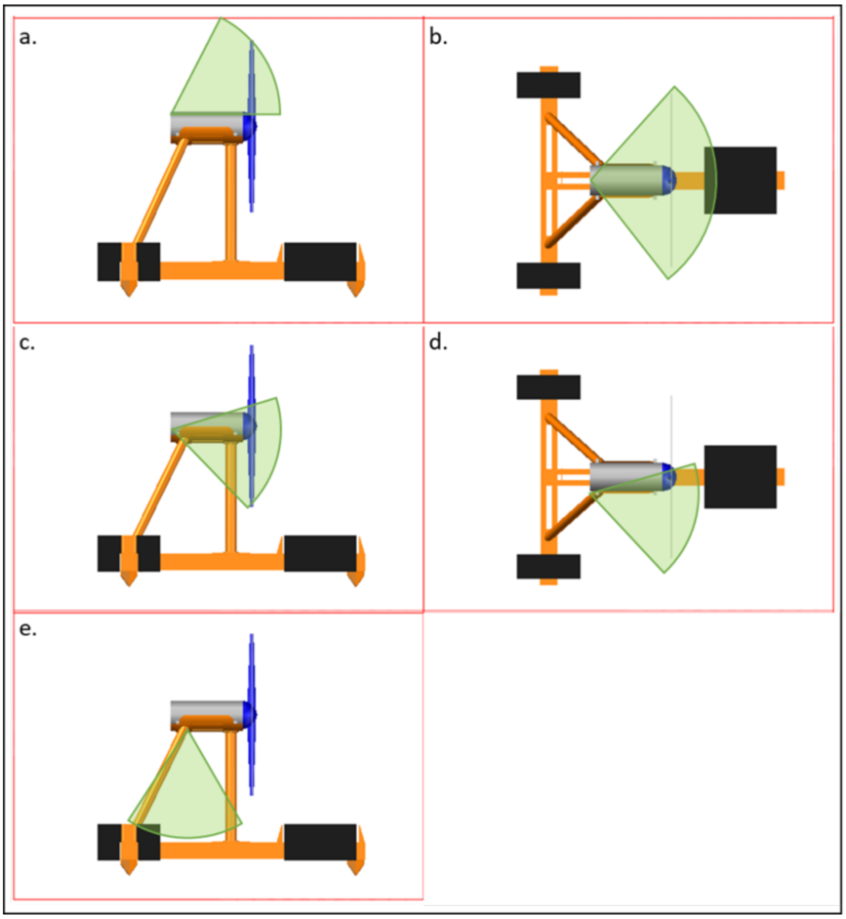

Figure 3-3 Configuration of turbine-mounted subsea cameras on T1, T2 and T3, showing (a & b) TOP camera looking towards the blades, (c & d) SIDE camera looking towards the blades and (e) DOWN camera looking towards the seabed. Figure is illustrative and not an accurate depiction of fields of view.

The cameras on T1 to T3 recorded continuously during daylight hours (dawn to dusk) in the current reporting period. Daylight in winter in Shetland averages between 6 and 7 hours, while in summer it averages between 17 and 18 hours. All footage was saved in 15-minute clips as MPEG video files with a unique code that includes an automatically assigned time and date-stamp (in GMT). The video clips are stored in a cloud-based storage system.

Each of the three direct drive turbines (T4, T5 and T6) was equipped with a single turbine-mounted camera with a horizontal field of view in water of 90^0, a sensitivity LUX rating of 0.1 and a resolution of 412,000 pixels. The camera configuration for T4 to T6 is illustrated in Figure 3-4.

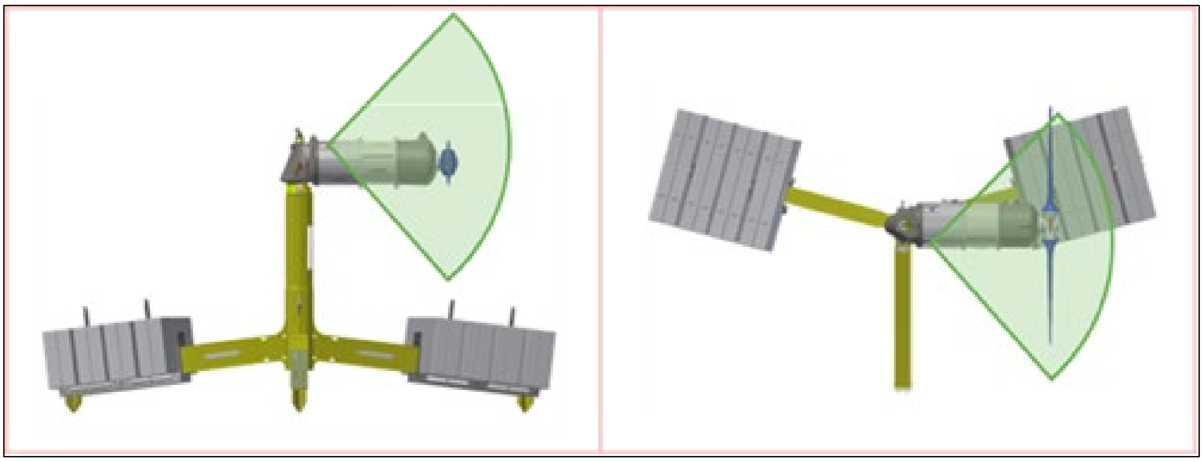

Figure 3-4 Subsea camera system for T4, T5 and T6. Camera position and field of view is indicative only, for illustrative purposes. Cameras is attached to the turbine nacelle.

The cameras on T4 to T6 recorded continuously during daylight hours (dawn to dusk) during the current reporting period. However, only footage that had been triggered by a motion detection system based on differences of contrast of light and dark across successive frames was retained and stored. Video was retained from a few seconds before the trigger up to a minimum of ten seconds, or until motion was no longer observed, up to a maximum of 15 minutes, at which point the trigger was reset. All retained footage from T4 to T6 is saved as MPEG video files with a unique code that includes an automatically assigned time and date-stamp (in GMT). The video clips are stored in folders organised by date and turbine.

Collectively the video footage acquired from turbine-mounted cameras between April 2022 and July 2023 amounts to more than 5 TB of data.

4 Development of automated video analysis

4.1 Introduction

Nova's subsea video monitoring at the Shetland Tidal Array generates significant quantities of data. As a consequence, storing, processing and analysing the data generated places a significant demand on Nova's resources. To date the video footage from the Shetland Tidal Array has been analysed by selecting representative samples for manual review which is an extremely time consuming and resource intensive process.

In 2022 Nova worked with CGG, a global technology and High Performance Computing leader to understand whether these issues might be addressed by automating data processing and analysis. The collaborative study led to the development of a model based on machine learning for automated analysis and reporting of Nova's subsea video data. This work was presented at the 2023 European Wave and Tidal Energy Conference (EWTEC), with a paper in press (Love et al, 2023).

Development of the machine learning model comprised two key stages – 'Training and Validation' and 'Testing', summarised below:

1. Development of code/algorithms to automatically filter the subsea video to remove 'unwanted footage' and extract only video that contains marine mammals, diving birds or fish ('targets'). Unwanted footage includes video files in which any movement is due to moving turbine blades, seaweed fragments and other detritus drifting in currents, or biofouling on the turbines.
2. Testing the effectiveness and accuracy of code/algorithms on further subsets of video data

Following development of the model for automated analysis, tools to assist with automated reporting on the results of analysis were also explored.

The workflow for the collaborative Nova/CGG study is illustrated in Figure 4-1.

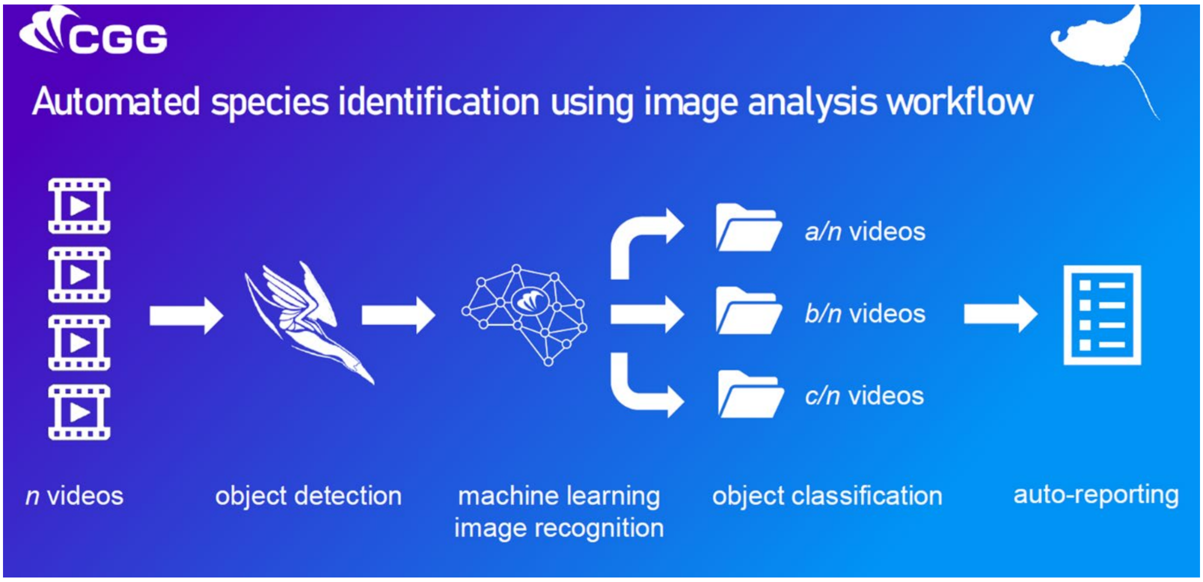

Figure 4-1 Workflow for Nova/CGG study to automate video analysis and reporting using machine learning.

4.2 Training and validation

Stage 1 in the development of a model to automate data analysis based on machine learning used two subsets of video footage from the Shetland Tidal Array for training and validation. These two subsets comprised a total of 1,123 separate videos ranging from 10 seconds in length up to 15 minutes. The content of all the videos in the two subsets was known, having been manually analysed and the results presented in previous Shetland Tidal Array monitoring reports (Nova Innovation 2017, 2021b, 2022c).

The first subset (Dataset A) comprised 931 videos which exhibited a number of wildlife occurrences consisting of seals, diving birds and fish. Examples of some of the wildlife occurrences in Dataset A that were used in model training are shown in Figure 4-2.

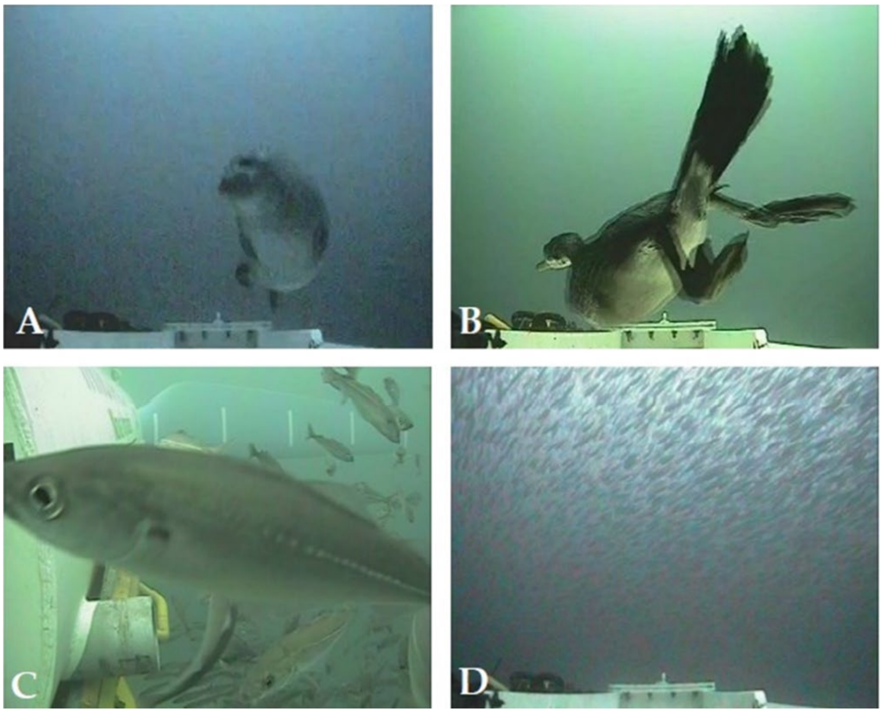

Figure 4-2 Examples of marine wildlife images from Dataset A which were used in model training. A) Grey Seal, B) European Shag, C) Individual fish close to camera D) Large shoal of fish in the distance.

The second subset (Dataset B) comprised 192 videos with just a few instances of diving birds and fish. The videos were of varying quality based on luminosity and hue of background (e.g. blue or green), turbidity and clarity of the water column, and degree of biofouling on the lens or close to the camera.

The machine learning model used in the study was a pretrained convolutional neural network called EfficientNet (MacLeod et al, 2010). This model is widely used for image classification tasks as it has learned representations for a variety of real-life objects, including wildlife occurrences (Mingxing and Le, 2019).

Videos from Dataset A were used in model training, so were manually labelled and sorted into three categories of ‘wildlife’, ‘detritus’ and ‘background’ depending on the content. The ‘wildlife’ category consisted of videos containing seals, diving birds and fish, whereas the ‘detritus’ category contained objects such as large kelp or small pieces of unidentifiable plant-like detritus. The ‘background’ category was for videos that did not contain any objects of interest (i.e., contained no wildlife or detritus).

Videos from Dataset A were sorted into further groups to use for model training or validation, respectively. Some videos from Dataset B containing diving birds were used to supplement the training and validation process given the limited number of videos containing wildlife occurrences.

4.3 Testing

Stage 2 involved testing the model on videos from Dataset B as it contained videos from a different temporal period and was deemed different enough to combat bias to the training datasets. Prior to testing the model, videos from Dataset B were manually labelled to categorize videos into ‘wildlife’, ‘background’ or ‘detritus’ to determine the success of the model. Due to many videos in Dataset B being 15 minutes long, a sampling method of watching 5 seconds of video every 30 seconds was used in the labelling process.

4.4 Results

4.4.1 Three categories (wildlife, algae, background)

The model had good results when tested on unseen videos (Dataset B), shown in Figure 4-3.

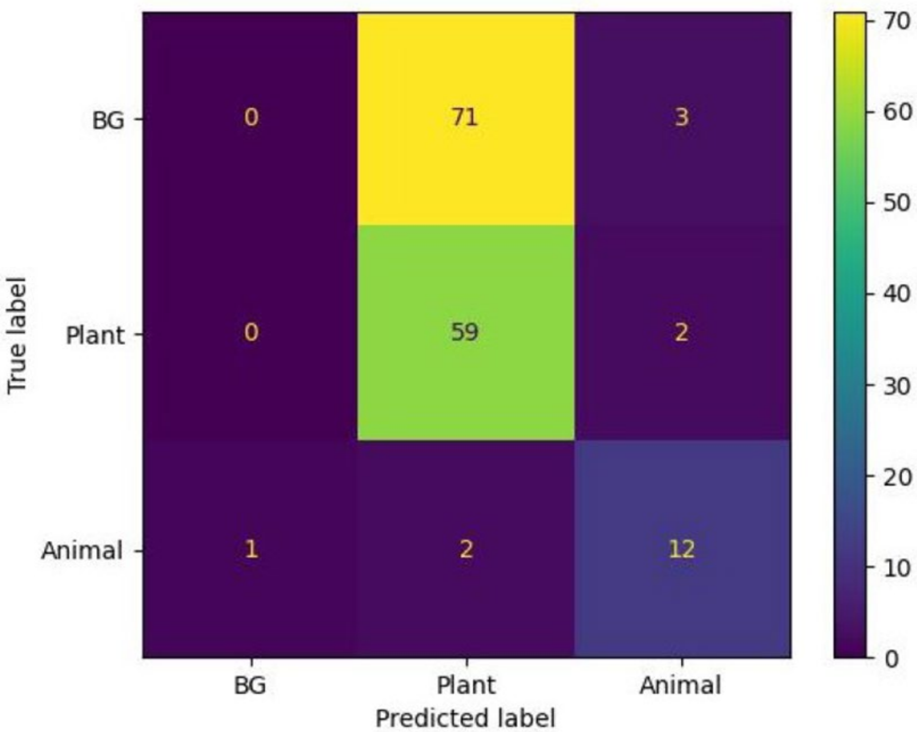

Figure 4-3 Model results for detecting 'wildlife' (Animal), 'detritus' (Plant) and 'background' (BG) categories in unseen videos (Dataset B).

Out of 15 videos containing wildlife interactions, 12 (80.0% accuracy) were correctly identified to contain mobile wildlife. One video was wrongly classed as ‘background’ and two videos wrongly classed as ‘detritus’. The model struggled to differentiate between the ‘background’ and ‘detritus’ categories, with 71 out of 74 videos wrongly identified as containing detritus and the remaining 3 videos wrongly identified as containing wildlife. The model therefore had a 0% accuracy for the ‘background’ category. The model performed well in detecting detritus, correctly identifying 59 out of 61 videos with detritus present (96.7% accuracy). The remaining 2 videos that contained occurrences of detritus were incorrectly identified as containing wildlife. Overall, 5 out of 135 videos were wrongly identified to contain wildlife where they belonged to the 'background' or 'detritus' categories. The ability of the model to differentiate between the 'background' and 'detritus' categories is discussed further below.

4.4.2 Two categories (target, non-target)

For the purposes of meeting the objectives of the Shetland Tidal Array monitoring programme, as set out in the PEMP (Nova Innovation, 2022a), differentiating between types of videos that contained false positives (i.e., no wildlife interactions) is not necessary. The model results for Dataset B were re-evaluated against two new categories: 'target' and 'non-target'. Videos previously labelled as 'background' and 'detritus' were grouped into the 'non-target' category and videos previously labelled as containing 'wildlife' were attributed to the 'target' category. Against the new category conditions, 94.1% of videos were accurately identified as either 'target' or 'non-target' by the model.

4.5 Automated reporting

To improve the efficiency of reviewing the model results and to provide a tool to assist with reporting on environmental monitoring, an auto-generated results report was created. The report details the number of videos identified to contain wildlife interactions and includes the videos identified by the model to contain wildlife interactions. Six frames per video were generated to include in the report, which was found to be a sufficient number of frames to characterise the nature of the encounter. The number of frames can be adjusted to suit the purpose of the report.

The report also contains some statistics to compare the number of file and total data size of the data sample before and after being run through the model. An example of this outputs from Dataset B is shown in Figures 4-4 and 4-5.

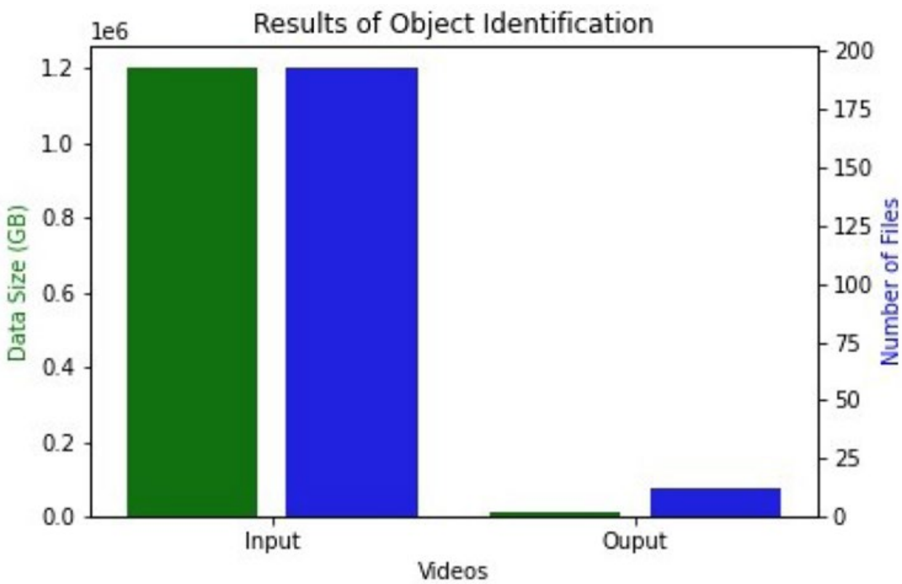

Figure 4-4 Example of statistics included in the automatically generated report showing the data size (amount of storage) in green and the number of files in blue, based on Dataset B.

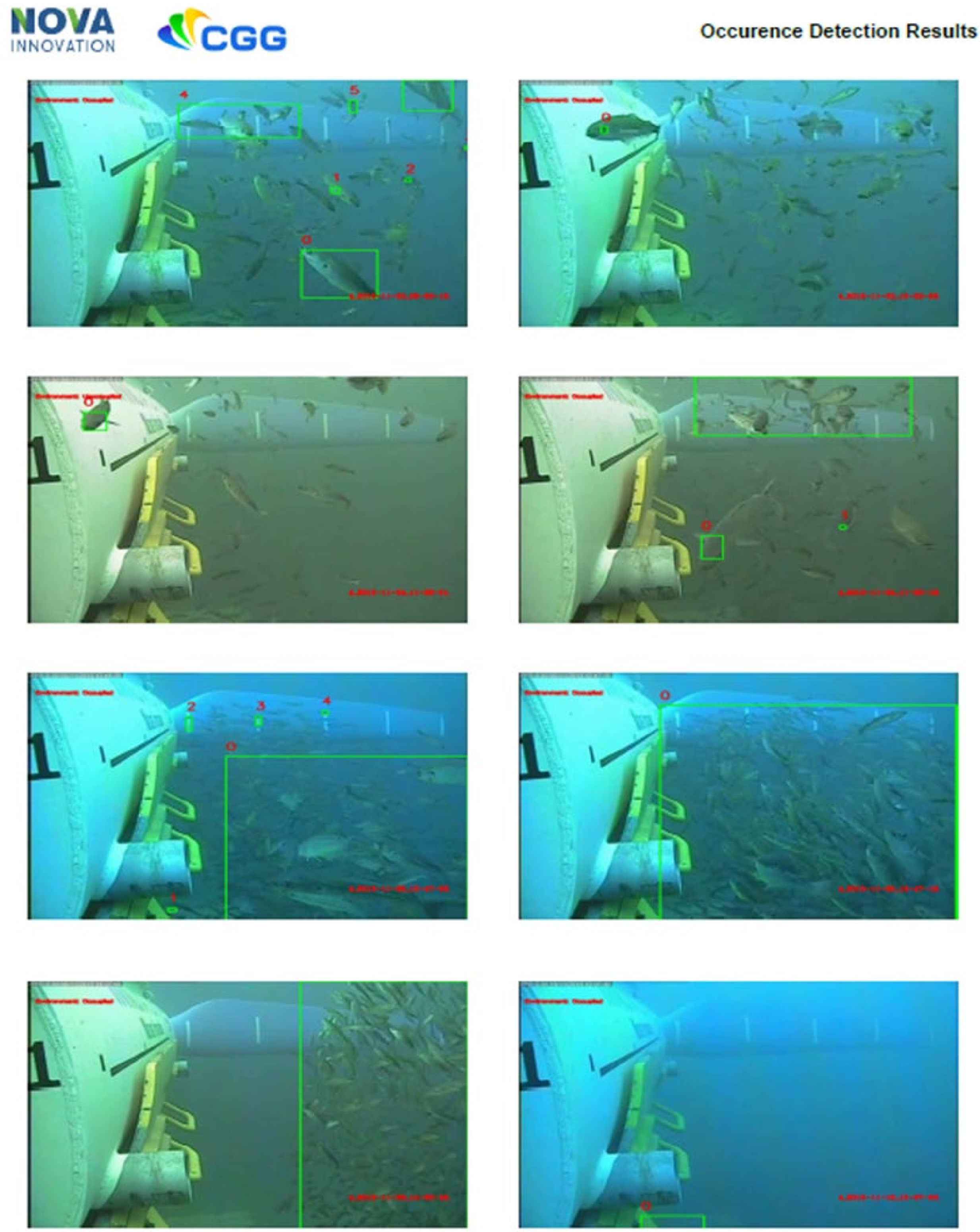

Figure 4-5 Example of frames automatically generated for inclusion in the report showing target detections, based on Dataset B.

There are several additional statistics that could be calculated within the automated workflow and included the report template. For example, a time analysis of the number of interactions recorded per month or season, or the frequency of bird detections in relation to fish presence.

4.6 Ongoing model refinement

The machine learning model developed in this study provides good success rates for three and two category identification in video footage from the Shetland Tidal Array. Machine learning through exposure to additional subsea video footage with a variety of shapes and sizes of detritus and wildlife will further enhance model accuracy.

The model is now undergoing a process of continual refinement and improvement, using additional subsea video footage from the Shetland Tidal Array. As part of this process, samples of subsea video from the current reporting period (April 2022 to July 2023) have been analysed using the model. The results of this are presented in Section 7. The implications of this work for the ongoing environmental monitoring at the Shetland Tidal Array are considered in Section 8 (Discussion).

This work was presented at the 2023 European Wave and Tidal Energy Conference (EWTEC), while a peer-reviewed paper on the study is in press (Love et al, 2023).

5 April 2022 to July 2023 data analysis

5.1 Land-based surveys

Analysis of data from land-based surveys from April 2022 to July 2023 presented in this report has two key aims:

1. To build on previous analysis to understand diving seabird and marine mammal presence and occupancy at the project site.
2. To inform a sampling protocol for analysis of subsea video data.

Descriptive statistics and qualitative analyses have been used to analyse data from snapshot scans carried out during each 2-hour survey to identify and count all birds and mammals in the survey area. The results further improve understanding for the potential for nearfield encounters occurring between turbines and diving birds and marine mammals, based on their presence in the array area, and how this varies throughout the year and tidal cycle. The ongoing low numbers of birds and mammals recorded in surveys and 'zero-dominance' in the data[5] prohibit the use of more advanced statistical modelling techniques.

5.2 Subsea video monitoring

5.2.1 Sample selection

Analysis of the data from subsea video monitoring detailed in this report has three key aims:

1. To identify any nearfield interactions between turbines and marine mammals and birds.
2. To understand the nature and consequences of any such interactions.
3. To further refine the machine learning model developed by CGG to automate the identification of marine wildlife in footage.

The turbine-mounted cameras generated in excess of 5 TB data between April 2022 and July 2023. A sample was selected to ensure that data analysed were representative of the full dataset. Samples were selected corresponding to times of known bird or mammal activity in the array area, based on the land-based surveys, thereby also providing annual, seasonal, diurnal and tidal state representation in the sampled video data. Periods immediately following deployment of new turbines in the array were also targeted, based on the potential for a greater likelihood of nearfield interactions with marine wildlife if animals become habituated to turbine presence in the longer term.

The protocol used to select samples of video footage from the full dataset for detailed analysis is shown in Table 5-1. The table also details whether the footage was analysed using the machine learning model and/or 'traditional' manual review to identify any occurrences of mobile species

[5] Statistical modelling has previously been used to analyse the land-based survey data to explore bird and mammal occupancy patterns and the probability of nearfield encounters with turbines. This modelling, carried out using data from a much longer time period and presented in previous Shetland Tidal Array monitoring reports, indicated a very low risk of nearfield encounters with operational turbines.

(birds, mammals or fish). As detailed in Section 4, the machine learning model has an accuracy of more than 94% for identifying ‘targets’ in footage (a target being a fish, bird or mammal).

Table 5-1 Sampling protocol for video footage acquired from April 2022 to July 2023. Italics detail whether analysis of footage in each subset was automated/manual or both. All clips identified by the model to contain targets were manually scrutinised.

<table>
<tr><th>Subset</th><th>Details & automated or manual analysis</th><th>Rationale for selection</th></tr>
<tr><td rowspan="2">1</td><td>Full days of footage immediately following turbine deployment. Footage selected:
- All footage from T5 from 17/01/2023 to 18/01/2023 inclusive.
- All footage from T6 from 14/01/2023 to 18/01/2023 inclusive.</td><td>Footage will be high quality with no biofouling on turbines or cameras due to recent installation of turbines.
Possible greater likelihood of nearfield interactions immediately following turbine installation (if animals habituate to turbine presence).</td></tr>
<tr><td colspan="2">Mainly automated analysis. Some clips in this subset were randomly selected for manual review to compare with automated results.</td></tr>
<tr><td rowspan="2">2</td><td>All available footage overlapping with the land-based bird and mammal surveys in Bluemull Sound.</td><td>Surveys are stratified for seasonal and tidal coverage so video subset provides the same structure.
Surface data available on birds and mammals available for comparison.</td></tr>
<tr><td colspan="2">Automated and manual analysis. Some clips selected for blind comparison to independently compare manual and automated results.</td></tr>
<tr><td rowspan="2">3</td><td>Full days of footage from April 2023. Footage selected:
- All footage from T5 and T6 on 02/04/2023.
- All footage from T5 and T6 on 09/04/2023.</td><td>Assumed to a time of year when variety and abundance of species are likely to be greater compared to other months.</td></tr>
<tr><td colspan="2">Mainly manual analysis though some clips in this sample were also in subset 2, so were subject to automated analysis to independently compare results.</td></tr>
<tr><td rowspan="2">4</td><td>Selected footage to fill critical gaps in coverage of subsets 1 to 3).
Footage selected:
- Additional footage outside times of land-based survey overlap for 23/07/2022 for full day of coverage T2.
- All footage from T4 on 22/12/2022 for T4 and December coverage.
- All footage from T1 on 15/02/2023 for T1 and February coverage.</td><td>Additional data selected to ensure that the video clips analysed were representative of the full dataset, covering all turbines/seasons/tidal states.</td></tr>
<tr><td colspan="2">Manual analysis only.</td></tr>
</table>

This sampling protocol generated around 40 GB data for analysis, comprising almost 600 individual video clips. Metadata for the footage analysed manually in this report are provided in Appendix A, while details of automatically analysed footage are provided in Appendix B. For manually analysed data, Appendix A provides details of tidal state and whether the turbine was observed to be operating in the clip. This information is not provided for files that were analysed using the machine learning model alone, since tidal categories and operational status are currently assigned manually using Nova's hydrodynamic model for Bluemull Sound[6].

In addition to the sample of video footage selected for systematic review and analysis detailed in the table above, video footage from turbine-mounted cameras is routinely reviewed for surveillance of turbine performance. Detailed records of footage reviewed for this purpose are not kept for environmental monitoring reporting purposes. However, Nova protocol requires that personnel conducting these checks report any instances of diving birds or marine mammals observed in footage immediately to Nova's Environmental Manager for closer investigation.

5.2.2 Automated analysis

The video clips selected for automated analysis were processed by the model in two separate 'batches'. Batch 1 comprised all footage from T5 from 17/01/2023 to 18/01/2023 and all footage from T6 from 14/01/2023 to 18/01/2023 (subset 1 in Table 5-1). This totalled 161 separate video clips. Batch 2 comprised selected footage overlapping with the land-based bird and mammal surveys in Bluemull Sound and all available footage from T5 and T6 on 02/04/2023 and 09/04/2023 (subsets 2 and 3 in Table 5-1). This totalled 140 separate video clips.

The 301 video clips that were processed and analysed using the machine learning model were also subject to targeted and random cross-checks for model validation. For example, all clips from 2nd and 9th April 2023 were analysed both manually and using the model for 'blind' comparison. Some of the footage from T5 and T6 in January 2023 were also randomly selected for manual review for blind comparison with the results of automated analysis.

Any clips that the model identified to contain targets (i.e. mobile marine species) were manually scrutinised to confirm whether the target was a fish, bird or mammal and, if so, to determine species identification and any notable behaviour, including any nearfield interactions with turbine rotors.

The date and time of any video clip in which mobile species were observed were recorded and one of six tidal periods manually assigned, derived from Nova's tidal model of the site (detailed Section 3.2).

5.2.3 Manual analysis

Two individuals conducted the review and analysis of the 242 video clips that were selected for initial manual review, detailed in Section 5.2.1. The clips were reviewed initially at speed x 2 to initially determine any possible occurrences of mobile species. Each video file identified as potentially containing a mobile species was scrutinised in greater detail at much slower speed (speed x 0.1) and using freeze frames to confirm whether the object was an animal or another mobile object such as seaweed fragments drifting in the tidal flow.

Any clips that the model identified to contain targets (i.e. mobile marine species) were also manually scrutinised.

The date and time of any video clip in which any mobile species was observed were recorded and one of six tidal periods manually assigned using Nova's hydrodynamic model for Bluemull Sound.

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[6] See Section 8.3 for a consideration of the potential to automate the assignment of tidal state and turbine operational status to video files in the future.

6 April 2022 to July 2023 land-based survey results

6.1 Species recorded

All birds and mammals recorded in land-based surveys between April 2022 and July 2023 were identified to species level with high confidence. The same surveyor has carried out land-based surveys since they started in 2010, so confidence in species identification is extremely high.

Nine species of diving bird and three marine mammal species were recorded, detailed in Tables 6-1 and 6-2. The tables show the number of surveys in which each species was recorded, and the percentage of snapshot scans in these surveys in which the species was recorded. Mean and maximum counts for the snapshot scans are provided, including mean counts based on:

i. Data from all snapshot scans during surveys in which the species was recorded (i.e. count ≥ 0), and;

ii. Data only from those snapshot scans where the species was recorded (i.e. excluding 0 count scans).

Collectively, these statistics provide an indication of the abundance and persistence/transience of each species in the array area. As indicated in Tables 6-1 and 6-2, data for most species were zero-dominated, whereby species were either not present, or were only recorded in a very small number of scans during 2-hour surveys, where they were present. Two species (cormorant and grey seal) were recorded in just one scan during a single survey, so for these species a qualitative description is provided.

Table 6-1 Mean (± standard deviation) and maximum counts of diving bird species in land-based snapshot scans. Dates of maximum counts for each species are in italics in last column. Column 2 shows % of snapshot scans in which the species was recorded. All figures are based on data only from surveys in which each species was recorded from the total (N=54).

Species	No. surveys recorded (N=54)	Mean count/scan (where count ≥ 0)	Mean count/scan (where count > 0)	Max. count in any single scan
Anatidae (ducks, geese and swans)				
Common eider *Somateria mollissima*	2 7.5% of scans	0.6 ± 2.8	8.3 ± 7.5	17 *29/10/22*
Alcidae (auks)				
Common guillemot *Uria aalge*	19 10.5% of scans	0.1 ± 0.4	1.2 ± 0.5	3 *19/10/22*
Razorbill *Alca torda*	4 6.3% of scans	0.1 ± 0.2	1.0 ± 0.0	1 *All surveys*
Black guillemot *Cepphus grylle*	54 49.9% of scans	1.4 ± 2.8	2.8 ± 3.4	33 *20/08/22*
Atlantic puffin *Fratercula articulata*	13 16.5% of scans	0.3 ± 0.7	1.6 ± 1.0	6 *09/04/23*
Gaviidae (divers)				
Red-throated diver *Gavia stellata*	10 7.0% of scans	0.1 ± 0.5	1.8 ± 1.1	4 *20/03/22; 09/04/23*

Species	No. surveys recorded (N=54)	Mean count/scan (where count ≥ 0)	Mean count/scan (where count > 0)	Max. count in any single scan
Sulidae (gannets)				
Northern gannet *Morus bassanus*	6 34.2% of scans	0.8 ± 1.4	2.2 ± 1.6	7 *23/07/22*
Phalacrocoracidae (cormorants and shags)				
Great cormorant *Phalacrocorax carbo*	1 individual recorded in a single scan in one survey *19/10/22*			
European shag *Gulosus aristotelis*	38 14.4% of scans	0.6 ± 8.6	4.4 ± 22.2	190 *05/02/23*

Table 6-2 Mean (± standard deviation) and maximum counts of marine mammal species in land-based snapshot scans. Dates of maximum counts are in italics in last column. Column 2 shows % of snapshot scans in which the species was recorded. All figures are based on data only from surveys in which each species was recorded from the total (N=54).

Species	No. surveys recorded (N=54)	Mean count/scan (where count ≥ 0)	Mean count/scan (where count > 0)	Max. count in any single scan
Phocidae (seals)				
Grey seal *Halichoerus grypus*	2 animals recorded in a single scan in one survey *29/10/22*			
Common seal *Phoca vitulina*	8 6.2% of scans	0.1 ± 0.3	1.1 ± 0.3	2 *20/08/22*
Phocoenidae (toothed whales)				
Harbour porpoise *Phocoena phocoena*	5 7.0% of scans	0.1 ± 0.5	1.9 ± 1.1	4 *19/10/22*

Each species in the tables above has previously been recorded in the land-based surveys, prior to April 2022. Consistent with previous surveys, only European shag (*Gulosus aristotelis*) and black guillemot (*Cepphus grylle*) occurred relatively consistently at the project site. This aligns with observations at other tidal sites in the north of Scotland (Dr James Waggitt, pers. comm.).

Variations in the presence and abundance of these twelve species throughout the year and across the tidal cycle are examined in the following sections. Only data from those snapshot scans where the species was recorded (i.e. counts > 0) have been included in analyses. This approach enables an indication of 'worst case scenario' for presence and abundance of each species in the array area given the zero-dominance in the data.

6.2 Variation by annual period

The land-based surveys conducted in Bluemull Sound in this reporting period (April 2022 to July 2023) distributed effort over four annual periods. These were defined by key annual stages in breeding cycles of diving birds and cetaceans and moulting and breeding periods of common and grey seals, detailed in Table 3-1 (Section 3).

Tables 6-3 and 6-4 provide descriptive statistics for diving bird and marine mammal species in the 2-hour surveys for each of the four annual periods in the current reporting period. Numbers are based only on data from snapshot scans in which the species was recorded (i.e. counts > 0).

Table 6-3 Mean count (± standard deviation) of diving bird species by annual period in land-based snapshot scans. Figures in brackets are the number of surveys in each annual period from the total (N) in which the species was present.

Species	April to July (N=24)	August to mid-September (N=12)	Mid-September to October (N=12)	November to March (N=6)
Common eider	(0/24)	(0/12)	8.3 ± 7.5 (2/12)	(0/6)
Common guillemot	1.4 ± 0.4 (7/24)	1.5 ± 0.8 (5/12)	1.2 ± 0.6 (4/12)	1.0 ± 0.0 (3/6)
Razorbill	1.0 ± 0.0 (2/24)	(0/12)	1.0 ± 0.0 (2/12)	(0/6)
Black guillemot	1.6 ± 0.9 (24/24)	1.9 ± 3.6 (12/12)	4.9 ± 4.4 (12/12)	1.7 ± 1.0 (6/6)
Atlantic puffin	1.6 ± 1.0 (11/12)	1.0 ± 0.0 (1/12)	1.0 ± 0.0 (1/12)	(0/6)
Red-throated diver	1.7 ± 0.9 (7/24)	1.0 ± 0.0 (2/12)	(0/12)	4.0 ± 0.0 (1/12)
Northern gannet	2.3 ± 2.2 (2/24)	2.6 ± 1.6 (2/12)	1.0 ± 0.0 (2/12)	(0/6)
Great cormorant	(0/24)	(0/12)	1.0 ± 0.0 (1/12)	(0/6)
European shag	1.0 ± 0.0 (13/24)	1.4 ± 0.6 (7/12)	1.6 ± 1.1 (12/12)	17.0 ± 49.8 (6/6)

Table 6-4 Mean count (± standard deviation) of marine mammal species by annual period in land-based snapshot scans. Figures in brackets are the number of surveys in each annual period from the total (N) in which the species was present.

Species	April to July (N=24)	August to mid-September (N=12)	Mid-September to October (N=12)	November to March (N=6)
Grey seal	(0/24)	(0/12)	2.0 ± 0.0 (1/12)	(0/6)
Common seal	1.0 ± 0.0 (3/12)	2.0 ± 0.0 (1/12)	1.0 ± 0.0 (3/12)	(0/6)
Harbour porpoise	1.0 ± 0.0 (1/12)	(0/12)	2.0 ± 1.1 (3/12)	(0/6)

Few species were present at the site year-round, with most showing some seasonal variation, reflecting their general life history strategies. Only black guillemot and European shag were present at the site year-round. Counts of all species were consistently low or very low, with the exception of shag which on two occasions in surveys both carried out on 5th February 2023 occurred in large flocks exceeding 100 individuals. While such large flocks are often observed feeding (Evans et al, 2019), on both these occasions, the birds were sitting on the water surface and not displaying any foraging or feeding behaviour (based on surveyor survey notes).

6.3 Variation by tidal period

Tables 6-5 and 6-6 detail the diving bird and marine mammal species recorded in each of the six tidal periods during land-based surveys between April 2022 and July 2023. Descriptive statistics of count data are provided for surveys in which the species was recorded (based only on data from counts > 0).

Table 6-5 Mean count (± standard deviation) of diving bird species by tidal period in land-based snapshot scans. Figures in brackets are the number of surveys from the total (N) of nine in each tidal period in which the species was present.

Species	Increasing flood (N=9)	Maximum flood(N=9)	Decreasing flood (N=9)	Increasing ebb (N=9)	Maximum ebb (N=9)	Decreasing ebb (N=9)
Common eider	(0/9)	(0/9)	(0/9)	4.0 ± 0.0 (1/9)	(0/9)	17.0 ± 0.0 (1/9)
Common guillemot	1.0 ± 0.0 (4/9)	1.4 ± 0.5 (3/9)	1.3 ± 0.8 (2/9)	1.3 ± 0.7 (4/9)	1.5 ± 0.5 (4/9)	1.0 ± 0.0 (2/9)
Razorbill	1.0 ± 0.0 (1/9)	1.0 ± 0.0 (2/9)	(0/9)	(0/9)	1.0 ± 0.0 (1/9)	(0/9)
Black guillemot	2.4 ± 3.3 (9/9)	3.1 ± 2.9 (9/9)	3.3 ± 3.5 (9/9)	4.5 ± 5.2 (9/9)	1.4 ± 0.6 (9/9)	1.9 ± 1.2 (9/9)
Atlantic puffin	2.1 ± 0.9 (2/9)	1.0 ± 0.0 (2/9)	1.0 ± 0.0 (2/9)	1.7 ± 1.2 (3/9)	1.6 ± 1.3 (3/9)	1.2 ± 0.4 (1/9)
Red-throated diver	2.0 ± 0.0 (2/9)	(0/9)	1.6 ± 1.3 (4/9)	1.0 ± 0.0 (1/9)	1.0 ± 0.0 (2/9)	2.0 ± 0.0 (1/9)
Northern gannet	2.8 ± 2.9 (1/9)	1.2 ± 0.2 (2/9)	1.0 ± 0.0 (1/9)	(0/9)	2.6 ± 2.2 (1/9)	2.6 ± 1.1 (1/9)
Great cormorant	(0/9)	(0/9)	(0/9)	1.0 ± 0.0 (1/9)	(0/9)	(0/9)
European shag	9.3 ± 38.5 (6/9)	9.9 ± 34.7 (7/9)	1.6 ± 0.9 (7/9)	1.6 ± 1.3 (6/9)	1.4 ± 0.5 (7/9)	1.3 ± 0.9 (7/9)

Table 6-6 Mean count (± standard deviation) of marine mammal species by tidal period in land-based snapshot scans. Figures in brackets are the number of surveys from the total (N) of nine in each tidal period in which the species was present.

Species	Increasing flood (N=9)	Maximum flood (N=9)	Decreasing flood (N=9)	Increasing ebb (N=9)	Maximum ebb (N=9)	Decreasing ebb (N=9)
Grey seal	(0/9)	(0/9)	(0/9)	(0/9)	(0/9)	2.0 ± 0.0 (1/12)
Common seal	1.3 ± 0.6 (1/9)	1.0 ± 0.0 (1/9)	1.0 ± 0.0 (1/9)	1.0 ± 0.0 (1/9)	(0/9)	1.0 ± 0.0 (1/9)
Harbour porpoise	2.0 ± 0.0 (1/9)	2.3 ± 1.5 (3/9)	(0/9)	1.3 ± 0.6 (2/9)	(0/9)	(0/9)

As with analysis of previous survey data, numbers of European shag were generally greater on the flood tide than the ebb. The two instances of large flocks of shag (exceeding 100 individuals) both occurred on the flood tide. Consistent with previous surveys, black guillemot numbers were generally greatest around high water slack. Determining any occupancy patterns by tidal state for other species is difficult, given the low numbers and zero-dominance in the data.

7 April 2022 to July 2023 subsea video results

7.1 System performance

The year-round excellent water clarity in Shetland and the relatively simple monitoring approach means that optical cameras continue to be an effective, robust, reliable and low-cost solution to gather data on nearfield interactions between turbines and mobile species. Although the cameras operate 24 hours a day, only footage from dawn to dusk is retained. Daylight in winter in Shetland averages between 6 and 7 hours, while in summer it averages between 17 and 18 hours.

Image quality was generally very good over the reporting period (April 2022 to July 2023. Figure 7-1 shows examples of the typical quality of images in the subset of data clips analysed in this report.

Figure 7-1 Stills from the video footage analysed in this report showing the typical image quality.

As has been previously reported, video quality varies with the level of biofouling on the lenses of cameras and the turbines[7]. The rate of biofouling varies with season and from year to year but is generally greater in summer months. It takes several months before images are completely obscured by biofouling and footage is rendered unusable.

Some biofouling does not impede analysis and it is only when images are completely obscured that they are rendered unusable. The image in Figure 7-2 shows a still image from the camera on T6 on 5th June 2023 (5 months post-installation). While there is some biofouling on the lens of the camera this did not affect the ability to carry out analysis. Section 7.3, which details the results of the automated analysis demonstrates that even significant biofouling did not impede the ability of the model to correctly identify targets.

Figure 7-2 Still from T6 camera from 5th June 2023. There is some biofouling on the camera lens, but the image is still of sufficient quality for analysis, with the rotor clearly visible.

Camera lenses are routinely cleaned during turbine maintenance operations to limit the effects of biofouling, while the current reporting period includes the installation of new turbines which will be free of biofouling.

The availability of footage from multiple cameras on multiple turbines (including new turbines) reduces the overall effects of biofouling on the overall coverage and representativity of the sample selected for analysis in this report. Despite some inevitable biofouling, across all cameras and all turbines, footage of sufficient quality was available to enable analysis of a representative sample from the full dataset that provided good seasonal, diurnal and tidal coverage for the current

[7] Biofouling and its effects on image quality and data analysis were considered in detail in the Shetland Tidal Array monitoring report covering the reporting period March 2020 to March 2022 (Nova Innovation, 2022c).

reporting period. The only month in which biofouling on all cameras prevented any data analysis was September.

7.2 Automated video analysis results

No collisions between fish, diving birds or marine mammals were observed in any of the automatically analysed video footage, with no occurrences at all of diving birds or marine mammals.

The machine learning model identified targets in 15 of the 161 video clips in ‘Batch 1’, which comprised all footage from T5 from 17/01/2023 to 18/01/2023 and all footage from T6 from 14/01/2023 to 18/01/2023. The model identified 29 targets in the 140 video clips in ‘Batch 2’, which comprised selected footage overlapping with the land-based bird and mammal surveys in Bluemull Sound and all available footage from T5 and T6 on 02/04/2023 and 09/04/2023. Full details of the video clips analysed automatically are provided in Appendix B.

All 44 video clips identified by the machine learning model to contain targets were subject to detailed manual scrutiny to confirm targets, determine species identification and any notable behaviour.

The automatically generated results for Batches 1 and 2, demonstrating the reduction in the size of the dataset requiring detailed manual scrutiny is shown in Figure 7-3.

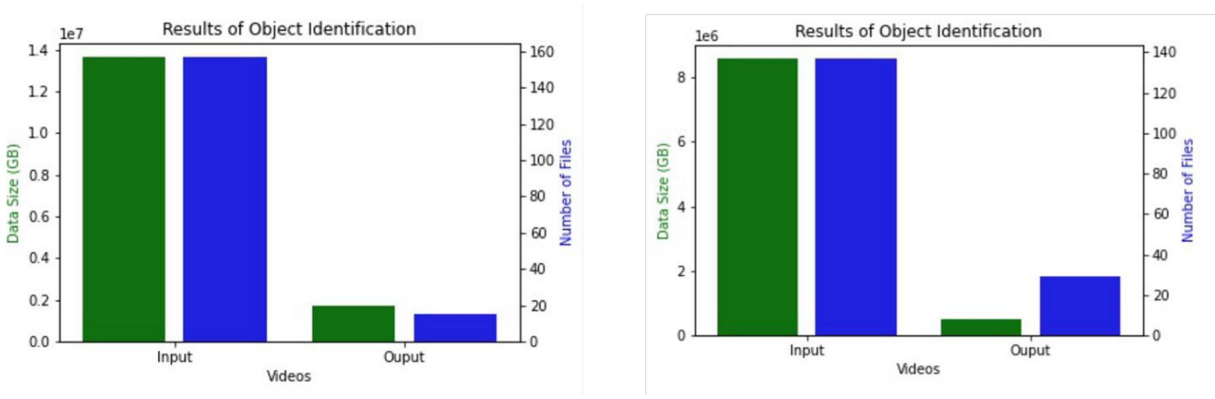

Figure 7-3 Results of automated analysis of video Batch 1 (left) and Batch 2 (right), showing the reduction in size (GB and number of files) in the dataset requiring manual scrutiny following automated analysis to identify potential targets.

Targets were found to be ‘false’ in 8 of the 44 clips, following closer scrutiny by a manual reviewer. The false targets in these 8 clips were confirmed by the manual reviewer to be detached macroalgae or marine litter drifting in the tidal flow. All of these false targets were at times when tidal flow was significant and turbines were operating such that the targets moved very quickly through the field of view.

The remaining 36 targets identified by the model were confirmed to be fish. There were no instances of diving birds or marine mammals. The turbine was operating in 15 of the clips and was stationary in the remaining 21, with little or no tidal flow.

In some of the clips in which the turbine was operating, transiting fish were seen to pass through the rotor swept area on the tidal flow. All of these occurred on the ebb tide when the flow was from south to north through Bluemull Sound. No collisions between fish and turbines were observed in any of the footage reviewed.

Details of the 36 clips containing occurrences of fish are provided in Table 7-1.

Table 7-1 Details of the 36 video clips containing fish following automated analysis. Time (GMT) is the start time of clips in which fish were observed.

Date	Time GMT	Tidal state	Turbine rotating?	Turbine	Details
19/10/2022	08:49	Increasing ebb	No	3	Single fish milling amongst macroalgal growth on nacelle
19/10/2022	11:34	Decreasing ebb	No	3	Single fish milling amongst milling amongst macroalgal growth on nacelle
19/10/2022	11:49	Decreasing ebb	No	3	Single fish milling amongst milling amongst macroalgal growth on nacelle
19/10/2022	12:04	Decreasing ebb	No	3	≈ 5 fish milling at hub height in water column and around macroalgal on nacelle
19/10/2022	12:19	Decreasing ebb	No	3	≈ 5 fish milling at hub height in water column and around macroalgal on nacelle
19/10/2022	12:49	Decreasing ebb	No	3	≈ 5 fish milling at hub height in water column and amongst macroalgal growth on nacelle
19/10/2022	13:04	Decreasing ebb	No	3	Single fish milling amongst macroalgal growth on nacelle
19/10/2022	13:19	Increasing flood	No	3	Single fish milling amongst macroalgal growth on nacelle
29/10/2022	10:45	Maximum flood	Yes	3	Two fish swimming just above nacelle facing into flow and amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**
29/10/2022	11:00	Maximum flood	Yes	3	Single fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**
29/10/2022	11:15	Maximum flood	Yes	3	Two fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**
29/10/2022	11:30	Maximum flood	Yes	3	Two fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**
29/10/2022	11:47	Maximum flood	Yes	3	≈ 5 fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**
29/10/2022	12:15	Maximum/ Decreasing flood	No	3	Single fish milling amongst macroalgal growth on nacelle
29/10/2022	12:30	Decreasing flood	No	3	≈ 5 fish milling above turbine in water column.
29/10/2022	12:45	Decreasing flood	No	3	≈ 5 fish milling above turbine in water column.
29/10/2022	13:15	Decreasing flood	No	3	Single fish milling amongst macroalgal growth on nacelle

Date	Time GMT	Tidal state	Turbine rotating?	Turbine	Details
29/10/2022	13:30	Decreasing flood	No	3	Single fish milling amongst macroalgal growth on nacelle
31/10/2022	07:35	Decreasing ebb	No	3	Single fish milling amongst macroalgal growth on nacelle
31/10/2022	07:50	Decreasing ebb	No	3	Single fish milling amongst macroalgal growth on nacelle
31/10/2022	08:05	Decreasing ebb	No	3	Single fish milling amongst macroalgal growth on nacelle.
31/10/2022	08:35	Decreasing ebb	No	3	Two fish above turbine in water column.
31/10/2022	08:50	Decreasing ebb	No	3	≈ 5 fish milling above turbine in water column.
31/10/2022	09:05	Decreasing ebb	No	3	> 5 fish milling above turbine in water column.
31/10/2022	09:20	Decreasing ebb	No	3	> 5 fish milling above turbine in water column.
31/10/2022	09:35	Increasing flood	No	3	Single fish milling amongst macroalgal growth on nacelle.
16/01/2023	09:19	Maximum ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
16/01/2023	09:49	Maximum ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
16/01/2023	10:19	Decreasing ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
16/01/2023	10:34	Decreasing ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
16/01/2023	10:50	Decreasing ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
16/01/2023	12:57	Increasing flood	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
18/01/2023	10:06	Increasing ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
02/04/2023	13:11	Maximum ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
02/04/2023	13:56	Maximum/ decreasing ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**
09/04/2023	14:05	Increasing ebb	Yes	6	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**

Figure 7-4 shows stills from some of the video clips identified to contain targets by the model, confirmed to be fish following detailed manual examination. In these clips the turbine rotors are stationary.

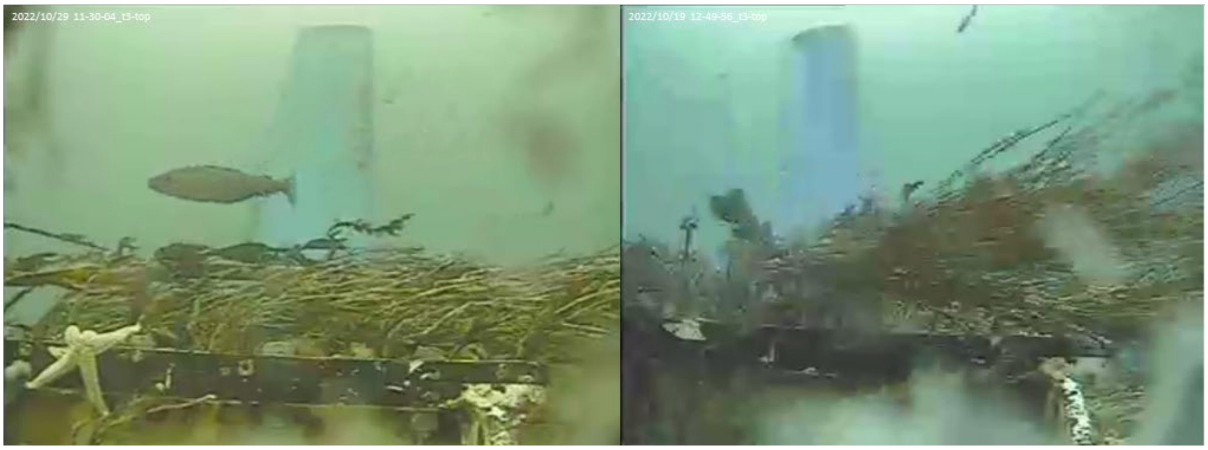

Figure 7-4 Stills from T3 camera containing fish identified by the model. In these clips tidal flow was minimal and the turbine blades are stationary. Images are from October 2023 and the turbine nacelle had been deployed since November 2020 so has considerable biofouling.

Figure 7-5 shows further stills from some of the video clips identified to contain targets by the model, which were confirmed to be fish following manual examination. In these videos the tide was running and the turbines were operating. The speed at which the fish passed through the camera's field of view in clips with the tidal flow prevented identification to species level, but they all appeared to be a small species of whitefish.

Figure 7-5 Stills from T6 camera containing fish identified by the model. In these clips the tide was running and the turbine blades were rotating. In the image on the right the fish which is small and passes quickly through the camera's field of view is circled.

The model was highly effective at detecting targets in conditions typical of the images above, in which fish passed the turbines rapidly on a fast flowing ebb tide (when the flow in from south to north in Bluemull Sound). In a 'blind test' of samples of footage from 2nd and 9th April 2023 that was independently analysed manually and automatically, none of these clips that the model identified to contain fish when the tide was flowing quickly were detected by the manual reviewer. The fish passed too quickly through the camera's field of view on the ebb flow for the manual reviewer to detect them.

The model was also highly effective at detecting targets when there was significant biofouling on the turbines. Figure 7-6 shows some stills from footage in which fish were correctly identified by the machine learning model, even when they were camouflaged and cryptic amongst macroalgal growth on the turbine nacelle. In some instances, particularly where macroalgal fronds were moving in the tides, a manual reviewer may have failed to detect some of these fish occurrences.

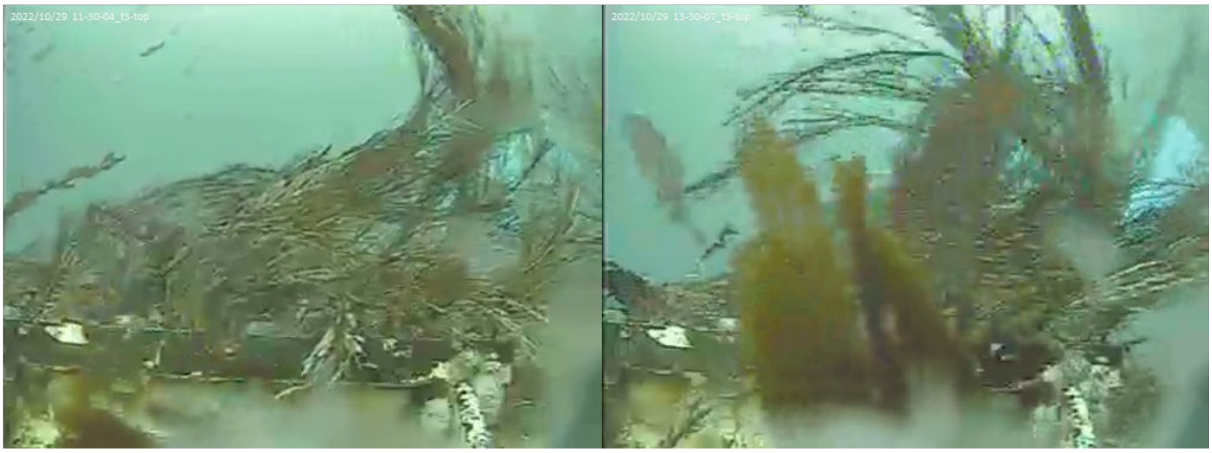

Figure 7-6 Stills from T3 camera identified to contain fish targets by the model when there was significant macroalgal growth on the turbine nacelle. Images are from October 2023 and the turbine nacelle had been deployed since November 2020 so has considerable biofouling.

7.3 Manual analysis results

No collisions between fish, diving birds or marine mammals were observed in any of the manually reviewed video footage, with no occurrences at all of diving birds or marine mammals. Fish were observed in 3 video clips, as detailed in Table 7-2. Full details of all footage that was reviewed manually are provided in Appendix A.

Table 7-2 Occurrences of fish in the subset of manually reviewed video footage from April 2022 to July 2023. Times are the start time of clips in which fish were observed.

Date	Time GMT	Tidal state	Turbine rotating?	Turbine	Details
02/04/2023	15:31	Decreasing ebb	No	6	One occurrence of two fish swimming at nacelle height.
09/04/23	04:40-04:55	Maximum ebb	Yes	6	Five occurrences of individual fish throughout this 15-minute clip. Assumed to be different fish, since the tide is flowing. Fish appear to be transiting the array area with the tide. Note some apparent evasion (either passive or active) is observed.
05/06/23	10:48-10:50	Decreasing flood (around high water slack)	No	5	Three occurrences of individual fish observed in a 2-minute period within this clip. Assumed to be the same individual, which appears to be milling around the nacelle.

Figure 7-7 shows a still from the video containing two fish on 2nd April 2023. The fish (*Pollachius* sp.) swim slowly across the camera's field of view from right to left. The turbine rotor was stationary and there were no signs of any tidal flow (the tidal state was decreasing ebb).

This observation was very similar to those in previous reporting periods, in which individual and groups of fish of genus Pollachius have been observed aggregating around turbine nacelles when tidal flow is absent or very limited.

Figure 7-7 Still from T6 camera from 02/04/2023 showing two fish observed swimming from right to left. There is no obvious tidal flow in the footage and the turbine rotor is stationary.

Figure 7-8 shows a still from the video on 5th June 2023 in which individual fish were seen three times in the 15-minute clip. All occurrences occurred within a 2-minute period, so are assumed to be the same individual, which appears to be milling around the nacelle. The turbine rotor was stationary and there were no signs of any tidal flow (the tidal state was decreasing flood, around high water slack).

Biofouling on the camera lens prevented identification of the fish to species level, but the behaviour and size of the fish indicate it may be *Pollachius* sp. which are commonly observed aggregating around turbine nacelles when tidal flow is absent or very limited.

Figure 7-8 Still from T5 camera from 5th June 2023 showing a single fish observed (circled in yellow). The object is only identifiable as a fish from observing the video in slowed speed. There is no obvious tidal flow in the footage and the turbine rotor is stationary.

In a 'blind test' of samples of footage from 2nd and 9th April 2023 that was independently analysed manually and automatically, none of the clips that the model identified to contain fish when the tide was flowing quickly were detected by the manual reviewer. However, in one clip on 9th April 2023 in which the tide was flowing, manual review did identify several individual fish passing quickly through the camera's field of view. This clip was not part of the subset subject to a 'blind test' with independent automatic analysis.

Figure 7-9 shows a still from this video on 9th April 2023 in which the tidal state at the time of the fish observations was maximum ebb. The fish observed are assumed to be different individuals transiting the array area with the tidal flow (south to north through Bluemull Sound). The low light levels and speed at which the fish pass through the camera field of view prevent identification to species level, but they appear to be a small species of whitefish. No collisions with turbine blades were observed.

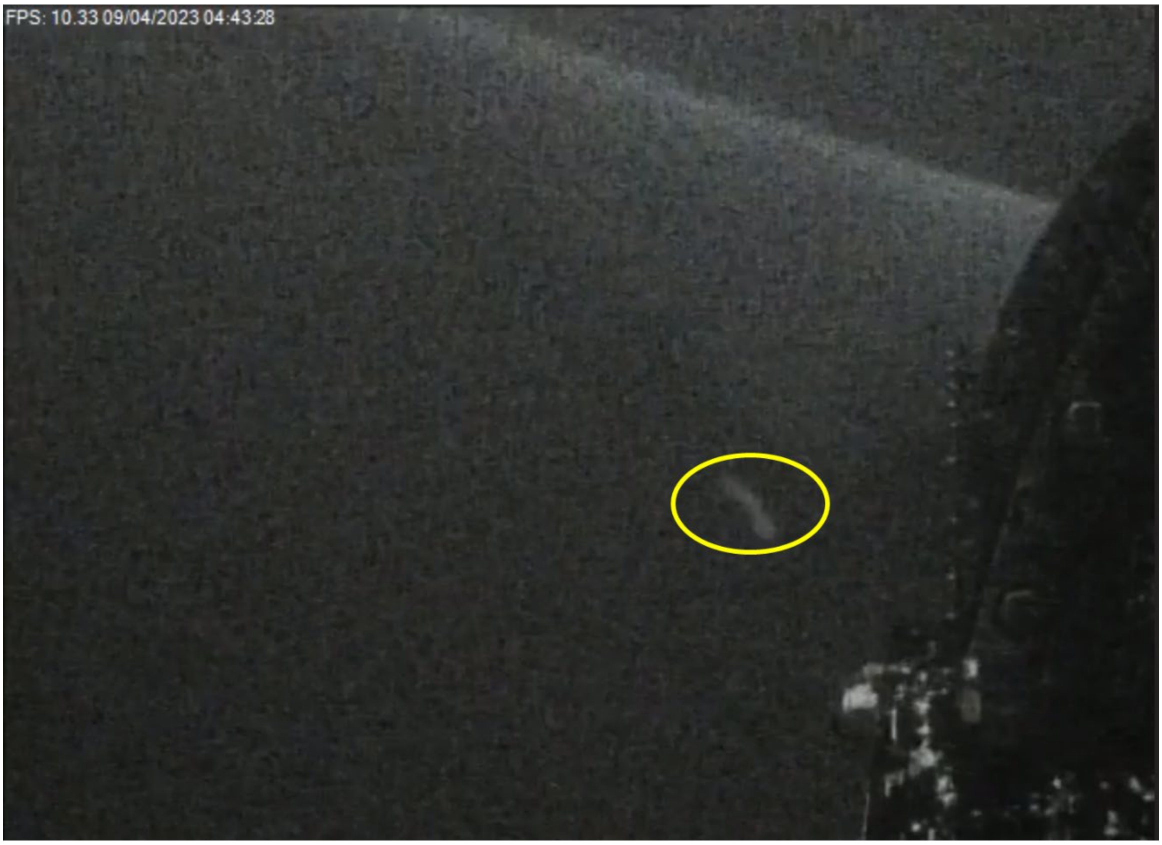

Figure 7-9 Still from T6 camera from 9 April 2023 showing a fish (circled in yellow) quickly passing the operating turbine on the maximum ebb tide. The object is only identifiable as a fish from observing the video at very slow speed.

8 Discussion

8.1 Collision risk

This report presents results from Nova's ongoing programme of environmental monitoring at the Shetland Tidal Array. The focus of monitoring activities, as set out in the PEMP (Nova Innovation, 2022a) is to gather evidence on the likely nature and consequences of any nearfield interactions between marine mobile species and turbines (i.e., collision risk). The data gathered from land-based surveys and turbine-mounted cameras between April 2022 and July 2023 continue to show that the likelihood of collisions between mobile species and operating turbines in the Shetland Tidal Array is extremely low. No collisions between fish, diving birds or marine mammals were observed in any of the video footage reviewed.

Bird and mammal presence and abundance at the array site in the land-based surveys between April 2022 to July 2023 continued to be very low. As previously reported, European shag (*Gulosus aristotelis*) and black guillemot (*Cepphus grylle*) were the only species that occurred either persistently year-round, or in high numbers. On this basis and given their known foraging behaviour (Furness et al., 2012), these continue to be the two species most likely to interact in the nearfield with turbines in the Shetland Tidal Array. Consistent with previous surveys, numbers of European shag were generally greater on the flood tide than the ebb, confirming the apparent preference for this species for foraging flood tides (Cole et al., 2019; Philpott, 2013). Also as with previous surveys, black guillemot numbers were generally greatest around high water slack. On the basis of the land-based survey data, all other bird and mammal species are likely to occur infrequently around turbines, so collision risk is very low.

Copping et al (2023, in press) have recently proposed a conceptual probabilistic framework for quantifying the likelihood of collision risk for marine animals and operational tidal energy turbines. This framework is illustrated in Figure 8-1 and is represented by a series of sequential events (steps) that must take place, each with an associated probability, for a marine animal to approach an operational turbine, be struck by a turbine blade and be harmed (i.e., suffer a critical injury or mortality).

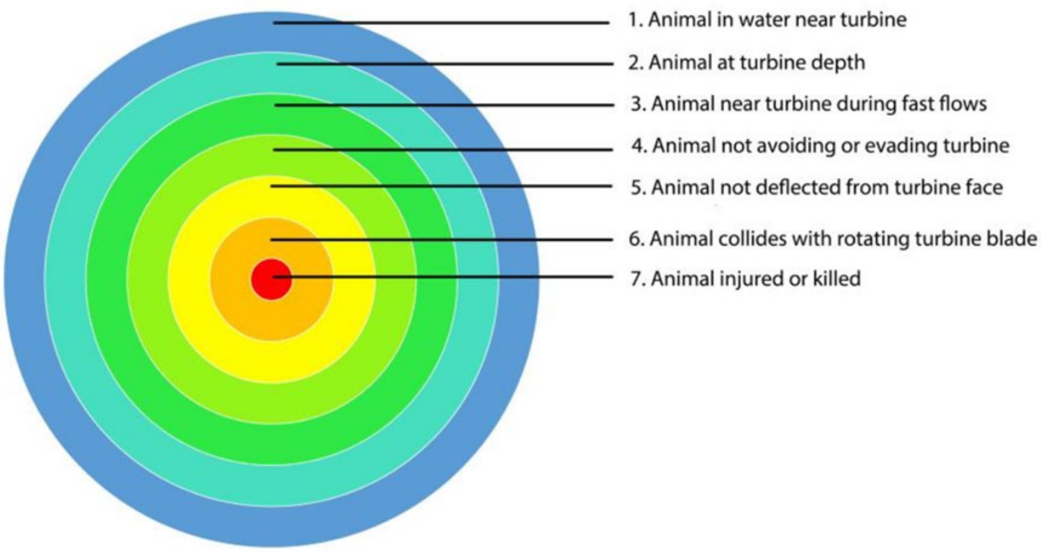

Figure 8-1 Conceptual probabilistic framework for quantifying the likelihood of collision risk for marine animals and operational tidal turbines. From Copping et al, 2023 (in press).

The Shetland Tidal Array environmental monitoring programme has shown that the likelihood of this co-location for fish, birds and mammals is extremely low (Nova Innovation, 2017; 2021a; 2021b; 2022b; 2022c). For collisions to take place, animals must be co-located in horizontal and vertical space with the rotor swept area of turbines at flow speeds greater than turbine 'cut in' speed (0.8 m/s).

An exception to this for the current reporting period is that in some clips small whitefish were seen to pass turbines on the ebb tide while they were operating. In some cases fish were observed passing through, or close to, the rotor swept area of turbines. This phenomenon has not previously been observed, probably because such occurrences of fish were not detected by manual reviewers (see Section 8.3 for further details).

No birds or mammals were observed in any of the video footage analysed from April 2022 to July 2023. Fish were observed in a total of 39 separate video clips (3 in manually reviewed footage and 36 in automated analysis). 23 of the 39 fish occurrences (59%) were at times of no or limited tidal flow, when the turbine rotor was stationary. These observations were similar to those in previous reporting periods (Nova Innovation, 2021b; 2022c) in which individual and groups of fish of genus Pollachius were observed around turbine nacelles when tidal flow was absent or limited.

In the remaining 16 video clips containing fish (41%), the tide was running and the turbine was operating. In many of these clips the fish were observed passing quickly through the camera's field of view with the tide. In these cases, the fish were assumed to be transiting the array area with the flow, rather than being part of the fish community observed aggregating around the turbines. The speed at which the fish passed through the camera's fields of view prevented identification to species level, but they appeared to be a small species of whitefish. While some of the fish in these clips where the tide was running were observed to pass through the rotor swept area, there were no collisions between fish and the turbine blades.

In previous reporting periods, while incidences of nearfield encounters between turbines and diving birds and marine mammals were exceptionally rare, occurrences of fish were relatively common. In particular, fish (*Pollachius sp.*) have been observed aggregating around the turbines as individuals or groups, moving vertically up and down in the water column according to tidal flow. This 'aggregating' behaviour was generally only observed in the footage from this reporting period in which biofouling (seaweed) growth was present on turbine nacelles.

These observations suggest that biofouling on turbine nacelles may influence the likelihood of fish occurring in proximity to the rotor swept area of blades. This in turn may influence the likelihood that birds and mammals might be co-located in horizontal and vertical space with the rotor swept area of turbines. However, it is important to note that for any nearfield animal presence around turbines to translate into collisions, animals must be co-located with the rotor swept area of turbines at flow speeds greater than 0.8 m/s. All evidence to date gathered at the Shetland Tidal Array indicates that the likelihood of this co-occurrence is extremely low, even when turbines are heavily biofouled and fish are abundant and persistent.

8.2 Ongoing monitoring

The monitoring programme for the Shetland Tidal Array is ongoing. In line with the approach set out in the Project Environmental Monitoring Plan (Nova Innovation, 2022a), the monitoring will be kept under review to ensure it remains necessary, proportionate and fit for purpose. This includes further refining methods to continue to focus on key outstanding uncertainties and knowledge gaps as the array is expanded and reconfigured. The monitoring must remain focused on the objectives set out in the PEMP.

In July 2023 Nova presented evidence to MD-LOT to support ending the land-based surveys in Bluemull Sound. This was on the basis that the surveys no longer play a key role in meeting the objectives of the monitoring, which should now focus effort on the subsea video monitoring which continues to provide valuable insights into the presence and behaviour of marine wildlife around the turbines. The case for ending the surveys is further supported by the results in this report, which demonstrate the effectiveness of using machine learning models to automate the detection of wildlife in proximity to Nova's tidal turbines, such that land-based data are no longer needed to inform a sampling strategy for subsea video analysis.

Nova will continue to utilise turbine-mounted subsea cameras for monitoring nearfield interactions between marine wildlife and the three remaining turbines in the Shetland Tidal Array. This has been shown to be a highly effective method for gathering data to better understand collision risk.

8.3 Automated analysis

In excess of 10 TB (estimated) of video footage has been gathered and stored from turbine-mounted cameras in the Shetland Tidal Array to date. To place the size of this dataset into context, The Crown Estate's Marine Data Exchange, an online portal for offshore industry survey and monitoring data, research and evidence contains a total of 260 TB (The Crown Estate, 2023).

The challenges associated with the large volumes of data generated by monitoring using subsea optical cameras are well documented (e.g. see Hasselman et al, 2020 for an overview). The development of tools to enable automated image analysis for monitoring wildlife interactions with marine renewable energy infrastructure could vastly reduce analysis time compared to manual expert processing (Wilding et al, 2017).

The work presented in this report demonstrates the effectiveness of using machine learning models to automate the detection of wildlife in proximity to Nova's tidal turbines. The CGG model delivered an accuracy of 94.1% in identifying videos within the 'target' ('wildlife') category and 'non-target' ('background' and 'detritus') category, which will increase as further data are analysed. This work represents "the most significant progress to date in the automation of analysis of subsea video from marine energy developments" (Andrea Copping, OES-Environmental pers. comm., following presentation of the work at the European Wave and Tidal Energy Conference 2023).

The model has been integrated into a novel, industry-ready workflow that can ingest around 200 videos or 20 hours of footage and produce an automated detection report of the results in approximately 30 minutes. When using a manual approach, it takes approximately 320 person-hours of analysis for 1600 hours of video. By comparison, this automated workflow could analyse 1600 hours of video in 40 hours resulting in an 87.5% reduction in interpretation time. In addition to streamlining data analysis, the use of the machine learning model to process the video data will reduce the overall size of the dataset requiring long term storage (currently all footage is retained).

The model provides an operationally ready solution to enable a greater proportion of Nova's video dataset to be analysed than is possible through manual review alone. Further, the potential for user error during manual processing should not be overlooked. Manual review is a laborious and repetitive task, which can lead to mental fatigue, which could induce errors. When flow speed in Bluemull Sound is significant, objects can pass through the field of view very quickly. It can be difficult for manual reviewers to determine the identity of moving objects without viewing individual freeze frames. Figure 8-2 provides examples of seaweed fragments drifting in the tidal flow, which when viewed in real time at fast flow speeds can be difficult to distinguish from mobile species.

Figure 8-2 Examples of seaweed fragments which when viewed by manual reviewers can be confused with mobile species, particularly during peak flow speeds in Bluemull Sound.

In some cases, automated analysis detected fish targets that were missed when the same footage was independently analysed manually. For example, the model was shown to be highly effective at detecting fish in video clips when the tide was running and the turbines were operating. The speed at which the fish passed through the camera's field of view mean that a manual reviewer may not have detected them.

This superior automatic fish detection under fast flowing tidal conditions was demonstrated in a 'blind test' of selected footage from 2nd and 9th April 2023 that was independently analysed automatically and manually. A number of fish targets were detected by the model that were missed by the manual reviewer.

Only one such instance of fish passing the turbines on a fast flowing ebb tide was detected in footage analysed manually, but this clip was not part of the subset subject to a 'blind test' with independent automatic analysis. This phenomenon of fish quickly passing the turbines on the ebb tide has not previously been observed in video footage, possibly because such occurrences of fish have not been detected by manual reviewers.

The model was also highly effective at detecting targets when there was significant biofouling on the turbines and fish were camouflaged and cryptic amongst macroalgal growth on the turbine nacelle. In some instances, particularly where macroalgal fronds were moving in the tides, a manual reviewer may have failed to detect some of these fish occurrences.

While in some cases, the model also identified such 'false targets', these could quickly and easily be identified manually. The use of initial automated processing appears to be more effective at target detection than a human reviewer and provides a more manageable subset of video clips for detailed manual scrutiny and analysis, for example to confirm targets, determine species identification and any notable behaviour.

The use of the machine learning model for future analysis will deliver significant efficiencies in analysis and reporting for the Shetland Tidal Array environmental monitoring programme. In future, Nova proposes that all video analysis is carried out in the first instance using the machine learning model. Samples of footage will still be manually reviewed for validation and quality assurance. In addition, any clips identified by the model to contain targets will be manually scrutinised.

Further enhancements in the analysis and interpretation of subsea video could be achieved through integration with Nova's cloud-based turbine analytics system. This integration could enable data on turbine performance and power outputs to be automatically assigned to the time- and date-stamped video footage to correlate any animal occurrences to tidal flow, turbine operational status and tip speed.

This interpretation is currently carried out manually, by assigning tidal state categories derived from Nova's hydrodynamic model for the site. However, discrepancies between modelled tidal data and observed flow can occur, most likely due to the effects of meteorological conditions such as storm surges not included in the hydrodynamic model. Through comparison of modelled and measured tidal data, Nova has identified that the timing of modelled and observed tides can differ by an hour or more, during which time the flow speed can change by up to 2 m/s.

8.4 Dissemination of learning and evidence transfer

Sharing learning and experience from environmental monitoring of the Shetland Tidal Array is important to Nova. It is critical to facilitate the development of best practice for cost-effective and reliable environmental monitoring of tidal energy projects, and for improving access to information on tidal energy to the general public. In addition to the formal monitoring reports provided to MD-LOT and Shetland Islands Council, information on environmental monitoring at the Shetland Tidal Array has been shared via the following mechanisms:

1. Key results and lessons learnt have been shared for inclusion in the upcoming 2024 "State of the Science" report dedicated to examining the environmental effects of marine renewable energy technologies.
2. Monitoring results and key learning have been shared and presented at UK and international workshops, conferences and seminars, including most recently at the 15th European Wave and Tidal Energy Conference.
3. Results have been shared in an accessible format for the general public in reports produced as part of the multi-partner £20million project Enabling Future Arrays in Tidal (EnFAIT) led by Nova (e.g., EnFAIT, 2022; Norwood et al, 2023).
4. Key findings and lessons learnt have been shared with a Tidal Task Force established by the Canadian Government to accelerate and de-risk consenting of tidal energy projects in the Bay of Fundy[8].
5. Results from the environmental monitoring of the Shetland Tidal Array will be used as part of the evidence base in the Environmental Impact Assessment and licence applications for Nova's other tidal energy projects.

Opportunities to further develop and expand the dissemination and transfer of knowledge and learning from the Shetland Tidal Array will continue to be explored and developed. This includes opportunities to combine evidence and knowledge from the Shetland Tidal Array with that gained from environmental monitoring of Nova's other tidal energy projects, such as the Nova Tidal Array in Petit Passage, Canada. This is anticipated to deliver further benefits by improving the evidence base on the environmental effects of tidal stream energy, de-risking and accelerating consenting, and reducing the cost of monitoring for the tidal sector.

[8] See https://www.dfo-mpo.gc.ca/pnw-ppe/ffhpp-ppph/publications/bay-fundy-tidal-interim-report-baie-fundy-marees-rapport-provisoire-eng.html for further details.

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Appendix A Metadata for manually analysed video footage

The table below provides details of all video footage analysed manually in this report. The table includes the date and time (in GMT) of each clip (as provided in filenames), one of six tidal states assigned using Nova's hydrodynamic model, details of whether the turbine rotor was observed rotating and details of any mobile species sightings in footage. The three instances in which a single fish was observed are highlighted in yellow. Times of high and low water (GMT) are also provided for each day for which footage were reviewed.

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
23/07/2022 (LW = 02:55; HW = 09:18)					
2022-07-23_05-36-37_t2-side	2	Increasing Flood	Yes	None	2
2022-07-23_05-51-42_t2-side	2	Increasing Flood	Yes	None	2
2022-07-23_06-06-38_t2-side	2	Increasing Flood	Yes	None	2
2022-07-23_06-21-44_t2-side	2	Increasing Flood	Yes	None	2
2022-07-23_06-36-40_t2-side	2	Increasing Flood	Yes	None	2
2022-07-23_06-51-36_t2-side	2	Increasing Flood	Yes	None	2
2022-07-23_07-06-41_t2-side	2	Maximum Flood	Yes	None	2
2022-07-23_07-21-37_t2-side	2	Maximum Flood	Yes	None	2
2022-07-23_07-36-42_t2-side	2	Maximum Flood	Yes	None	2
2022-07-23_07-51-38_t2-side	2	Maximum Flood	Yes	None	4
2022-07-23_08-06-43_t2-side	2	Maximum Flood	Yes	None	4
2022-07-23_08-21-39_t2-side	2	Maximum Flood	Yes	None	4
2022-07-23_08-36-44_t2-side	2	Maximum Flood	Yes	None	4
2022-07-23_08-51-40_t2-side	2	Maximum Flood	Yes	None	4
21/08/2022 (HW = 05:08; LW = 11:10; HW = 17:52)					
2022-08-21_10-59-43_t3-top	3	Maximum Ebb	Yes	None	2
2022-08-21_11-14-44_t3-top	3	Decreasing Ebb	Yes	None	2
2022-08-21_11-29-41_t3-top	3	Decreasing Ebb	Yes	None	2
2022-08-21_11-44-45_t3-top	3	Decreasing Ebb	Yes	None	2

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2022-08-21_11-59-45_t3-top	3	Decreasing Ebb	Yes	None	2
2022-08-21_12-14-41_t3-top	3	Decreasing Ebb	Yes	None	2
2022-08-21_12-29-42_t3-top	3	Decreasing Ebb	Yes	None	2
29/10/2022 (LW = 06:40; HW = 13:18)					
2022-10-29_16-30-03_t3-top	3	Maximum Ebb	Yes	None	2
22/12/2022 (HW = 08:50; LW = 14:40)					
1_2022-12-22_11-17-05	4	Increasing Ebb	Yes	None	4
1_2022-12-22_11-19-51	4	Increasing Ebb	Yes	None	4
1_2022-12-22_11-20-18	4	Increasing Ebb	Yes	None	4
1_2022-12-22_11-35-19	4	Increasing Ebb	Yes	None	4
1_2022-12-22_11-50-20	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-11-29	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-11-42	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-15-11	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-20-01	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-21-23	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-25-26	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-27-49	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-28-15	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-36-33	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-41-15	4	Increasing Ebb	Yes	None	4
1_2022-12-22_12-50-33	4	Maximum Ebb	Yes	None	4
1_2022-12-22_13-04-28	4	Maximum Ebb	Yes	None	4
1_2022-12-22_13-05-28	4	Maximum Ebb	Yes	None	4
1_2022-12-22_13-20-29	4	Maximum Ebb	Yes	None	4
1_2022-12-22_13-35-30	4	Maximum Ebb	Yes	None	4

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
1_2022-12-22_13-50-30	4	Maximum Ebb	Yes	None	4
1_2022-12-22_14-05-31	4	Maximum Ebb	Yes	None	4
1_2022-12-22_14-20-32	4	Maximum Ebb	Yes	None	4
1_2022-12-22_14-35-33	4	Maximum Ebb	Yes	None	4
1_2022-12-22_14-50-34	4	Decreasing Ebb	Yes	None	4
1_2022-12-22_15-05-35	4	Decreasing Ebb	Yes	None	4
1_2022-12-22_15-15-56	4	Decreasing Ebb	Yes	None	4
17/01/2023 (HW = 5:31; LW = 11:14)					
2_2023-01-17_11-27-44	6	Decreasing Ebb	Yes	None	1
3_2023-01-17_15-34-18	5	Maximum Flood	Yes	None	1
18/01/2023 (HW = 06:40; LW = 12:29)					
2_2023-01-18_10-21-19	6	Decreasing Flood	Yes	None	1
2_2023-01-18_15-36-10	6	Increasing Flood	Yes	None	1
15/02/2023 (LW = 10:38; HW = 17:32)					
2023-02-15_12-15-06_t1-top	1	Decreasing Ebb	No	None	4
2023-02-15_12-30-02_t1-top	1	Decreasing Ebb	No	None	4
2023-02-15_12-45-03_t1-top	1	Increasing Flood	No	None	4
2023-02-15_13-00-03_t1-top	1	Increasing Flood	No	None	4
2023-02-15_13-15-05_t1-top	1	Increasing Flood	No-Yes	None	4
2023-02-15_13-30-05_t1-top	1	Increasing Flood	Yes	None	4
2023-02-15_13-45-05_t1-top	1	Increasing Flood	Yes	None	4
2023-02-15_14-00-06_t1-top	1	Increasing Flood	Yes	None	4
2023-02-15_14-15-06_t1-top	1	Increasing Flood	Yes	None	4
2023-02-15_14-30-07_t1-top	1	Increasing Flood	Yes	None	4
2023-02-15_14-45-03_t1-top	1	Maximum Flood	Yes	None	4

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2023-02-15_15-00-03_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_15-15-04_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_15-30-05_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_15-45-05_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_16-00-06_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_16-15-06_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_16-30-02_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_16-45-03_t1-top	1	Maximum Flood	Yes	None	4
2023-02-15_17-00-03_t1-top	1	Maximum Flood	Yes-No	None	4
20/03/2023 (HW = 08:50; LW = 15:05)					
3_2023-03-20_11-26-00	5	Increasing Ebb	No	None	2
3_2023-03-20_11-32-40	5	Increasing Ebb	No	None	2
3_2023-03-20_11-37-34	5	Increasing Ebb	No	None	2
3_2023-03-20_11-37-47	5	Increasing Ebb	No	None	2
3_2023-03-20_16-35-42	5	Decreasing Ebb	Yes	None	2
3_2023-03-20_16-50-44	5	Decreasing Ebb	Yes	None	2
3_2023-03-20_17-05-45	5	Decreasing Ebb	Yes	None	2
3_2023-03-20_17-20-47	5	Increasing Flood	Yes	None	2
3_2023-03-20_17-35-48	5	Increasing Flood	Yes	None	2
3_2023-03-20_17-50-48	5	Increasing Flood	Yes	None	2
3_2023-03-20_18_05-50	5	Increasing Flood	Yes	None	2
3_2023-03-20_18-20-52	5	Increasing Flood	Yes	None	2
3_2023-03-20_18-35-54	5	Increasing Flood	Yes	None	2
02/04/2023 (LW = 01:36 ; HW = 07:55; LW = 14:06)					
2_2023-04-02_04-56-03	6	Increasing Flood	Yes	None	3
2_2023-04-02_05-11-04	6	Increasing Flood	Yes	None	3

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2_2023-04-02_05-26-05	6	Increasing Flood	Yes	None	3
2_2023-04-02_05-41-06	6	Maximum Flood	Yes	None	3
2_2023-04-02_05-56-07	6	Maximum Flood	Yes	None	3
2_2023-04-02_06-11-08	6	Maximum Flood	Yes	None	3
2_2023-04-02_06-26-09	6	Maximum Flood	Yes	None	3
2_2023-04-02_06-41-10	6	Maximum Flood	Yes	None	3
2_2023-04-02_06-56-12	6	Maximum Flood	Yes	None	3
2_2023-04-02_07-11-13	6	Maximum Flood	Yes	None	3
2_2023-04-02_07-26-15	6	Maximum Flood	Yes	None	3
2_2023-04-02_07-41-16	6	Maximum Flood	Yes	None	3
2_2023-04-02_14-11-12	6	Decreasing Ebb	Yes	None	3
2_2023-04-02_15-31-00	6	Decreasing Ebb	No	Two fish milling at nacelle height.	3
2_2023-04-02_16-25-52	6	Increasing Flood	Yes	None	3
2_2023-04-02_16-40-52	6	Increasing Flood	Yes	None	3
2_2023-04-02_16-55-54	6	Increasing Flood	Yes	None	3
2_2023-04-02_17-10-55	6	Increasing Flood	Yes	None	3
2_2023-04-02_17-25-56	6	Increasing Flood	Yes	None	3
2_2023-04-02_17-40-57	6	Increasing Flood	Yes	None	3
2_2023-04-02_17-55-57	6	Increasing Flood	Yes	None	3
2_2023-04-02_18-10-59	6	Maximum Flood	Yes	None	3
2_2023-04-02_18-26-00	6	Maximum Flood	Yes	None	3
2_2023-04-02_18-41-00	6	Maximum Flood	Yes	None	3
2_2023-04-02_18-56-01	6	Maximum Flood	Yes	None	3
2_2023-04-02_19-11-02	6	Maximum Flood	Yes	None	3
2_2023-04-02_19-19-24	6	Maximum Flood	Yes	None	3
2_2023-04-02_19-19-36	6	Maximum Flood	Yes	None	3

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
09/04/2023 (LW = 05:15; HW = 11:54; LW = 17:38)					
2_2023-04-09_03-02-30	6	Increasing Ebb	Yes	None	3
2_2023-04-09_03-39-39	6	Maximum Ebb	Yes	None	3
2_2023-04-09_04-39-59	6	Maximum Ebb	Yes	Five occurrences of single fish all passing turbine on tidal flow. **No collisions with moving rotor.**	3
3_2023-04-09_04-42-45	5	Maximum Ebb	Yes	None	3
2_2023-04-09_04-54-59	6	Maximum Ebb	Yes	None	3
3_2023-04-09_04-57-46	5	Maximum Ebb	Yes	None	3
2_2023-04-09_05-10-00	6	Maximum Ebb	Yes	None	3
3_2023-04-09_05-12-48	5	Maximum Ebb	Yes	None	3
2_2023-04-09_05-25-01	6	Decreasing Ebb	Yes	None	3
3_2023-04-09_05-27-49	5	Decreasing Ebb	Yes	None	3
2_2023-04-09_05-40-03	6	Decreasing Ebb	Yes	None	3
3_2023-04-09_05-42-50	5	Decreasing Ebb	Yes	None	3
3_2023-04-09_07-00-42	5	Decreasing Ebb	Yes	None	3
2_2023-04-09_07-00-48	6	Decreasing Ebb	Yes	None	3
3_2023-04-09_07-15-43	5	Decreasing Ebb	Yes	None	3
3_2023-04-09_14-20-46	5	Increasing Ebb	Yes	None	3
2_2023-04-09_14-20-57	6	Increasing Ebb	Yes	None	3
3_2023-04-09_14-35-47	5	Increasing Ebb	Yes	None	3
2_2023-04-09_14-35-58	6	Increasing Ebb	Yes	None	3
3_2023-04-09_14-50-50	5	Increasing Ebb	Yes	None	3
3_2023-04-09_15-05-50	5	Increasing Ebb	Yes	None	3
2_2023-04-09_15-12-41	6	Increasing Ebb	Yes	None	3
2_2023-04-09_15-20-05	6	Increasing Ebb	Yes	None	3

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
3_2023-04-09_15-20-51	5	Increasing Ebb	Yes	None	3
2_2023-04-09_15-35-06	6	Increasing Ebb	Yes	None	3
3_2023-04-09_15-35-52	5	Increasing Ebb	Yes	None	3
2_2023-04-09_15-50-08	6	Increasing Ebb	Yes	None	3
3_2023-04-09_15-50-53	5	Increasing Ebb	Yes	None	3
2_2023-04-09_16-05-09	6	Maximum Ebb	Yes	None	3
3_2023-04-09_16-05-54	5	Maximum Ebb	Yes	None	3
2_2023-04-09_16-20-10	6	Maximum Ebb	Yes	None	3
3_2023-04-09_16-20-55	5	Maximum Ebb	Yes	None	3
2_2023-04-09_16-35-11	6	Maximum Ebb	Yes	None	3
3_2023-04-09_16-35-56	5	Maximum Ebb	Yes	None	3
2_2023-04-09_16-50-12	6	Maximum Ebb	Yes	None	3
3_2023-04-09_16-50-57	5	Maximum Ebb	Yes	None	3
2_2023-04-09_17-05-12	6	Maximum Ebb	Yes	None	3
3_2023-04-09_17-05-57	5	Maximum Ebb	Yes	None	3
2_2023-04-09_17-20-14	6	Maximum Ebb	Yes	None	3
3_2023-04-09_17-20-59	5	Maximum Ebb	Yes	None	3
2_2023-04-09_17-35-15	6	Maximum Ebb	Yes	None	3
3_2023-04-09_17-36-00	5	Maximum Ebb	Yes	None	3
2_2023-04-09_17-50-15	6	Decreasing Ebb	Yes	None	3
3_2023-04-09_17-51-01	5	Decreasing Ebb	Yes	None	3
2_2023-04-09_18-05-17	6	Decreasing Ebb	Yes	None	3
3_2023-04-09_18-06-03	5	Decreasing Ebb	Yes	None	3
3_2023-04-09_18-50-08	5	Decreasing Ebb	Yes	None	3
3_2023-04-09_19-30-44	5	Decreasing Ebb	Yes	None	3
2_2023-04-09_19-30-52	6	Decreasing Ebb	Yes	None	3

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
05/06/2023 (HW = 10:42; LW = 16:22)					
2_2023-06-05_10-48-51	6	Decreasing Flood	No	Single fish milling around nacelle.	2
2_2023-06-05_10-49-17	6	Decreasing Flood	No	None	2
2_2023-06-05_10-49-31	6	Decreasing Flood	No	None	2
2_2023-06-05_10-49-43	6	Decreasing Flood	No	None	2
2_2023-06-05_10-50-04	6	Decreasing Flood	No	Single fish milling around nacelle.	2
2_2023-06-05_10-50-36	6	Decreasing Flood	No	Single fish milling around nacelle.	2
2_2023-06-05_10-51-14	6	Decreasing Flood	No	None	2
2_2023-06-05_10-51-31	6	Decreasing Flood	No	None	2
2_2023-06-05_10-52-16	6	Decreasing Flood	No	None	2
2_2023-06-05_10-54-12	6	Decreasing Flood	No	None	2
2_2023-06-05_10-55-22	6	Decreasing Flood	No	None	2
2_2023-06-05_10-56-44	6	Decreasing Flood	No	None	2
2_2023-06-05_10-56-54	6	Decreasing Flood	No	None	2
2_2023-06-05_10-57-25	6	Decreasing Flood	No	None	2
2_2023-06-05_10-58-27	6	Decreasing Flood	No	None	2
2_2023-06-05_10-59-16	6	Decreasing Flood	No	None	2
2_2023-06-05_11-00-27	6	Decreasing Flood	No	None	2
2_2023-06-05_11-01-44	6	Decreasing Flood	No	None	2
2_2023-06-05_11-02-22	6	Decreasing Flood	No	None	2
2_2023-06-05_11-03-38	6	Decreasing Flood	No	None	2
2_2023-06-05_11-03-51	6	Decreasing Flood	No	None	2
2_2023-06-05_11-04-45	6	Decreasing Flood	No	None	2
2_2023-06-05_11-07-05	6	Decreasing Flood	No	None	2
2_2023-06-05_11-08-31	6	Decreasing Flood	No	None	2
2_2023-06-05_11-09-49	6	Decreasing Flood	No	None	2

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2_2023-06-05_11-15-14	6	Decreasing Flood	No	None	2
2_2023-06-05_11-15-23	6	Decreasing Flood	No	None	2
2_2023-06-05_11-16-18	6	Decreasing Flood	No	None	2
2_2023-06-05_11-17-58	6	Decreasing Flood	No	None	2
2_2023-06-05_11-18-14	6	Decreasing Flood	No	None	2
2_2023-06-05_11-19-07	6	Decreasing Flood	No	None	2
2_2023-06-05_11-19-41	6	Decreasing Flood	No	None	2
2_2023-06-05_11-20-06	6	Decreasing Flood	No	None	2
2_2023-06-05_11-20-25	6	Decreasing Flood	No	None	2
2_2023-06-05_11-20-48	6	Decreasing Flood	No	None	2
2_2023-06-05_11-21-10	6	Decreasing Flood	No	None	2
2_2023-06-05_11-22-14	6	Decreasing Flood	No	None	2
2_2023-06-05_11-23-25	6	Decreasing Flood	No	None	2
2_2023-06-05_11-23-45	6	Decreasing Flood	No	None	2
2_2023-06-05_11-24-34	6	Decreasing Flood	No	None	2
2_2023-06-05_11-25-34	6	Decreasing Flood	No	None	2
2_2023-06-05_11-26-02	6	Decreasing Flood	No	None	2
2_2023-06-05_11-26-36	6	Decreasing Flood	No	None	2
2_2023-06-05_11-26-57	6	Decreasing Flood	No	None	2
2_2023-06-05_11-29-23	6	Decreasing Flood	No	None	2
2_2023-06-05_11-30-14	6	Decreasing Flood	No	None	2
2_2023-06-05_11-30-50	6	Decreasing Flood	No	None	2
2_2023-06-05_11-31-08	6	Decreasing Flood	No	None	2
2_2023-06-05_11-32-34	6	Decreasing Flood	No	None	2
2_2023-06-05_11-33-08	6	Decreasing Flood	No	None	2
2_2023-06-05_11-33-30	6	Decreasing Flood	No	None	2

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2_2023-06-05_11-33-49	6	Decreasing Flood	No	None	2
2_2023-06-05_11-34-05	6	Decreasing Flood	No	None	2
2_2023-06-05_11-34-29	6	Decreasing Flood	No	None	2
2_2023-06-05_11-35-44	6	Decreasing Flood	No	None	2
2_2023-06-05_11-36-03	6	Decreasing Flood	No	None	2
2_2023-06-05_11-36-52	6	Decreasing Flood	No	None	2
2_2023-06-05_11-37-05	6	Decreasing Flood	No	None	2
2_2023-06-05_11-38-03	6	Decreasing Flood	No	None	2
2_2023-06-05_11-38-32	6	Decreasing Flood	No	None	2
2_2023-06-05_11-38-49	6	Decreasing Flood	No	None	2
2_2023-06-05_11-39-02	6	Decreasing Flood	No	None	2
2_2023-06-05_11-40-05	6	Decreasing Flood	No	None	2
2_2023-06-05_11-40-37	6	Decreasing Flood	No	None	2
2_2023-06-05_11-41-03	6	Decreasing Flood	No	None	2
2_2023-06-05_11-41-15	6	Decreasing Flood	No	None	2
2_2023-06-05_11-56-45	6	Decreasing Flood	No	None	2
2_2023-06-05_12-11-46	6	Decreasing Flood	No	None	2
2_2023-06-05_12-26-47	6	Decreasing Flood	No	None	2
2_2023-06-05_12-41-49	6	Decreasing Flood	No	None	2
2_2023-06-05_12-56-49	6	Increasing Ebb	No	None	2
2_2023-06-05_13-11-50	6	Increasing Ebb	No	None	2
2_2023-06-05_13-26-51	6	Increasing Ebb	No	None	2
2_2023-06-05_13-41-52	6	Increasing Ebb	No	None	2
2_2023-06-05_13-26-51	6	Increasing Ebb	No	None	2
2_2023-06-05_13-56-53	6	Increasing Ebb	No	None	2
2_2023-06-05_14-11-53	6	Increasing Ebb	No	None	2

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2_2023-06-05_14-26-55	6	Increasing Ebb	No	None	2
2_2023-06-05_14-56-56	6	Increasing Ebb	No	None	2

Appendix B Metadata for automatically analysed video footage

The table below provides details of the subsets of video footage from April 2022 to July 2023 analysed using the machine learning model developed by CGG (see Section 4 of this report). The table includes the dates and time (in GMT) of all footage analysed by date and the corresponding total number and size of the files. Unlike footage that was analysed manually, metadata on the tidal state and operational status of turbines is not provided for this subset, since this is currently assigned to individual files by the manual reviewer.

Date	Time (GMT)	Turbine	Number of video clips (files)	Size of subset (GB)	Subset
20/05/2022	15:00-18:00	2	4	< 0.1	2
19/10/2022	07:00-14:00	3	21	0.1	2
25/10/2022	07:00-14:00	3	11	0.1	2
29/10/2022	07:00-15:00	3	22	0.1	2
20/05/2022	13:00-17:00	2	4	< 0.1	2
19/10/2022	07:20-13:40	3	21	0.1	2
25/10/2022	07:00-14:00	3	11	0.1	2
29/10/2022	08:40-16:20	3	23	0.1	2
31/10/2022	06:00-09:00	3	13	0.1	2
14/01/2023-18/01/2023	All footage	6	90	8.7	1
17/01/2023-18/01/2023	All footage	5	71	4.5	1
20/03/2023	12:00-15:00	5	6	0.3	2
02/04/2023	06:55-12:55	6	17	1.7	2
09/04/2023	06:15-13:30	5	28	2.3	2
09/04/2023	06:15-13:30	6	23	3.4	2

The table below provides details of all video clips analysed using the machine learning model in which confirmed targets (fish) were identified by manual scrutiny. The table includes the date and time (in GMT) of each clip (as provided in filenames), one of six tidal states assigned using Nova's hydrodynamic model, details of whether the turbine rotor was observed rotating and details of the mobile species sightings in footage. Times of high and low water (GMT) are also provided.

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
19/10/2022 (HW = 05:20; LW = 11:17; HW = 17:32)					
2022-10-19_08-49-53_t3-top	3	Increasing ebb	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-19_11-34-57_t3-top	3	Decreasing ebb	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-19_11-49-53_t3-top	3	Decreasing ebb	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-19_12-04-53_t3-top	3	Decreasing ebb	No	≈ 5 fish milling at hub height in water column and around macroalgal on nacelle.	2
2022-10-19_12-19-56_t3-top	3	Decreasing ebb	No	≈ 5 fish milling at hub height in water column and around macroalgal on nacelle.	2
2022-10-19_12-49-56_t3-top	3	Decreasing ebb	No	≈ 5 fish milling at hub height in water column and amongst macroalgal growth on nacelle.	2
2022-10-19_13-04-55_t3-top	3	Decreasing ebb	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-19_13-19-53_t3-top	3	Increasing flood	No	Single fish milling amongst macroalgal growth on nacelle.	2
29/10/2022 (LW = 05:40; HW = 12:18; LW = 18:06)					
2022-10-29_10-45-04_t3-top	3	Maximum flood	Yes	Two fish swimming just above nacelle facing into flow and amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**	2
2022-10-29_11-00-06_t3-top	3	Maximum flood	Yes	Single fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**	2
2022-10-29_11-15-02_t3-top	3	Maximum flood	Yes	Two fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**	2
2022-10-29_11-30-04_t3-top	3	Maximum flood	Yes	Two fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**	2
2022-10-29_11-45-07_t3-top	3	Maximum flood	Yes	≈ 5 fish swimming amongst macroalgal growth on nacelle. **No interactions or collisions with moving rotor.**	2
2022-10-29_12-15-05_t3-top	3	Maximum/ Decreasing flood	No	Single fish milling amongst macroalgal growth on nacelle.	2

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2022-10-29_12-30-03_t3-top	3	Decreasing flood	No	≈ 5 fish milling above turbine in water column.	2
2022-10-29_12-45-02_t3-top	3	Decreasing flood	No	≈ 5 fish milling above turbine in water column.	2
2022-10-29_13-15-05_t3-top	3	Decreasing flood	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-29_13-30-07_t3-top	3	Decreasing flood	No	Single fish milling amongst macroalgal growth on nacelle.	2
31/10/2022 (HW = 01:50; LW = 07:23; HW = 14:02)					
2022-10-31_07-35-08_t3-top	3	Decreasing ebb	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-31_07-50-07_t3-top	3	Decreasing ebb	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-31_08-05-09_t3-top	3	Decreasing ebb	No	Single fish milling amongst macroalgal growth on nacelle.	2
2022-10-31_08-35-11_t3-top	3	Decreasing ebb	No	Two fish above turbine in water column.	2
2022-10-31_08-50-07_t3-top	3	Decreasing ebb	No	≈ 5 fish milling above turbine in water column.	2
2022-10-31_09-05-08_t3-top	3	Decreasing ebb	No	> 5 fish milling above turbine in water column.	2
2022-10-31_09-20-08_t3-top	3	Decreasing ebb	No	> 5 fish milling above turbine in water column.	2
2022-10-31_09-35-11_t3-top	3	Increasing flood	No	Single fish milling amongst macroalgal growth on nacelle.	2
16/01/2023 (HW = 04:20; LW = 09:56; HW = 16:33)					
2_2023-01-16_09-19-10	6	Maximum ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	1
2_2023-01-16_09-49-12	6	Maximum ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	1
2_2023-01-16_10-19-14	6	Decreasing ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	1
2_2023-01-16_10-34-16	6	Decreasing ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	1
2_2023-01-16_10-50-42	6	Decreasing ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	1
2_2023-01-16_12-57-04	6	Increasing flood	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	1
18/01/2023 (HW = 06:40; LW = 12:29)					

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2_2023-01-18_10-06-19	6	Increasing ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	1
02/04/2023 (LW = 01:36; HW = 07:55; LW = 14:06)					
2_2023-04-02_13-11-05	6	Maximum ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	2
2_2023-04-02_13-56-10	6	Maximum ebb/ decreasing ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	2
09/04/2023 (LW = 05:15; HW = 11:54; LW = 17:38)					
2_2023-04-09_14-05-56	6	Increasing ebb	Yes	Single fish (small whitefish) passing turbine on tidal flow. **No collision with moving rotor.**	2

The table below provides details of all video clips analysed using the machine learning model in which targets were confirmed to be inanimate objects following detailed manual scrutiny. The table includes the date and time (in GMT) of each clip (as provided in filenames), one of six tidal states assigned using Nova's hydrodynamic model, details of whether the turbine rotor was observed rotating and details of the false target. Times of high and low water (GMT) are also provided.

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
16/01/2023 (HW = 04:20; LW = 09:56; HW = 16:33)					
2_2023-01-16_09-05-11	6	Maximum ebb	Yes	Inanimate object (marine litter) drifting past turbine on tide.	1
2_2023-01-16_09-34-11	6	Maximum ebb	Yes	Inanimate object (kelp fragment) drifting past turbine on tide.	1
2_2023-01-16_10-04-12	6	Decreasing ebb	Yes	Inanimate object (kelp fragment) drifting past turbine on tide.	1
2_2023-01-16_11-17-01	6	Decreasing ebb	Yes	Inanimate object (marine litter) drifting past turbine on tide.	1
2_2023-01-16_13-12-05	6	Increasing flood	Yes	Inanimate object (seaweed fragment) drifting past turbine on tide.	1

Filename	Turbine	Tidal state	Rotor moving?	Mobile species	Video subset
2_2023-01-16_13-34-35	6	Increasing flood	Yes	Inanimate object (seaweed fragment) drifting past turbine on tide.	1
2_2023-01-16_13-58-42	6	Increasing flood	Yes	Inanimate object (seaweed fragment) drifting past turbine on tide.	1
18/01/2023 (HW = 06:40; LW = 12:29)					
2_2023-01-18_14-51-06	6	Increasing flood	Yes	Inanimate object (marine litter) drifting past turbine on tide.	1