Shetland Tidal Array Monitoring Report: Subsea video monitoring

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Prepared for:	Marine Scotland Licencing Operations Team and Shetland Islands Council
Author:	Kate Smith
Approved by:	Gavin McPherson
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Revision history

Version	**Release date**	**Purpose/summary of amendments**
1.0	01/05/2020	To present results from analysis of subsea video footage from the Shetland Tidal Array, Bluemull Sound
2.0	31/01/2021	To address comments received from MS-LOT and Shetland Islands Council on Version 1.0.
3.0	27/05/2021	To address comments received from NatureScot and MS-LOT on Version 2.0.
4.0	17/09/2021	To address comments received from NatureScot Marine Scotland on Version 3.0. Confidentiality restrictions on report removed for publication.

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Contents

1 Non-technical summary

This report presents the results from analysis of subsea video footage gathered between October 2015 and March 2020 as part of Nova Innovation's programme of environmental monitoring for the Shetland Tidal Array, Bluemull Sound. The use of turbine-mounted subsea cameras to monitor nearfield interactions with mobile species (fish, birds and marine mammals) commenced in October 2015, when the first turbine in the array was deployed. A second turbine was added in August 2016 followed by a third in August 2017. Subsea cameras have been used continuously throughout this period to monitor the nearfield environment around each of the turbines in the array and is ongoing. Each of the three turbines deployed in the Shetland Tidal Array up to March 2020 has three integrated cameras, as follows:

1. One on top of the nacelle directed towards the blades.
2. One on the side of the nacelle directed towards the blades.
3. One on the underside of the nacelle directed towards the seabed.

Video recording is continuous, with footage retention triggered by a motion detector system. Retained footage includes a few seconds captured prior to the trigger event to facilitate identification of the cause. In addition to the recorded video, the camera motion detector system records a still image from the video, which provide a more rapid method of detecting potential "events" of interest. The total length of recordings varies from a few seconds up to 15 minutes. All triggered footage is retained and stored. To the end of March 2020, the total dataset of retained and stored video footage comprised nearly 1 million videos, representing almost 20,000 hours of footage. The storage footprint totalled more than 3 TB.

This report presents the results from examination and analysis of four subsets sampled from the full 20,000 hours dataset of retained footage spanning October 2015 to March 2020. Collectively, the subsets comprise 4,049 hours of video, representing over 20% of all retained video footage.

Subset 1 comprised footage captured only during daylight hours and when turbines were operating. Footage in this subset was also selected from within three months of camera maintenance, so that biofouling on cameras was minimal, ensuring images of high quality. This subset comprised 1,115 videos totalling 28 hours of footage.

Subset 2 comprised footage corresponding to the times of the highest surface counts of black guillemot (*Cepphus grylle*) and European shag (*Phalacrocorax aristotelis*) in the array area, derived from Nova's Bluemull Sound vantage point survey data[1]. This subset comprised 451 videos totalling 18 hours of footage.

Subset 3 comprised footage corresponding to times when sightings of marine mammals were recorded in the array area, derived from Nova's Bluemull Sound vantage point survey data. This subset comprised 336 videos totalling 3 hours of footage.

Subset 4 comprised all retained footage covering the entire period March 2016 to January 2017, with some additional footage gathered from a short deployment of Nova's first installed turbine in October 2015. This subset comprised 92,000 videos totalling 4000 hours of footage and 72,000 stills images derived from the motion detection capture system. This subset had previously been examined and summarised in report submitted to MS-LOT in 2017. Revisiting footage in this way, as the subsea video dataset grows, is a valuable way of optimising the value of the data to improve understanding for nearfield interactions between turbines and mobile species.

[1] Nova Innovation (2021). Shetland Tidal Array monitoring report: Vantage point surveys. EnFAIT-0347. pp111.

In the absence of automated data processing based on machine learning or algorithms to filter or categorise the subsea video, the four subsets were analysed manually. For each video clip, the source of the trigger was identified along with any occurrences of mobile marine species in the rest of the footage. The total number of occurrences of species of marine mammal, diving bird or fish in reviewed footage were quantified and species identified. Occupancy patterns and behaviour in relation to the operational state of the turbines was examined through the sampling strategy. All sampled footage was scrutinised for any evidence of nearfield encounters or contact between individual animals and turbine blades (collisions). The very low numbers of animals observed in the subsea video data meant that there were insufficient data to perform detailed analyses.

There were no instances of physical contact between marine species and the turbine blades in any of the four subsets of video footage and stills examined. All mobile species were identified with high confidence to species level. Saithe (*Pollachius virens*) was the most frequently observed and abundant species, with groups observed aggregating around the turbines, moving vertically up and down in the water column according to tidal flow. The only other mobile species in the sampled four subsets of footage were very infrequent observations of individual European shag (*Phalacrocorax aristotelis*), black guillemot (*Cepphus grylle*) and harbour seal (*Phoca vitulina*), with fewer than thirty occurrences of these species in total across the four subsets. These species were only observed at times when the turbines were not operating (i.e., blades were stationary). Jellyfish, such as Lion's mane, *Cyanea capillata*, were occasionally observed in video either actively swimming at slack tide or being carried passively past the turbines during the ebb and flood.

On the basis of fine-scale occupancy patterns observed in the mobile species in the footage examined comprising the four sampled subsets, a very low risk of encounters with operational turbines in the Shetland Tidal Array is indicated. Diving birds and marine mammals were only observed in the nearfield environment of turbines in subsea footage at times when they were not operating (i.e., blades were stationary). No diving birds or mammals were observed in any of the footage when turbines were operating. Similarly, fish observed in footage were seen to generally drop to the seabed as current speed increases. When fish were observed at times when turbines were operating (rotating), there was evidence of some nearfield evasion in individuals.

The monitoring and the results presented in this report provide insights into interactions between mobile species and Nova's turbines in the Shetland Tidal Array. This includes during periods when the turbines are rotating and generating, as well as periods of lower current speed when blades are stationary. The implications of the analysis presented in this report for refining understanding about collision risk for the Shetland Tidal Array are discussed. The contribution that the results make to the wider advancement of the knowledge base on the environmental effects of tidal energy and best practice in environmental assessment is also considered.

2 Introduction

Nova Innovation's Shetland Tidal Array in Bluemull Sound, Shetland has an associated programme of environmental monitoring, as set out in the Project Environmental Monitoring Plan[2]. The monitoring programme comprises two key components for gathering data to improve the evidence base on the likely nature and consequences of any nearfield interactions between marine mammals and diving birds with the operating turbines, as follows:

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

This report presents the results from analysis of subsea video footage from turbine-mounted cameras gathered between October 2015 and March 2020. It presents the results of examination and analysis of four subsets of footage sampled from the full dataset. The focus of the analysis of the subsea video data presented in this report is on refining understanding for the likelihood and consequences of any nearfield interactions between operational turbines in the Shetland Tidal Array and diving birds, marine mammals and fish.

The report is provided in support of discharge of conditions attached to the following licences for the Shetland Tidal Array:

1. Marine Licence 06642/20/0[3], issued by Marine Scotland Licensing Operations Team on behalf of the Scottish Ministers, under the Marine (Scotland) Act 2020, part 4 (condition 3.2.1.1)
2. Shetland Islands Council (SIC) Works Licence 2018/021/WL, issued under the Zetland County Council Act 1974 (condition 3)

This information is structured in the following sections in this document:

Section 1: Non-technical summary

Section 2: Introduction

Section 3: The Shetland Tidal Array

Section 4: Subsea video objectives and methods

Section 5: Subsea video sampling and analysis

Section 6: System performance

Section 7: Results

Section 8: Discussion

Section 9: Next steps

Annex A: Environmental Monitoring Report submitted to Marine Scotland in 2017

[2] Nova Innovation (2020). EnFAIT-0362 Version 0.4. Shetland Tidal Array Project Environmental Monitoring Plan.

[3] Note that this has subsequently been superseded by Marine Licence MS-00009110, issued as a variation to 06642/20/0 by Marine Scotland on 09/02/2021. Licence conditions remain unchanged.

3 The Shetland Tidal Array

3.1 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 3-1.

Figure 3-1 Location of the Shetland Tidal Array in Bluemull Sound, Shetland.

3.2 Project details

In June 2014 Nova installed and commissioned a 30 kW turbine in Bluemull Sound. The turbine was fully decommissioned in 2016. During the period of this study, the Shetland Tidal Array consisted of three Nova M100 turbines: T1 and T2 (deployed in 2015[4] and 2016) and T3 (deployed in 2017). In 2018, Nova was awarded licences from Marine Scotland and Shetland Islands Council to extend the array to six turbines. A fourth turbine (T4) was installed in October 2020, and two further turbines (T5 and T6) will be deployed in 2021. Analysis of video data from T4-6 will be included in subsequent monitoring reports.

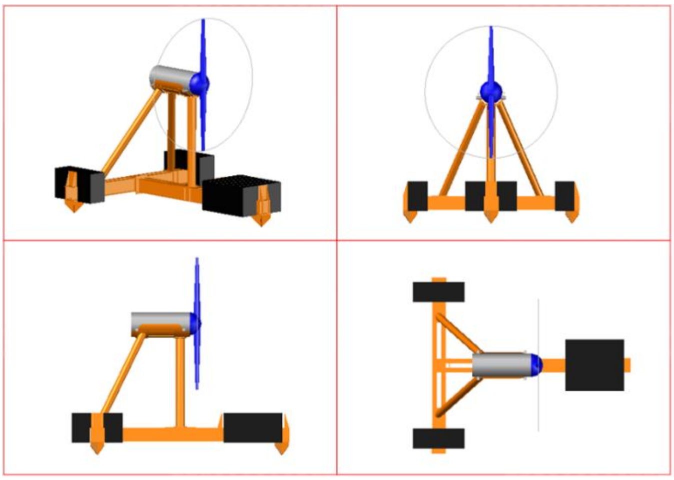

Figure 3-2 The Nova M100 turbine. *Source: Nova Innovation 2018*

The turbines within the Shetland Tidal Array are installed subsea at a depth of 30-40m. The turbines use gravity base foundations that require no piling or drilling. The Nova M100 turbine is a 2-bladed, horizontal axis device, as illustrated in Figure 3-2.

[4] T1 was initially deployed for a short period in October 2015, before being retrieved and redeployed in March 2016). T2 was deployed in August 2016. T3 was deployed in August 2017.

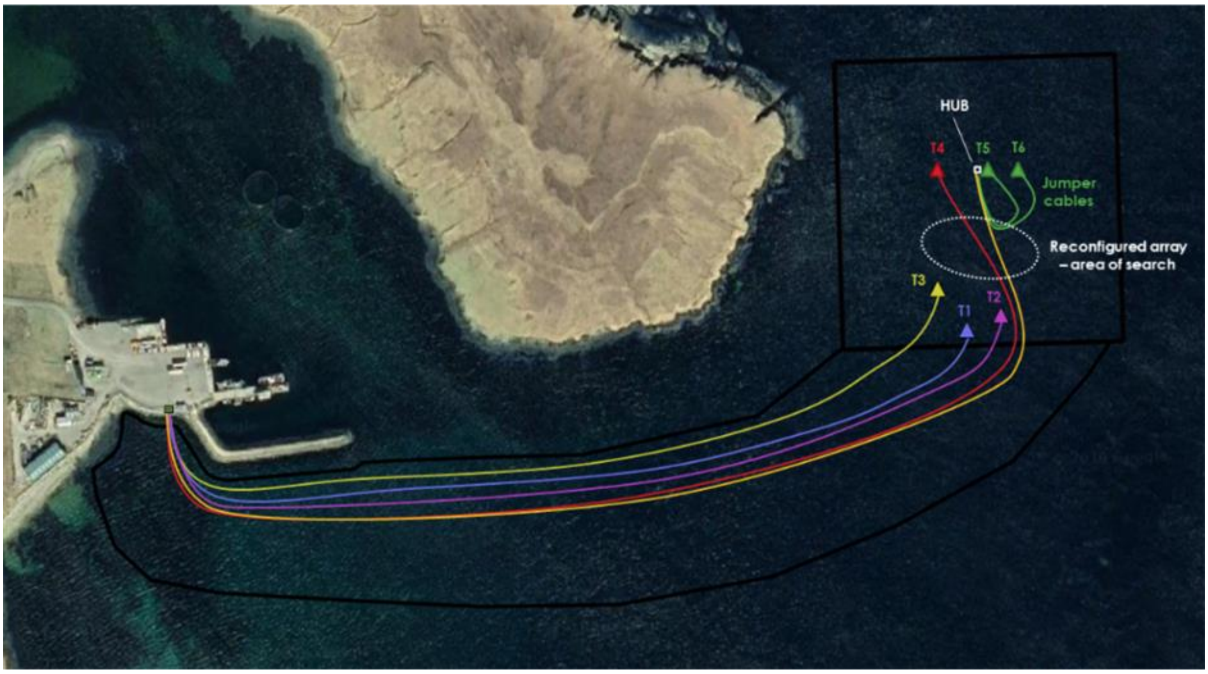

Figure 3-3 Shetland Tidal Array layout (satellite view). *Source: Nova Innovation 2020*

Figure 3-3 and Figure 3-4 show the layout of the existing three turbines and infrastructure in the Shetland Tidal Array, as well as the location of T4 (deployed August 2020) and the planned location of T5 and T6.

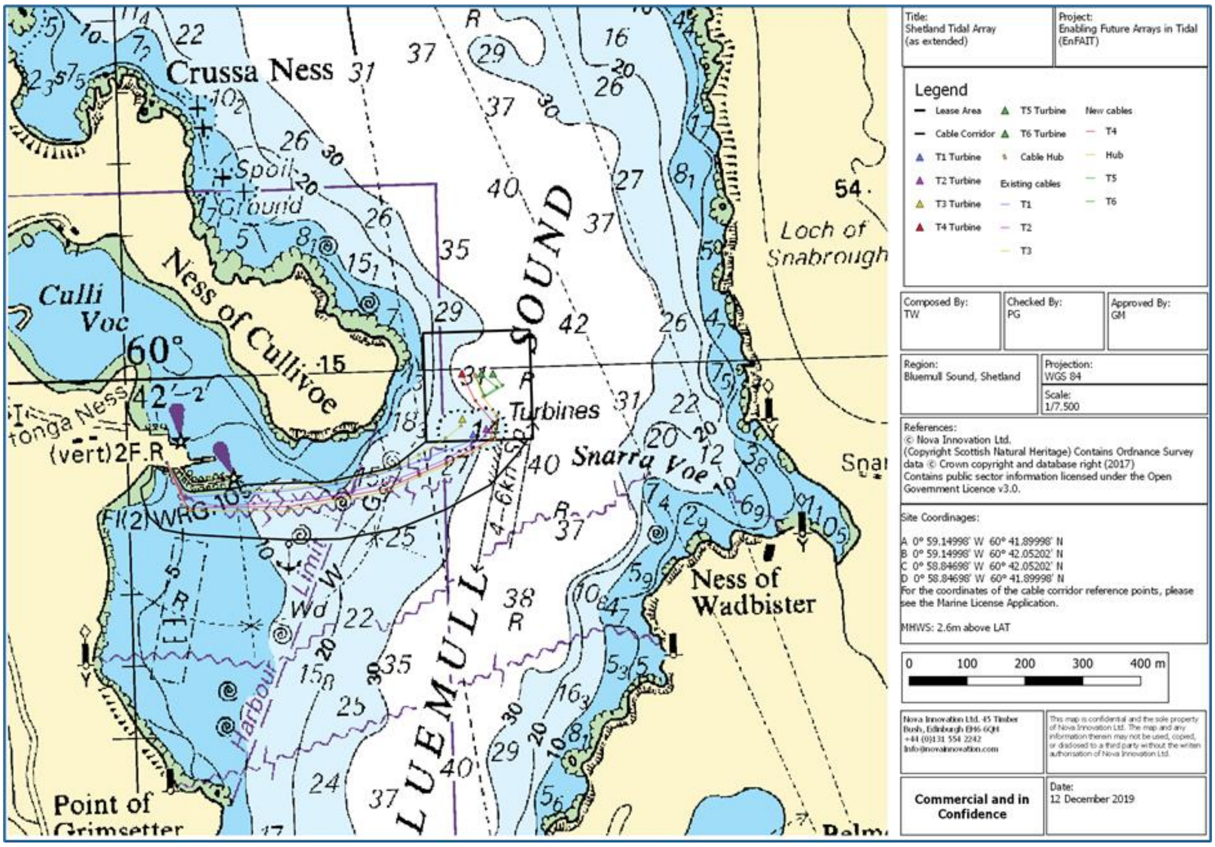

Figure 3-4 Shetland Tidal Array layout (Admiralty Chart). *Source: Nova Innovation 2020 © Crown Copyright*

4 Subsea video objectives and methods

4.1 Overview and objectives

Subsea video monitoring has been carried out throughout the operational phase of the Shetland Tidal Array (STA) as part of Nova Innovation's programme of environmental monitoring. Subsea video is used to monitor the presence and nearfield behaviour of mobile species (fish, diving birds and marine mammals) around the turbines. Subsea video monitoring commenced in October 2015, when the first turbine was deployed in Bluemull Sound. A second turbine was deployed in August 2016, followed by a third in August 2017. Subsea video footage has been recorded and stored throughout this period and is ongoing.

Nova's programme of subsea video monitoring of turbines in the Shetland Tidal Array has the following objectives, as set out in the Project Environmental Monitoring Plan (PEMP)[5]:

1. To gather information on the nature and frequency of nearfield interactions between marine mammals, diving birds and their prey and the turbines to improve understanding for actual (versus modelled) collision risk.
2. To gather information on avoidance and evasion behaviour of marine mammals and diving birds around the operating turbines to enable refinement of modelled collision risk for the Project.
3. To identify any individuals interacting with turbines to species level (where possible) to refine understanding for collision risk.
4. To gather information for co-analysis with vantage point data to better understand the relationship between surface and subsea wildlife observations and, ultimately, collision risk.
5. To meet the requirements of condition 3.2.1.1 of Marine Licence ML006642/20/0[6] issued by Marine Scotland.
6. To meet the requirements of conditions 3 and 11 of Works Licence 2019/021/WL issued by Shetland Islands Council.

4.2 Subsea cameras and configuration

Three cameras are attached to each of the first three deployed turbines (T1 to T3) in the Shetland Tidal Array, in the following configuration:

1. One attached to the side of the nacelle pointing towards the blades (TOP).
2. One attached to the top of the nacelle pointing towards the blades (SIDE).
3. One attached to the bottom of the nacelle pointing towards the seabed (DOWN).

The nine cameras utilized for T1, T2 and T3 have a horizontal field of view in water of 70^0, a sensitivity LUX rating of 0.001 and a resolution of 750 TV lines (TVL). They are colour submersible bullet charge-coupled device (CCD) cameras with a resolution of 412,000 pixels. Files are coded into MPEG and the capture rate is 16 Frames Per Second (FPS).

Figure 4-1 (over) provides an indicative illustration of the location and approximate field of view of the three turbine-mounted cameras.

[5] Nova Innovation (2020). EnFAIT-0362 Version 0.4. Shetland Tidal Array Project Environmental Monitoring Plan.

[6] Now Marine Licence MS-00009110 issued by MS-LOT on 09/02/2021.

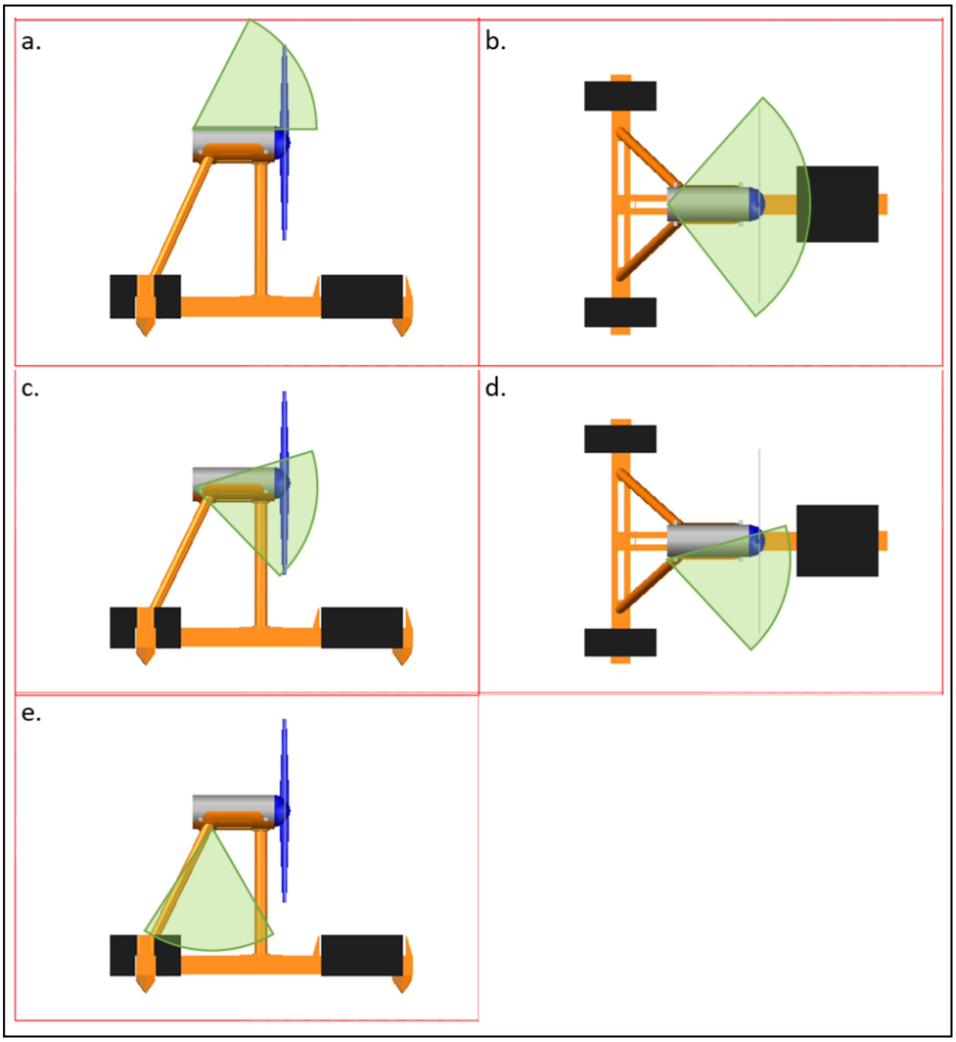

Figure 4-1 Configuration of turbine-mounted subsea cameras, showing (a & b) TOP camera looking towards the blades, (c & d) SIDE camera looking towards the blades and (e) DOWN camera looking towards the seabed. Figure is illustrative and not an accurate depiction of fields of view. *Copyright © Nova Innovation 2020.*

The camera triggering system is detailed in the next section, while further details on the spatial coverage provided by cameras is provided in Section 6 (System performance).

4.3 Video recording and retention

All nine turbine-mounted cameras record continuously. Footage is only retained and stored when “triggered” by the camera motion detector system. This trigger mechanism is based on a standard CCTV charged-coupled device (CCD) system. The motion detector system is based on differences of contrast of light and dark across successive frames, detected by focussing light from the camera lens onto the CCD image sensor. If the CCD sensor detects differences in light and dark, motion is assumed to have taken place and corresponding footage is retained. The sensitivity of the trigger and the depth of range depends on light conditions, water quality and the degree of biofouling, which are further discussed in Section 6 (System performance). The motion trigger system is also sensitive to movements of the blades when turbines are operational.

Retained footage captures video frames just prior to the trigger event to facilitate identification of the cause of the trigger and continues until motion (contrast in light and dark) is no longer detected, up to a maximum of 15 minutes. The trigger is designed to reset after 15 minutes of recording. If "motion" continues beyond 15 minutes, the trigger is reset, and the footage is retained as a separately stored MPEG video file with a unique code. The total length of retained recordings varies from a few seconds to 15 minutes, depending on any ongoing cause of triggering in the camera field of view. All triggered footage is retained and stored, allowing for further examination and analysis.

In addition to the recorded video, the camera motion detector system also records an image at the exact time it has been triggered. These stills provide a more rapid method of detecting potential "events" of interest.

In the absence of a reliable automated system for filtering out "false positives" (i.e., footage not triggered by mobile species), videos are reviewed manually to establish the cause of the trigger. If footage has been triggered by mobile species, it is further scrutinised to determine the identity and behaviour of any species recorded in the footage and the nature and outcome of any interactions with the turbine rotor.

The cameras operate 24 hours a day, though as discussed in Section 6 (System performance), are only effective during periods of sufficient light conditions. Triggering during hours of complete darkness is generally limited to that caused by bioluminescent organisms.

5 Subsea video sampling and analysis

5.1 Selection of samples for manual review

Between October 2015 and March 2020, nearly 1 million videos from the subsea cameras on turbines in the Shetland Tidal Array were retained and stored, representing almost 20,000 hours and over 3 TB of footage. In the absence of a reliable automated system for filtering out "false positives" (i.e., footage not triggered by mobile marine species), videos are currently reviewed manually to establish the cause of the trigger. For this report, a sampling strategy was developed to extract representative subsets from the full dataset, for detailed manual review and analysis. These subsets comprised video footage and the corresponding stills captured by the camera motion detector system. The sampling strategy was designed to ensure that samples of video and stills selected for manual review included footage which:

1. Was representative of the range of conditions in Bluemull Sound and covered all seasons and multiple years.
2. Covered periods across the entire tidal cycle and flow conditions at the site (0 to 3 m/s) and included representative samples of periods when turbines were operating (0.8 m/s to 3 m/s) and non-operating (< 0.8 m/s).
3. Included samples specifically corresponding to times when land-based bird and mammal survey data identified species at potential risk of collision with turbines in close proximity to the Shetland Tidal Array.

Based on this strategy, four samples or subsets of footage were extracted from the full 20,000-hour dataset for manual review. Collectively, the four subsets comprise 4,049 hours of video footage, representing approximately 20% of all footage retained between October 2015 and March 2020. Each subset is described below.

Subset 1: Footage recorded only when turbine blades were rotating

For Subset 1, the following filter criteria were used to extract a sample of footage from the full 20,000 hours dataset:

4. **Daylight hours:** The expected daylight hours for the turbine location were estimated through http://www.srrb.noaa.gov/highlights/sunrise/calcdetails.html. Only footage within these times were chosen as there is no artificial lighting on the camera system.
5. **Image quality:** The camera lenses are subject to the build-up of biofouling over time. Footage from > 3 months after camera maintenance was excluded, to ensure only good quality footage was selected and images could be clearly assessed and interpreted.
6. **Turbine blades moving:** Selection of footage was limited to periods when the turbines were generating to focus on the interactions between mobile species and the moving blades. Only footage with corresponding turbine blade movement (blade RPM > 0) was selected.
7. **TOP and SIDE cameras only:** Only footage from the top and side cameras facing the blade was selected to focus on interactions between mobile species and the blades.

Application of these filters to the full dataset generated 111,971 videos, varying from a few seconds to 15 minutes in length, comprising over 125 days (3000 hours) of footage. To generate Subset 1 for review and analysis, 1% of the 111,971 videos were randomly selected. This resulted in 1,115 videos totalling 28 hours of footage and 7,000 corresponding stills images derived from the motion detection capture system.

Subset 2: Footage corresponding to highest surface bird counts in array area

For Subset 2, footage was extracted from the full dataset corresponding to the times when the twenty highest surface counts of black guillemot (*Cepphus grylle*) and European shag (*Phalacrocorax aristotelis*) were recorded in proximity to the Shetland Tidal Array (where there was relevant stored footage for these times). This was derived from analysis of Nova's land-based bird and mammal surveys in Bluemull Sound[7], as shown in Table 5-1.

Table 5-1: Dates and times of the top twenty counts of black guillemot and European shag within the array area in land-based surveys of the Shetland Tidal Array. Dates and times from vantage point survey data were used to extract subsea video Subset 2.

Black guillemot		European shag	
Date	**Time (GMT)**	**Date**	**Time (GMT)**
11/10/2016	13:05	13/12/2016	12:10
25/10/2016	13:45	22/02/2017	11:15
15/04/2017	13:40	26/06/2017	19:40
26/06/2017	19:20	25/07/2017	16:30
29/07/2017	13:30	21/08/2017	17:20
17/09/2017	12:10	18/10/2017	10:00
16/10/2017	11:40	20/11/2017	11:40
21/11/2017	12:40	12/12/2017	11:20
12/12/2017	11:30	29/12/2017	12:45
29/12/2017	13:05	02/01/2018	10:50
02/01/2018	10:40	04/02/2018	12:30
20/01/2018	11:30	21/02/2018	13:30
04/02/2018	11:50	05/03/2018	13:45
21/02/2018	13:00	31/03/2018	15:20
03/03/2018	11:45	06/04/2018	12:20
22/05/2018	15:40	31/05/2018	14:25
31/05/2018	13:35	06/07/2018	14:25
16/06/2018	17:10	17/07/2018	12:20
06/07/2018	13:35	02/02/2019	11:40
16/07/2018	16:10	14/02/2019	10.10

Black guillemot and European shag are the two most commonly observed deep-diving bird species in the land-based surveys, accounting for over 90% of all birds recorded[5]. On this basis, they might be expected to be the most likely species to occur in the nearfield environment of turbines. Details

[7] Nova Innovation (2021). Shetland Tidal Array monitoring report: Vantage point surveys. EnFAIT-0347, pp111.

of the top twenty surface counts of black guillemot and European shag within the array area are shown in Table 5-1.

Only footage corresponding to times when turbines would have been operational (blade RPM > 0) were extracted in this subset, since the main objective was to ascertain whether birds observed on the surface translated through to an increased risk of encountering operational turbines (i.e., collision risk).

Only footage from the TOP and SIDE cameras facing the blades was selected, to focus on potential interactions with the moving blades. Subset 2 generated 451 videos totalling 18 hours of footage for review and analysis.

Subset 3: Footage corresponding to marine mammal sightings in array area

For Subset 3, video footage was extracted from the full dataset corresponding to the occasions when marine mammals were observed in proximity to the Shetland Tidal Array in Nova's land-based surveys in Bluemull Sound[8].

Nova started vantage point surveys in Bluemull Sound in 2010 before any turbines were deployed at the project site. Operational data from the Shetland Tidal Array was used to identify a subset from the total of thirty-four mammal sightings in the array area, which coincided with times when turbines were in situ, such that simultaneous subsea video footage might be available. Table 5-2 provides details of the resulting subset of nine marine mammal sightings that occurred within the array area in land-based surveys and details of turbines deployed at the time.

Table 5-2: Dates and times (GMT) of marine mammal sightings within the array area in vantage point surveys coinciding with times when turbines were in situ and details of turbines deployed.

Species	Date	Time of sighting	Turbines deployed at time of sighting
Harbour porpoise	23/07/2014	18:30	Nova30
Harbour porpoise	17/04/2015	13:50	Nova30
Harbour porpoise	03/07/2015	18:45	Nova30
Harbour seal	04/11/2015	12:00, 13:20, 14:00	Turbine 1 (M100)
Harbour porpoise	17/03/2016	12:20	Turbine 1 (M100)
Harbour porpoise	12/10/2016	15:00	Turbines 1 & 2 (M100)
Harbour porpoise	17/06/2018	13:20	Turbines 1 & 2 (M100)

Harbour seal and harbour porpoise were the only marine mammal species recorded within the array area in land-based surveys at times when turbines were installed. A total of nine sightings of these two species occurred at times when turbines were present, so this subset of sightings was used to extract any corresponding video data. A precautionary 60-minute buffer either side of the time of each of these nine sighting times was used to extract all available video. Subset 3 generated 336 videos totalling 3 hours of footage for review and analysis.

Subset 4: All footage retained between March 2016 and January 2017

[8] See: Nova Innovation (2021). Shetland Tidal Array monitoring report: Vantage point surveys. EnFAIT-0347, pp111 for full details.

Subset 4 comprised all retained footage from all three cameras (TOP, SIDE and DOWN) covering the entire period from March 2016 to January 2017, with some additional footage gathered from a short deployment of the first installed turbine in October 2015. This subset had previously been examined and summarised in report submitted to MS-LOT in 2017 and included at Annex A but was examined again to produce this report. Such revisiting of footage as the subsea video dataset grows is a necessary and valuable approach to maximising the value of the data and improve understanding for nearfield interactions between turbines and mobile species. Subset 4 generated over 92,000 videos totalling 4,000 hours of footage, and 72,000[9] stills corresponding stills images derived from the motion detection capture system.

5.2 Subset review and analysis

Video footage and, where available, stills derived from the motion detection capture system for the four sampled subsets were manually reviewed and examined in detail. The cause of the trigger for all videos was identified and any occurrences of mobile marine species (fish, diving birds, marine mammal, macro- and mega-plankton) recorded. The behaviour of any mobile species observed was also recorded.

Still images captured by the camera motion detector system at the time of triggering were reviewed as an aid to identifying occurrences of mobile marine species. Initially, this involved visually reviewing the images recorded at the moment the trigger fired. but all videos in the four sampled subsets were thoroughly examined, to ensure that occurrences of mobile species in footage subsequent to the original trigger were identified.

Much of the video footage was reviewed at x2 to x10 speed, which was found to accelerate the process without compromising the quality of the review. Footage affected by biofouling often required closer scrutiny to determine the cause of the trigger and any occurrences of mobile marine species, due to reduced contrast between objects in the water and the image background in these images. This was not an issue for Subset 1 since the selection criteria for this sample excluded footage affected by biofouling, to ensure images could be clearly assessed and interpreted. Full details of the information recorded during examination and analysis of the four subsets is provided below.

Subset 1: Footage recorded only when turbine blades were rotating

The review and analysis of Subset 1 was carried out by three individuals. The key objective in selecting this sample of video was to quantify and describe the presence of mobile species around the turbines at times when they were operational (corresponding to times of potential collision risk). The 1115 videos (28 hours of footage) in this sample were manually reviewed at speed x2 to speed x10 to identify any occurrences and key behaviours of mobile species. For all 1115 videos, the cause of the trigger was identified and one of the following six categories applied to each video:

1. **Fish > 5:** Greater than five fish at one time present in the video.
2. **Fish ≤ 5:** Up to five fish at one time present in the video.
3. **Marine mammals:** Presence of a pinniped or cetacean in the video.
4. **Diving birds:** Presence of a diving bird in the video.
5. **Other mobile species:** Presence of other mobile species in the video (e.g., macro- and mega-plankton).

[9] Stills images were not available for every triggered video in this sample.

6. **Nothing:** No mobile species present in the video.

Each category was applied to the entire video, even if the event occurred only during a portion of the footage. In the case of multiple categories of fish present in one video, the tag with the greater number of fish (i.e., Fish > 5) was applied. For footage assigned to categories 1 to 5, species identification was confirmed by qualified experts[10]. All mobile species were identified to species level. Video footage in each of the six categories was analysed to determine the length and proportion of the sample corresponding to each. Key behaviour of any individuals observed in footage was also recorded (descriptively).

Subset 2: Footage corresponding to highest surface bird counts in array area

The review and analysis of Subset 2 was carried out by three individuals. The 415 videos (18 hours of footage) in this sample were manually reviewed at speed x2 to speed x10 to identify the cause of the trigger and any occurrences of black guillemot, European shag or other bird and mammal species. The key objective in examining this subset was to ascertain whether higher numbers of black guillemot or European shag within the array area correlated with occurrences of these or other mobile species around the turbines.

This subset was also analysed to explore the relationship between surface density and mobile species occurrence around the turbines. This was carried out by calculating mean relative densities (birds per scan, per km^2) for this subset, derived from the land-based observations gathered during Nova's vantage point surveys.

Subset 3: Footage corresponding to marine mammal sightings in array area

The review and analysis of Subset 3 was carried out by two individuals. The 336 videos (3 hours of footage) in this sample were manually reviewed at speed x2 to speed x10 to identify the cause of the trigger and any occurrences of harbour seal, harbour porpoise or other mobile species. The key objective in examining this subset was to ascertain whether sightings of marine mammals within the array area correlated with occurrences of these or other mobile species around the turbines, including fish, which might be indicative of foraging behaviour around turbines.

Subset 4: All footage retained between March 2016 and January 2017

The review and analysis of footage comprising Subset 4 was carried out by one individual. This footage had previously been reviewed (by the same individual) to produce a report originally submitted to MS-LOT in June 2017, as appended at Annex A. The main purpose in re-examining this subset was to further explore the presence of mobile species and any key behaviours around turbines over an extended period of time (eleven months) in relation to factors such as season, time of day and turbine operational state.

The proportion of footage within this subset triggered by mobile species was calculated. Some inaccurate species identifications were also corrected during re-examination. These have been corrected in the version of the report provided at Annex A.

This subset was also analysed to explore the relationship between surface density and mobile species occurrence around the turbines. This was carried out by calculating mean relative densities (animals per scan, per km^2) for the species observed in subsea footage, derived from the land-

[10] Dr Kate Smith, Nova Innovation's Environmental Manager, with advice on fish identification provided by Dr Ross Gardiner, Marine Scotland Science.

based observations, where simultaneous vantage point survey data were available. In some cases, vantage point survey data were available corresponding to the time of sightings of birds and mammals in subsea footage, but had been excluded during the quality assurance process, due to poor visibility caused by changing weather conditions). In these cases, the numbers of individuals counted in surface scans corresponding to the time of species occurrence in subsea footage were used to explore this relationship.

A preliminary analysis of relationships between hydrodynamic conditions (tidal state and flow speed) and bird and mammal occurrences in this subset was carried out using modelled historic tidal data generated by Nova Innovation's hydrodynamic model for Bluemull Sound. The preliminary analyses identified discrepancies between modelled tidal data and observed flow, 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, during which time the flow speed can change by up to 2 m/s. Modelled tide is therefore not always a good indicator of actual flow speed at the turbines.

Accurate analyses to examine relationships between hydrodynamic conditions and mobile species presence around turbines would therefore need to utilise measured tidal data to have confidence in any conclusions. Nova plans to investigate ways of gathering the necessary tidal data to carry out these analyses as part of the ongoing environmental monitoring programme. In acknowledgement of the importance of this further analysis, it is identified as priority tasks in Section 9 (Next steps).

6 System performance

6.1 General performance and limitations

Nova's optical camera system operates 24 hours a day but is only effective for monitoring nearfield interactions between turbines and mobile species during periods of sufficient light conditions (further detail below). Triggering during hours of complete darkness is generally limited to that caused by bioluminescent organisms.

The (typically) exceptional year-round clarity of the seas around Shetland means optical cameras are an effective, robust, reliable and low-cost solution to monitoring nearfield interactions between turbines and mobile species at the Shetland Tidal Array. The simple design of Nova Innovation's camera system, incorporated into the design of the turbine themselves, minimizes technical faults and system failure, limiting the potential for large data gaps. More complex approaches to nearfield turbine monitoring at other locations, utilising active and passive acoustic instruments deployed or mounted remotely to turbines have encountered significant issues and technical failures with instruments and connectors[11]. The use of three cameras per turbine provided contingency in the approach to avoid technical problems while the technique was being refined to avoid interruptions in the dataset. The use of a camera on each turbine directed towards the seabed enabled Nova to gain useful insights into fine-scale occupancy patterns of mobile species around the turbines (in particular fish) in relation to tidal flow, which would not have been possible from rotor-facing cameras only.

The camera system used by Nova is highly sensitive and image quality is good from sunrise to sunset, enabling images to be scrutinised and the cause of triggers identified. Daylight hours are a key factor affecting the effectiveness of the approach, particularly during winter months when daylight hours average between 6 and 7 hours[12]. Daylight hours during summer average between 17 and 18 hours, so are less limiting.

Current speed does not affect the image quality, though weather conditions (e.g., winter storm events) and particularly intense plankton blooms can reduce image quality. Biofouling on cameras and turbines can affect triggering and image quality, so is addressed separately below.

6.2 Camera fields of view and coverage

The use of three cameras per turbine provided good spatial coverage of the nearfield environment around turbines, including valuable information on fine-scale occupancy patterns of mobile species (in particular fish) in relation to tidal flow.

Combined, the two cameras facing the turbine blades (TOP and SIDE) provide approximately 60-65% coverage of the rotor swept area. This has been estimated from combined images of the two fields of view using Computer-Aided Design (CAD), shown in Figure 6-1 (over).

[11] Hasselman DJ, Barclay DR, Cavagnaro RJ, Chandler C, Cotter E, Gillespie DM, Hastie GD, Horne JK, Joslin J, Long C, McGarry LP, Mueller RP, Sparling CE and Williamson BJ (2020). Environmental monitoring technologies and techniques for detecting interactions of marine animals with turbines. In Copping AE and Hemery LG (Eds.) (2020). 2020 State of the Science Report: Environmental effects of marine renewable energy development around the world. Report for Ocean Energy Systems (OES). (pp. 176-212). doi:10.2172/1633202.

[12] Based on NOAA solar calculator http://www.srrb.noaa.gov/highlights/sunrise/calcdetails.html

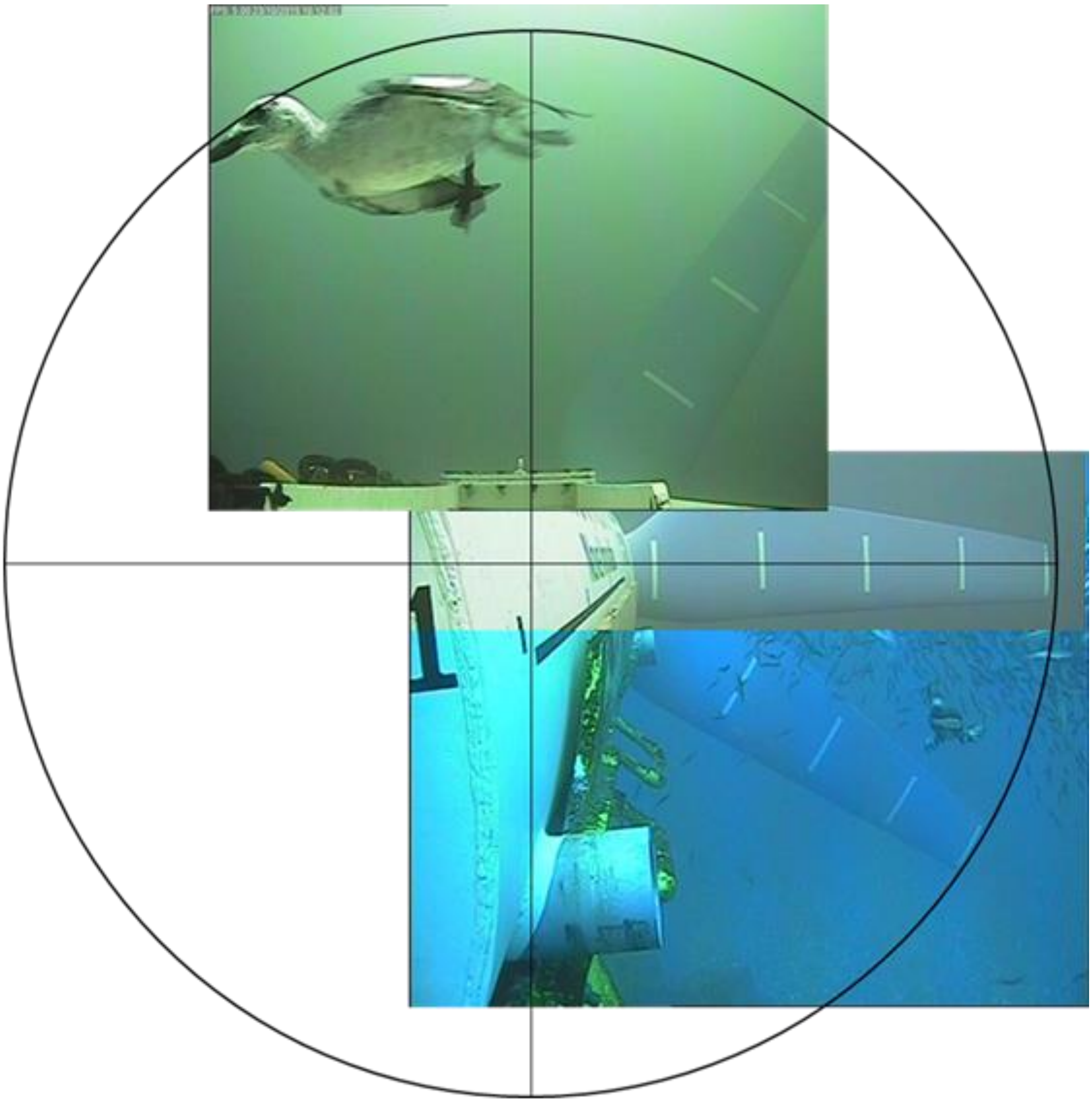

Figure 6-1 Field of view of TOP and SIDE cameras mounted on turbines in the Shetland Tidal Array. *Copyright © Nova Innovation 2020.*

6.3 Effects of biofouling

The quality of retained footage generally degrades over time due to biofouling of the camera lenses. Scanning images to identify occurrences and behaviour of mobile species becomes harder as biofouling progresses. While partial biofouling of cameras does not prevent triggering caused by mobile species in the field of view, the contrast between objects in the water and the image background becomes reduced, so it becomes harder to determine what a picture shows without close scrutiny. This can add significant time to processing and analysis of footage.

Figure 6-2 (over) illustrates how the image quality of the T2 TOP camera degraded over five months of deployment from August 2016 to January 2017. The rate of biofouling on cameras and turbines varies with time of year, but a recent study indicated that it is greatest over winter, and not during spring and summer plankton blooms as might be expected[13]. It generally takes several months before footage is rendered unusable and contingency through multiple cameras on multiple turbines reduces the overall effects of biofouling on continuity of the dataset.

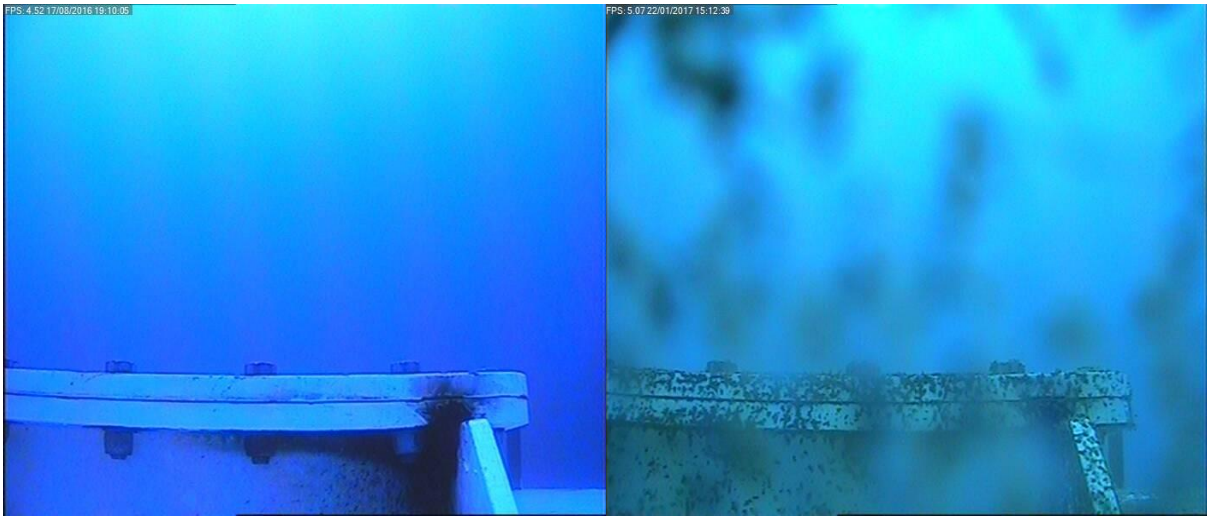

Figure 6-2 Images from T2 TOP camera illustrating biofouling on camera lens between August 2016 (left) and January 2017 (right). *Copyright © Nova Innovation 2017.*

In addition to affecting image quality, movements of biofouling on the camera and turbine can trigger retention of footage, resulting in thousands of additional "noise" events which currently require manual filtering. With tens of thousands of pictures to review for every month of deployment, the probability of correctly identifying occurrences of mobile species reduces as biofouling increases.

Camera lenses are routinely cleaned during turbine maintenance operations. Nova is also currently exploring a range of biofouling management options, including the use of UV lights, to reduce the need for such maintenance and extend the periods between lens clearing, building of the findings of a recent study[11].

6.4 Software performance and data storage

The trigger system is designed to reset after 15 minutes of recording. This means that no footage should last longer than 15 minutes, which typically limits video sizes to less than 20 MB. However, on occasion during early operations (pre-2017) the trigger failed to reset, and the file size grew up to several GB in size. These large files were corrupted, and useful video could not be captured from them, leading to gaps of a few days in the video record. The trigger mechanism has subsequently been improved, and a system put in place to frequently check the size of video files and restart the recording system if a file grows too large.

Up the end of March 2020, the total dataset of retained and stored video footage comprised nearly 1 million videos, representing almost 20,000 hours of footage. The storage footprint totalled just over 3 TB. This has significant data management and cost implications for Nova Innovation but does not affect monitoring quality or capability.

[13] Vezza R (2019). An anti-biofouling strategy for operators: A systems approach for the tidal energy industry. Thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Engineering, jointly awarded by the University of Edinburgh, the University of Exeter and the University of Strathclyde.

In early 2021 all of the retained video footage from Nova's deployed 100 KW turbines in Bluemull Sound was transferred to a cloud-based storage system with a user-friendly front-end portal. This Video Management System provides a remote access solution which enables scrutiny and analysis of footage that was previously only possible in Nova's main office in Edinburgh. The Video Management System enables remote users to extract samples of footage from the full dataset, filtering by date and time, as well as by specific turbines and camera positions (TOP, DOWN, SIDE). Users can add tags to video clips to aid filtering and build analysis efficiencies. Early trials used to inform analyses in this report indicate that this system provides an effective and efficient and user-friendly system that enables remote access to Nova's footage. Over time, as the proportion of tagged footage increases, this will facilitate more targeted processing and analyses.

7 Results

7.1 Quality of subsets

Manual review of all four subsets sampled from the full dataset and examined in this report found them to be of general good quality, with some exceptional images captured of nearfield interactions between turbines and mobile species. Water clarity and light levels during daylight hours, between sunrise and sunset, were sufficient to enable the manual reviewers to assign high confidence in the ability to identify the presence and key behaviours of mobile species. Images of all mobile species observed in the four subsets were of sufficient quality to identify targets to species level with high confidence. There were instances of biofouling on camera lenses in all four subsets which eventually affected image quality. For Subset 1, footage of low quality as a result of biofouling was excluded by the sampling protocol, which selected footage captured within three months of deployment.

7.2 Manual review and behavioural observations

Subset 1: Footage recorded only when turbine blades were rotating (RPM > 0)

Manual review and examination of the 1,115 videos in this subset and corresponding 7,000 stills derived from the motion detection capture system confirmed them to be of good quality, as would be expected based on the filtering criteria used to extract the subset (detailed in Section 5.1). Water clarity and light levels were sufficient to provide the reviewer with high confidence in determining whether they contained any occurrences of mobile species, to identify individuals to species level, and to observe and note any key behaviour.

The only mobile species observed in Subset 1 were fish of the genus *Pollachius*. Individuals have been identified as saithe (*Pollachius virens*) determined from the shape of the lateral line[14]. While systematic confirmation of each individual fish occurring in the footage has not been possible, spot checks indicate that all fish in this subset (as well as Subsets 2 and 3) are saithe. This subset contained no occurrences of diving birds, marine mammals or other mobile species. The causes of triggering of footage in this subset not resulting from fish (saithe) were either turbine motion, or marine growth (biofouling) movement on the turbine or camera lens.

Saithe observed in footage in this subset generally occurred in groups, with individuals mostly swimming independently to one another, rather than displaying typical schooling behaviour. Occasionally, individuals were observed foraging on marine growth on the turbine nacelle or sub-structure, particularly at low flow speeds. No fish were observed passing through the swept area of the blades. No physical contact between fish and the turbine blades was observed in any of the video footage or stills. Occasionally, an individual fish was seen to approach moving turbines blades, but to divert course as a blade approached, suggesting possible evasive behaviour. Sample size for this observed behaviour was very low (< 5 individuals), limiting the ability to draw any firm conclusions. Most fish observations in this subset corresponded to time of slower flow speeds when turbine rotational speed (RPM) was low.

[14] In the original version of Nova Innovation (2017) submitted to MS-LOT, these fish were identified as Atlantic pollack, *Pollachius pollachius*. Subsequent examination has determined that these species are more likely to be saithe. The species identification has been corrected in the revised version of the report appended at Annex A.

Subset 2: Footage corresponding to highest surface bird counts in array area

This subset comprised 451 videos totalling 18 hours of footage triggered at times corresponding to the times of the twenty highest counts of black guillemot (*Cepphus grylle*) and European shag (*Phalacrocorax aristotelis*) in Nova's land-based vantage point surveys. Table 7-1 details the date and time of the surface counts. For each species mean relative densities (birds per scan, per km^2) derived from the vantage point survey data are also provided, for the entire survey (All zones), the array area only (Zone 1) and for birds observed diving in the array area (Diving Zone 1).

Table 7-1 Date and time (GMT) of the twenty highest surface counts of a) black guillemot and b) European shag in vantage point surveys. Mean relative densities are provided, derived from vantage point survey data for the entire survey (All zones), the array area only (Zone 1) and for birds observed diving in the array area (Diving Z1).

a) Black guillemot (*Cepphus grylle*)

		Mean relative density (birds per scan/km^2)		
Date	**Time (GMT)**	**All zones**	**Zone 1**	**Diving Z1**
11/10/16	12:05	38.12	1.24	0.00
25/10/16	12:45	25.95	14.93	8.71
15/04/17	12:40	10.57	1.86	0.00
26/06/17	18:20	15.38	1.24	0.00
29/07/17	12:30	10.37	1.24	0.00
17/09/17	11:10	8.83	1.24	0.00
16/10/17	10:40	19.86	0.62	0.00
21/11/17	12:40	17.05	1.87	0.00
12/12/17	11:30	30.30	0.62	0.00
29/12/17	13:05	41.67	0.00	0.00
02/01/18	10:40	22.34	1.87	0.00
20/01/18	11:30	6.49	0.62	0.00
04/02/18	11:50	17.66	1.87	0.62
21/02/18	13:00	16.92	1.24	0.62
03/03/18	11:45	19.40	2.49	0.00
22/05/18	14:40	14.65	2.49	0.62
31/05/18	12:35	19.06	1.24	0.62
16/06/18	16:10	9.36	1.24	0.00
06/07/18	12:35	8.63	3.11	0.62
16/07/18	15:10	26.22	2.49	1.24

b) European shag (*Phalacrocorax aristotelis*)

		Mean relative density (birds/km^2)		
Date	**Time (GMT)**	**All zones**	**Zone 1**	**Diving Z1**
13/12/16	12:10	4.95	1.87	0.62
22/02/17	11:15	6.62	0.00	0.00
26/06/17	18:40	1.00	0.62	0.00
25/07/17	15:30	0.47	0.62	0.00
21/08/17	16:20	2.27	0.62	0.00
18/10/17	09:00	5.75	1.24	0.00
20/11/17	11:40	13.24	0.00	0.00
12/12/17	11:20	19.66	0.00	0.00
29/12/17	12:45	4.82	0.00	0.62
02/01/18	10:50	6.49	0.00	0.00
04/02/18	12:30	13.84	0.62	0.00
21/02/18	13:30	7.83	0.00	0.00
05/03/18	13:45	8.76	0.00	0.00
31/03/18	14:20	8.16	0.62	0.00
06/04/18	11:20	4.68	1.24	0.00
31/05/18	13:25	2.47	0.62	0.62
06/07/18	13:25	0.47	0.62	0.00
17/07/18	11:20	0.54	0.00	0.00
02/02/19	11:40	5.82	0.00	0.00
14/02/19	10.10	3.95	0.00	0.00

Manual review of the 415 videos in this subset confirmed them to be of good quality. Water clarity and light levels were sufficient to provide the reviewer with high confidence in determining whether they contained any occurrences of mobile species, to identify individuals to species level and to observe and note any key behaviour.

No black guillemot, European shag or other bird or marine mammal species were observed in any footage comprising this subset. The only species observed was saithe (*Pollachius virens*), although less than 20 of the 451 videos in this subset (< 5%) contained occurrences of the species. The causes of triggering of the remaining > 95% footage in this subset were either turbine motion, or marine growth (biofouling) movement on the turbine or camera lens. No physical contact between fish and the turbine blades was observed in any of the video footage or stills in this subset.

The absence of black guillemot, European shag or other bird or marine mammal species in footage in this subset aligns with the findings of Nova's land-based surveys, in which black guillemot was observed diving in the array area in fewer than 3% of all scans and European shag in 1% of all scans, indicating that diving bird numbers are low in the array area. These combined datasets indicate that the surface presence of species in the array area does not directly correlate with presence underwater around the turbines and therefore collision risk. Analysis of the vantage point data for these two species[15] indicated an elevated probability of birds diving in proximity to the turbines around low water slack and on increasing flood tides and lowest probability on maximum ebb tides, suggesting they may not be expected to be seen in subsea video when turbines are operating.

The only species observed in Subset 2 was saithe (*Pollachius virens*), although less than 20 of the 451 videos in this subset (< 5%) contained occurrences of the species. The causes of triggering of the remaining > 95% footage in this subset were either turbine motion, or marine growth (biofouling) movement on the turbine or camera lens. No physical contact between fish and the turbine blades was observed in any of the video footage or stills in this subset.

Subset 3: Footage corresponding to marine mammal sightings in array area

The dates and times of the nine occasions when marine mammals (harbour seal and harbour porpoise) were recorded in proximity to the Shetland Tidal Array in Nova's vantage point surveys at times when turbines were installed are shown in Table 7-2. The time windows used to search for available corresponding video, incorporating a precautionary 60-minute buffer either side of the sightings are shown, with details of any corresponding video available. Simultaneous video footage was available corresponding to four of the nine sightings, totalling 336 videos and 3 hours of footage. An overview of video content including any occurrences of mobile species in the corresponding video are detailed in the table.

Table 7-2 Details of available simultaneous subsea video and content corresponding to the nine sightings of harbour seal and harbour porpoise in the array area at times when turbines were installed.

Date	Time of sighting	Time of video searched	Video available?	Summary of content
Harbour seal				
04/11/2015	12:00	11:00-13:00	25 videos	Large shoal of saithe milling at hub height. At around 11:40 presence of predator indicated by sudden schooling behaviour (predator not seen on camera). One shag observed at 11:58, when the turbine rotor was stationary.
04/11/2015	13:20	12:20-14:20	1 video	No mobile species
04/11/2015	14:00	13:00-15:00	No	n/a
Harbour porpoise				
23/07/2014	18:30	17:30-19:30	No	n/a
17/04/2015	13:50	12:50-14:50	No	n/a
03/07/2015	18:45	17:45-19:45	No	n/a
17/03/2016	12:20	11:20-13:20	10 videos	Large shoal of saithe milling at hub height. At around 12:23 presence of predator indicated by sudden schooling behaviour (predator not seen on camera). One shag observed at 12:40 and fish observed schooling when the turbine rotor was stationary.

[15] Nova Innovation (2021). Shetland Tidal Array monitoring report: Vantage point surveys. EnFAIT-0347, pp111.

Date	Time of sighting	Time of video searched	Video available?	Summary of content
12/10/2016	15:00	14:00-16:00	300 videos	Some shoaling saithe. No predators or schooling behaviour observed.
17/06/2018	13:20	12:20-14:20	No	n/a

Manual review of the 336 videos in this subset confirmed them to be of generally good quality. There was some biofouling of cameras in some footage which affected image quality. Water clarity and light levels were generally sufficient to provide the reviewer with confidence in determining whether they contained any occurrences of mobile species, to identify individuals to species level and to observe and note any key behaviour.

No harbour seal, harbour porpoise or other marine mammal species were observed in footage comprising this subset. On two occasions, a European shag was observed in the videos at times corresponding closely to the marine mammal sighting in the vantage point surveys; on both occasions the turbine rotor was stationary. The only other mobile species observed in this subset was saithe (*Pollachius virens*), which were observed milling at hub height in much of the footage. On several occasions, the fish rapidly switched from general shoaling to schooling behaviour, indicating the possible presence of predators. All instances of this change in fish behaviour coincided with either the times of the marine mammal sightings in vantage point surveys, or the observed presence of shag in the video.

The turbine blades were stationary in all videos in which shag or fish were present at hub height. The causes of triggering of the remaining footage in this subset were either marine growth (biofouling) movement on the turbine or camera lens or turbine motion. No physical contact between mobile species and the turbine blades was observed in any of the video footage in this subset.

The absence of harbour seal and harbour porpoise in footage in this subset aligns with the findings of Nova's land-based surveys. Harbour seal was observed in the array area in just 0.3% of all surface scans and harbour porpoise in 0.7% of all scans, indicating that marine mammal presence in the array area is generally very low.

The presence of European shag and the observed schooling behaviour of fish in some of the video in this subset indicates overlap in habitat utilisation of the area around the turbines by predators. In all these instances, the blades of the turbines were stationary, indicating an elevated probability of foraging birds and mammals around turbines at slack tide and during conditions of low flow speed, coinciding with when fish are observed milling at hub height.

Subset 4: All footage retained between March 2016 and January 2017

This subset comprised all retained (i.e., triggered) footage for the period from March 2016 to January 2017, with some additional footage from a short deployment of the first installed turbine in October 2015. Subset 4 has been previously summarised in a report submitted to Marine Scotland in 2017, which is provided at Annex A and references to figures below relate to those provided in the Annex. Subset 4 was revisited for the purpose of producing the current report., including some re-examination of footage and associated data.

Manual review of the 4,000 hours of footage in this subset confirmed it to be of good quality. Water clarity and light levels were sufficient to provide the reviewer with high confidence in determining whether they contained any occurrences of mobile species, to identify individuals to species level and to observe and note any key behaviour. Some of the footage in this subset was of exceptional quality, capturing clear images of nearfield interactions between turbines and mobile species (for example, see Annex A, Figures 12 to 30).

The following mobile species were identified from footage in this subset:

- Saithe, *Pollachius virens*
- Black guillemot, *Cepphus grylle*
- European shag, *Phalacrocorax aristotelis*
- Harbour or common seal, *Phoca vitulina*

In addition, jellyfish such as Lion's mane jellyfish, *Cyanea capillata*, were occasionally recorded either actively swimming at slack tide or being carried passively past the turbines by the flowing tide (Figure 19, Annex A). On one occasion, a scorpion fish was observed attached to one of the camera lenses (Figure 36 & 37, Annex A)[16].

Black guillemot were the cause of triggering in 0.008% (less than 1 in ten thousand) of video in this subset, while European shag triggered 0.012% of video and harbour seal 0.014% (taking account of multiple consecutive triggers by the same individuals). The remaining > 99% of video in this subset was triggered by saithe, turbine motion or marine growth (biofouling) movement on the turbine or camera lens.

As with Subsets 1 to 3, saithe (*Pollachius virens*) were the most frequently observed mobile species in this subset. The species was generally observed in groups, with individuals sometimes swimming independently to one another (Figure 4, Annex A), and at other times displaying typical schooling behaviour (Figure 14, Annex A). On two occasions shoals of fish were seen being actively pursued by predators (European shag, Figure 15, Annex A).

This subset included footage from across the entire tidal cycle, covering the full range of tidal speeds at the site (0 to 3 m/s) and for almost a full annual cycle (11 months). This facilitated exploration of patterns in species occupancy with tidal state and season.

Table 7-3 details the date and time corresponding to all occurrences of black guillemot, European shag and harbour seal in Subset 4. Video time stamps were cross-referenced with vantage point survey metadata to check for simultaneous surface sightings. Where there were corresponding surveys, mean relative densities for each species have been provided in Table 7-3 for the entire survey (All zones) and the array area only (Zone 1). In some cases, vantage point data were available but had previously been excluded during the quality assurance (QA) process[17] for this dataset. Where this was the case, vantage point data were used to provide numbers of individuals in surface scans corresponding to the time of species occurrence in subsea footage to provide a relative indication of surface presence.

[16] Note in the original 2017 report, this individual was referred to as a "lumpfish".

[17] Quality assurance procedure for vantage point data detailed in: Nova Innovation (2021). Shetland Tidal Array monitoring report: Vantage point surveys. EnFAIT-0347, pp111.

Table 7-3 Date and time of observations of a) black guillemot (*Cepphus grylle*), b) European shag (*Phalacrocorax aristotelis*) and c) harbour seal (*Phoca vitulina*) in video Subset 4 (March 2016 to January 2017). Where corresponding vantage point survey data were available mean relative densities or counts are provided for the entire survey (All zones) and the array area (Zone 1).

a) Black guillemot (*Cepphus grylle*)

Date	Time (GMT)	Mean relative density (birds/km^2) / counts per 10-minute scan
23/10/2015	10:12	No corresponding vantage point data.
07/11/2015	07:53	No corresponding vantage point data.
25/10/2016	13:44	Vantage point data excluded during quality assurance process, due to poor visibility. Raw count data from scan at 13:45 GMT on 25/10/2016: 43 individuals (All zones); 0 individuals (Zone 1).
25/10/2016	13:49	Vantage point data excluded during quality assurance process, due to poor visibility. Raw count data from scan at 13:45 GMT on 25/10/2016: 43 individuals (All zones); 0 individuals (Zone 1).
18/11/2016	12:54	Vantage point data excluded during quality assurance process, due to poor visibility. Raw count data from scan at 13:00 GMT on18/11/2016: 1 individual (All zones); 0 individuals (Zone 1).
24/11/2016	13:50	No corresponding vantage point data.

b) European shag (*Phalacrocorax aristotelis*)

Date	Time (GMT)	Mean relative density/counts
04/11/2015	11:58	Vantage point data excluded during quality assurance process, due to poor visibility. Raw count data from scan at 12:00 GMT on 04/11/2015: 1 individual (All zones); 0 individuals (Zone 1).
24/11/2015	08:29	No corresponding vantage point data
02/03/2016	15:03	No corresponding vantage point data
18/03/2016	14:02	No corresponding vantage point data
01/04/2016	18:28	No corresponding vantage point data
03/08/2016	14:01	No corresponding vantage point data
25/08/2016	14:42	0.20 per scan/km^2 (All zones); 0.00 per scan/km^2 (Zone 1)
05/10/2016	06:41	No corresponding vantage point data
05/10/2016	06:42	No corresponding vantage point data**
05/10/2016	06:44	No corresponding vantage point data

** Two individual European shag were observed simultaneously in footage at 06:42 on 05/10/2016.

c) Harbour seal (*Phoca vitulina*)

Date	Time (GMT)	Mean relative density/counts
25/10/2015	14:52	No corresponding vantage point data

Date	Time (GMT)	Mean relative density/counts
04/11/2015	15:55	Vantage point survey carried out between 10:40 and 14:40 GMT on 04/11/2015. One harbour seal was recorded in Zone 1 between 12:00 and 13:00 GMT. Included here as highly likely to be the same individual.
08/11/2015	15:09	No corresponding vantage point data
08/11/2015	15:10	No corresponding vantage point data
09/11/2015	07:33	No corresponding vantage point data
09/11/2015	08:00	No corresponding vantage point data
09/11/2015	15:05	No corresponding vantage point data
09/11/2015	15:08	No corresponding vantage point data
12/11/2015	16:05	No corresponding vantage point data
17/11/2015	09:09	No corresponding vantage point data
02/03/2016	14:33	No corresponding vantage point data
09/09/2016	10:11	No corresponding vantage point data
14/10/2016	15:34	No corresponding vantage point data

Systematic analysis of relationships between season or time was not possible for sightings of birds and mammals in subsea video footage, since observations were insufficient to perform detailed analyses.

Fish (saithe) were observed frequently around the nacelle during times of slack tide or low flow speed at the start of the flood or ebb tide. As the tidal flow increased the fish were seen to drop to the seabed, presumably to shelter from the main flow. Examination of footage in this subset, as well as the subset corresponding to times when turbines were operating (Subset 1) indicates that some individual fish persist in the vicinity of the nacelle and blades at slow current speeds when turbines are rotating (> 0.8 m/s flow speed). This species was observed consistently throughout the year.

Other species were observed very infrequently in footage in this subset. There were ten observations of European shag, six of black guillemot and thirteen of harbour seal. Some observations were the same individuals recorded on different cameras or in sequential triggered footage, while one video included two simultaneous European shag. The total number of separate individuals observed were estimated to be ten European shag, five black guillemot and ten harbour seal, representing < 0.01%, < 0.005% and < 0.01% of footage, respectively (less than 1 in ten thousand). These species were only observed in subsea footage when turbines were not operating, such that blades were not rotating.

The causes of triggering of footage in this subset not resulting from the presence of the mobile species referred to above were either turbine motion, marine growth (biofouling) movement on the turbine or camera lens, or floating or snagged matter such as kelp.

7.3 Further analysis of video footage in Subset 1 (RPM > 0)

The 1,115 videos in Subset 1 were further analysed to determine the length and proportion of the sample corresponding to each of the following categories:

1. **Fish > 5:** Greater than five fish at one time present in the video.
2. **Fish ≤ 5:** Up to five fish at one time present in the video.
3. **Marine mammals:** Presence of a pinniped or cetacean in the video.
4. **Diving birds:** Presence of a diving bird in the video.
5. **Other mobile species:** Presence of other mobile species in the video (e.g., macro- and mega-plankton).
6. **Nothing:** No mobile species present in the video.

The results of this analysis are shown in Table 7-4.

Table 7-4 Categories of footage content with corresponding number of observations (where footage contains mobile species) and corresponding length of footage for Subset 1 (1,115 videos, 28 hours recorded when turbine RPM > 0). Final column is % of total footage in the entire subset for each category.

Category	Number of observations	Corresponding length of footage	% of footage
Fish > 5	*122*	*02h:00m:19s*	*7.1*
Fish ≤ 5	*253*	*06h:22m:58s*	*22.7*
Fish (Total)	375	08h:23m:17s	29.8
Marine mammals	0	00h:00m:00s	0.0
Diving birds	0	00h:00m:00s	0.0
Other mobile species	0	00h:00m:00s	0.0
Nothing	740	19h:44m:47s	70.2
Total	1115	**28h:08m:04s**	**100.0**

Saithe were observed in 30% of the footage in this subset. Of these, the vast majority of observations were of individuals or small groups of fish (≤ 5 individuals). Examination of the remaining 70% of the footage and the corresponding stills derived from the motion detector system confirmed the cause of the trigger to be the motion of the turbine blades, or the movement of biofouling growth. Table 7-5 breaks down the results in Table 7-4 by turbine and camera.

Table 7-5 Number of observations and corresponding length of footage for Subset 1 content categories, broken down by turbine and camera. Final column is % of total footage in the entire subset for each category.

Category	Number of observations	Corresponding length of footage	% of footage
Turbine 1 SIDE camera			
Fish > 5	8	00h:07m:56s	3.0
Fish ≤ 5	60	01h:21m:00s	30.9
Marine mammals	0	00h:00m:00s	0.0
Diving birds	0	00h:00m:00s	0.0
Other mobile species	0	00h:00m:00s	0.0
Nothing	206	02h:52m:56s	66.1
Total	274	04h:21m:52s	100.0
Turbine 1 TOP camera			
Fish > 5	0	00h:00m:00s	0.0
Fish ≤ 5	19	01h:22m:48s	28.2

Category	Number of observations	Corresponding length of footage	% of footage
Marine mammals	0	00h:00m:00s	0.0
Diving birds	0	00h:00m:00s	0.0
Other mobile species	0	00h:00m:00s	0.0
Nothing	83	03h:31m:02s	71.8
Total	102	04h:53m:50s	100.0
Turbine 2 SIDE camera			
Fish > 5	33	01h:05m:58s	11.8
Fish ≤ 5	100	01h:50m:45s	19.9
Marine mammals	0	00h:00m:00s	0.0
Diving birds	0	00h:00m:00s	0.0
Other mobile species	0	00h:00m:00s	0.0
Nothing	226	06h:20m:42s	68.3
Total	359	09h:17m:25s	100.0
Turbine 2 TOP camera			
Fish > 5	2	00h:00m:28s	0.1
Fish ≤ 5	9	01h:11m:58s	20.3
Marine mammals	0	00h:00m:00s	0.0
Diving birds	0	00h:00m:00s	0.0
Other mobile species	0	00h:00m:00s	0.0
Nothing	100	04h:42m:41s	79.6
Total	111	05h:55m:07s	100.0

Category	Number of observations	Corresponding length of footage	% of footage
Turbine 3 SIDE camera			
Fish > 5	68	00h:28m:05s	53.9
Fish ≤ 5	46	00h:10m:23s	19.9
Marine mammals	0	00h:00m:00s	0.0
Diving birds	0	00h:00m:00s	0.0
Other mobile species	0	00h:00m:00s	0.0
Nothing	59	00h:13m:40s	26.2
Total	173	00h:52m:08s	100.0
Turbine 3 TOP camera			
Fish > 5	11	00h:17m:49s	10.6
Fish ≤ 5	19	00h:26m:01s	15.5
Marine mammals	0	00h:00m:00s	0.0
Diving birds	0	00h:00m:00s	0.0
Other mobile species	0	00h:00m:00s	0.0
Nothing	66	02h:03m:44s	73.8

Category	Number of observations	Corresponding length of footage	% of footage
Total	96	02h:47m:34s	100.0

There is variation between the number of videos/observations and the corresponding times due to the large variation in lengths of the videos analysed. For instance, there were 173 video samples from Turbine 3 SIDE camera totalling 00h:52m, while Turbine 3 TOP camera only had 96 videos but these totalled 02h:47m in length.

8 Discussion

This report presents the results from examination of over 20% of the subsea video footage gathered between October 2015 and March 2020 as part of Nova Innovation's programme of environmental monitoring for the Shetland Tidal Array, Bluemull Sound.

The use of turbine-mounted subsea cameras to monitor nearfield interactions with mobile species (fish, diving birds and marine mammals) commenced in October 2015, when the first turbine in the array was deployed. A second turbine was added in August 2016 followed by a third in August 2017. Subsea cameras have been used continuously throughout this period to monitor the nearfield environment around each of the turbines in the array and is ongoing. The footage analysed in this report includes 4,049 hours sampled from the total 20,000 hours retained and stored up to March 2020. The full dataset comprises nearly 1 million videos, with a storage footprint of more than 3 TB.

This report demonstrates that subsea video is a highly effective approach for gathering information on the behaviour and nearfield interactions of mobile species around turbines in the Shetland Tidal Array during daylight hours. Nova has gathered a high quality, continuous dataset throughout the operation of the Shetland Tidal Array. This is predominantly due to the water clarity at the site and the relative simplicity of the approach. The approach has enabled Nova to avoid some of the technical issues and failures associated with more complex monitoring approaches[18]. The use of three cameras per turbine provided contingency in the event of equipment failure, which was particularly useful while the technique was being refined during initial data acquisition in the early stages of the project. The use of a camera on each turbine directed towards the seabed has enabled Nova to gain valuable insights into fine-scale occupancy patterns of mobile species around the turbines (in particular fish) in relation to hydrodynamic conditions (tidal state and flow speed).

In the 4,049 hours of footage examined in this report, sampled from the full 20,000-hour dataset, no physical contact was observed between mobile species (fish, birds or mammals) and the turbine blades. All mobile species in footage were identified with high confidence to species level. Saithe (*Pollachius virens*) was the most frequently observed and abundant species, with groups observed aggregating around the turbines, moving vertically up and down in the water column according to tidal flow. This aligns with similar observation of the species aggregating around shipwrecks and other artificial structures[19]. The only other mobile species in the examined footage were infrequent observations of individual European shag (*Phalacrocorax aristotelis*), black guillemot (*Cepphus grylle*) and harbour seal (*Phoca vitulina*), with fewer than thirty occurrences of these species in total across the four subsets examined. These species were only observed at times when the turbines were not operating (i.e., blades were stationary). Jellyfish, such as Lion's mane, *Cyanea capillata*, were occasionally observed in video either actively swimming at slack tide or being carried passively past the turbines during the ebb and flood.

The results presented in this report indicate a very low risk of encounters between operational turbines in the Shetland Tidal Array and the mobile species observed in the footage examined. Diving birds (black guillemot and European shag) and marine mammals (harbour seal) were very rarely observed in subsea video footage. In the footage in which they were observed, the turbine blades were stationary. Fish (saithe) were mostly seen in the vicinity of the nacelle and blades

[18] E.g., Tidal Energy Limited and Simec Atlantis experienced connector failures in the power take off system for remote acoustic monitoring systems for their Delta Stream and MeyGen projects respectively, impacting monitoring and operations.

[19] E.g., https://www.marlin.ac.uk/species/detail/9

around the slack tide and the start of the flood and ebb. As flow speeds increased, fish were generally seen to sink down towards the seabed, presumably to shelter from the main tidal flow. Some individuals were seen to persist in the vicinity of the nacelle and blades once the turbines started rotating (> 0.8 m/s flow speed). Most fish observations in footage when turbines were operating corresponded to time of slower flow speed, with no individuals observed around the blades when turbines were operating at full capacity. Fish that were present at times when turbine blades were rotating were generally observed to be swimming independently to one another, rather than displaying schooling behaviour. Occasionally, individuals were observed foraging on the growth on turbine nacelle or sub-structure. No fish were observed passing through the swept area of the blades. Occasionally, an individual was seen to approach the moving blades but to divert its course when a blade approached, indicating some evasive behaviour.

In footage coinciding with slack tide and the start of the flood and ebb, saithe were sometimes observed displaying shoaling behaviour around the turbine nacelle and substructure. On two occasions, individual European shag were observed in pursuit of schools of fish in footage coinciding with slack tide.

The presence of shag in footage and the observed schooling behaviour of fish typical of predator evasion in some of the video coinciding with times of surface sightings of marine mammals, indicates possible overlap in habitat utilisation of the area around the turbines by predators on occasions when large shoals of fish are present. In all these instances, the blades of the turbines were stationary, indicating an elevated probability of foraging birds and mammals around turbines at slack tide and during conditions of low flow speed, coinciding with when fish are observed milling at hub height.

The data and results presented in this report provide an insight into interactions between mobile species and turbines within the Shetland Tidal Array, as summarised below:

1. Saithe, *Pollachius virens* was the only frequently observed and abundant species in the footage examined. The species was commonly seen aggregating around the turbine structures in small to large groups. This behaviour is typical of the species, which is known to aggregate around shipwrecks and other artificial subsea structures.

2. Saithe were generally seen in proximity to the nacelle and blades around the slack tide when the turbine is stationary and the start of the flood and ebb, dropping to the seabed at higher tidal flows. Any observations of saithe in proximity to the nacelle during periods when blades were rotating corresponded to times of slower flow speeds, when turbines were not operating at full capacity.

3. Saithe that were present at times when turbine blades were rotating (slowly) were never observed to pass through the swept area of the blades.

4. Some apparent evasive behaviour was observed in saithe. Individuals were seen to approach the moving blades but divert course as a blade approached. This apparent behavioural response was seen in fewer than five individuals.

5. Other mobile species were observed infrequently in footage, with ten occurrences of European shag (*Phalacrocorax aristotelis*), six of black guillemot (*Cepphus grylle*) and thirteen of harbour seal (*Phoca vitulina*). Some of these observations were thought to be the same individuals recorded on different cameras or in sequential triggered footage. The total number of individuals observed in the 4,049 hours of footage examined were estimated to be twelve European shag, five black guillemot and ten harbour seal.

6. European shag, black guillemot and harbour seal were only observed in footage when turbines were not operating, such that blades were stationary.

Based on the current data and analysis, the results presented in this report indicate the likelihood of mobile species encountering and colliding with the moving blades of Nova's turbines is extremely low. Fish (saithe) have been observed to show some apparent evasive behaviour around the moving turbine blades. Marine mammals and diving birds have not been seen in the vicinity of the turbine blades when they are rotating and mainly overlap spatially with the turbines at time of slack water or flow speeds less than 0.8 m/s, when blades are stationary. These results align with observations from monitoring programmes for other operational tidal turbines, which together are resulting in a growing body of evidence to suggest that mobile species interactions with generating (i.e., rotating) tidal turbines are likely to be extremely rare events[20].

The results presented in this report indicate that the Shetland Tidal Array is operating within acceptable levels of collision risk, determined through the consenting process and Habitats Regulations Assessment for the Project[21]. The results indicate that the collision risk for diving birds and marine mammals is lower than was predicted by the collision risk modelling carried out to inform the Marine Licensing process for the 6-turbine extended Shetland Tidal Array[22].

For collisions to occur, individuals of species must first occupy the area immediately around the turbines and overlap spatially and temporally with the area swept by rotating blades (i.e., during flow speeds exceeding 0.8 m/s). This report indicates that the frequency of such nearfield encounters between turbines and mobile marine species is extremely low. Saithe is the only species to have been observed in the nearfield environment around rotating turbines, and only during times of low flow speed when turbines are not generating at full capacity so rotational speed is low. Further, individual saithe have been seen to exhibit what appears to be nearfield evasion of moving turbine blades.

[20] Copping AE and Hemery LG (Eds.) (2020). OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). doi:10.2172/1633088.

[21] Marine Scotland (2018). Appropriate Assessment for Nova Innovations Ltd, Extended Shetland Tidal Array, March 2018.

[22] Detailed in Nova Innovation (2018). Shetland Tidal Array Extension Environmental Assessment Report. Submitted to Marine Scotland and Shetland Island Council in support of Marine Licence and Works Licence applications.

9 Next steps

Nova will build on the findings summarised in this report through the ongoing environmental monitoring programme for the Shetland Tidal Array, as the project-scale is expanded from three to six turbines. The use of subsea video to monitor nearfield interactions and behaviour of mobile species around turbines has been shown to be an effective technique for the Shetland Tidal Array, so will continue, as set out in the Project Environmental Monitoring Plan (PEMP)[23]. Priority tasks in relation to the subsea video monitoring include:

1. Analysis of a greater proportion of the full subsea video dataset. This report presents the results of analysis of over 20% of all retained footage gathered between October 2015 and March 2020. As a first task Nova will carry out an exercise to identify the proportion of footage that will be analysed to draw conclusions with certainty about patterns of fish, bird and mammal presence and distribution around turbines. This will be completed by 30 November 2021, subject to approval by MSLOT.

2. Further processing, examination and analysis of historical retained video footage alongside newly acquired data from the ongoing monitoring programme for the Shetland Tidal Array. The introduction of Nova's new Video Management System is anticipated to enable increased efficiency in data processing and analysis. The ability to revisit stored footage as the subsea video dataset grows, and the use of tags for identifying key footage of interest will maximise the value of the data and improve understanding for nearfield interactions between turbines and mobile species. Analysis of the greater proportion of retained footage from subsea video monitoring programme identified in task 1 will help to build a more comprehensive understanding for fine-scale occupancy patterns of mobile species around operating turbines in the Shetland Tidal Array (and therefore collision risk).

3. Analysis of relationships between hydrodynamic conditions (tidal state and flow speed) and bird and mammal occurrences in subsea footage. This exercise would need to utilise measured tidal data for Bluemull Sound cross-referenced with subsea video footage and vantage point survey data. Ways of gathering sufficiently accurate tidal data to enable these further analyses will be explored as part of the ongoing programme of environmental monitoring.

4. Exploration of the potential to use the subsea video data to provide a measure of subsea animal density that more accurately reflects fine-scale occupancy patterns of species at risk of collisions. This would enable more accurate predictions of collision risk than is currently possible through use of surface density estimates. These further analyses will be considered out as part of the ongoing programme of environmental monitoring.

5. Improvement in the ability to exclude footage triggered by turbine motion or movement of biofouling growth, including the development of machine learning and algorithms to automatically filter footage and reduce manual processing. Nova is exploring options to develop such tools through collaborative research projects.

6. Improvements to biofouling measures to improve system performance and reduce effects on subsea video quality. Nova is considering new approaches to biofouling management through ongoing research and development.

[23] Nova Innovation (2020). EnFAIT-0362 Version 0.4. Shetland Tidal Array Project Environmental Monitoring Plan.

7. Measures to improve the ability to report on system performance and image quality. The introduction of Nova's Video Management System which enable remote access to stored footage is expected to lead to improvements and efficiencies in this area.

In relation to Tasks 1 and 2, the data presented in this report indicate that diving bird and marine mammal interactions with turbines in the Shetland Tidal Array are likely to be extremely rare events. Analysis of a greater proportion of video may simply confirm this. While validation of the preliminary conclusions in this report will be valuable, acquisition and analysis of further subsea video may not improve the ability to perform detailed analyses, due to small numbers of observations.

Some of the tasks above will be more effectively progressed as part of a collaborative research agenda involving industry, regulators, advisory bodies and the academic community. Such an approach could optimise the combined value of Nova and other developers' monitoring and data to reduce uncertainty about collision risk and improve the evidence base to de-risk consenting.

Annex A Nova Innovation (2017). Shetland Tidal Array Environmental Monitoring Report

Note only sections of this report relating to subsea video monitoring have been included in Annex A.

Nova Innovation Ltd

Shetland Tidal Array
Environmental Monitoring Report

The Clock House
Bonnington Mill
72 Newhaven Road
Leith
Edinburgh
EH6 5QG

Tel: +44 (0)131 554 2242

www.novainnovation.com

Author:	Gavin McPherson and Kate Smith
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Commercial and strictly confidential

CONTENTS

1 Introduction

This document relates to Marine License 04859/15/1 for the Nova Innovation Limited Tidal Array, located in the Bluemull Sound, Shetland. Condition 3.6, paragraph 5 of this license states that "The Licensee must submit monitoring reports detailing bird and mammal observations, in accordance with the agreed Environmental Mitigation and Monitoring Plan (EMMP), to determine any associated impacts. The reports will be submitted to the licensing authority in accordance with the reporting strategy."

This document also relates to licenses MS EPS 10/2015/00 ("License to Disturb Marine Species") and MS BS 02/2015/00 ("License to Disturb Basking Sharks"), and the associated license conditions to report actions taken in accordance with the terms of these licenses.

This report provides details of the methodology and results of environmental monitoring at the Shetland Tidal Array.

1.1 Summary of basking shark and cetacean observations

No cetaceans were observed in subsea video footage. Cetaceans were observed during surface surveys in the periphery of the array (survey zone 2), and on the surface in the vicinity of the array (zone 1), as summarised in the table below. The location of survey zones 1 and 2 and the survey methodology are described in Section 4.

Table 1-1 Summary of cetacean observations in surface surveys

Observation	Survey period	Total #individuals in zone 2 (zone 1)	Report section
Harbour porpoise	Aug 14 – Oct 14	29-32	5.2
Harbour porpoise	Nov 14 – Jan 15	5	6.2
Harbour porpoise	Feb 15 – Apr 15	9	7.2
Harbour porpoise	May 15 – Jul 15	4	8.2
Harbour porpoise **Risso's dolphin**	Aug 15 – Oct 15	70 3-4 (1)	9.2
Harbour porpoise	Nov 15 – Jan 16	40	10.2
Harbour porpoise **Risso's dolphin** **Humpback whale**	Feb 15 – Apr 16	55 (3) 20 2	11.2
Harbour porpoise	May 16 – Jul 16	12 (3)	12.2
Harbour porpoise	Aug 16 – Oct 16	19 (2)	13.2
Harbour porpoise **Killer whale**	Nov 16 – Jan 17	25 8-10	14.2

**Individual records, not necessarily different animals*

No basking sharks were observed during surface surveys or in subsea video footage.

No interactions were observed between the turbine blades and cetaceans or basking sharks (or indeed any other animals).

2 Overview of operations

The operations undertaken at the site since construction started are outlined below.

Table 2-1 Summary of offshore operations on the Shetland Tidal Array

Operation/event	Date	Observations
T1 deployment 1	09/10/2015	Analysis of video collected from deployment to recovery is included in this report.

T1 recovery 1	03/02/2015	
T1 deployment 2	02/03/2016	Analysis of video collected from deployment to recovery is included in this report.
T1 recovery 2	10/05/2016	
T1 deployment 3	13/08/2016	Video connection was lost on 20/10. Analysis of video collected from deployment to 20/10 is included in this report.
T2 deployment	14/08/2016	The turbine is operating normally, undergoing a phased series of commissioning tests. Analysis of video collected from deployment to 22 Jan 2017 is included in this report.
T3 deployment	18/01/2017	The turbine is operating normally, undergoing a phased series of commissioning tests. Analysis of video collected from T3 will be included in the next environmental report.

3 Video analysis

Video footage collected from the turbines was analysed with a view to observing any bird or mammal interactions. This section provides a summary of the monitoring methodology and results.
In summary: video footage analysed in this report covers the period from October 2015 to January 2017. 4,000 hours of footage were collected from six cameras located on the T1 and T2 nacelles (at approximately 21m depth). In this time, a number of birds and seals were observed on the footage; all such observations are included in this report. No interaction was observed between any animals and the turbine blades.

3.1 Methodology

3.1.1 Equipment

Each Nova M100 turbine includes three cameras: on the side of the turbine looking towards the blades (SIDE); on the top of the turbine looking towards the blades (TOP); and on the bottom of the turbine looking towards the seabed (DOWN). The analysis in this report features video from the turbines over the following periods.

- Analysis of T1 footage runs to October 2016, when the video connection was lost.
- Analysis of T2 footage runs from deployment in August 2016 to January 2017. Since then the turbine has been operating normally; additional footage stored locally on Shetland will be returned to Edinburgh for analysis in the next environmental report. However, biofouling is beginning to limit the utility of this footage.
- T3 was deployed in January 2017 and is undergoing commissioning. Analysis of footage from T3 will be included in the next report.

The cameras used are colour submersible bullet CCD cameras; resolution is 412,000 pixels, coded into MPEG; capture rate is 16 FPS.

3.1.2 Triggering

Recording was triggered by a motion detection system. Video was recorded from a few seconds before the trigger 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.
The system uses a standard CCTV trigger mechanism, which looks for changes in contrast between successive video images. The sensitivity of the trigger and the depth of range depends on light conditions, water quality and the degree of biofouling. Occasionally on some cameras the trigger mechanism failed, and continuous footage was recorded until the trigger was reset.
The camera also operates at night, when it can catch brief flashes of light as can be seen in Figure 1. Such images are presumed to be caused by passing bio-luminescent organisms.

Figure 1 Flash of light recorded on T2 TOP on 2016-08-2 at 04:04 am

3.1.3 Footage analysis methodology

Video footage was captured every day during the turbine operational periods described above. During this commissioning period for the turbines they were only operated under the direct supervision of a Nova Innovation engineer, who watched live video footage on a display in Edinburgh.

Triggered footage was visually inspected by a Nova staff member. This involved visually reviewing the images recorded at the moment the trigger fired; where the immediate cause of the trigger was not apparent the footage was inspected visually to determine the cause of the trigger. All occasions where birds or mammals were seen in the footage have been recorded below.

3.1.4 Impact of biofouling

The quality of the footage degraded through time due to biofouling of the camera lens. Figure 2 illustrates how the image quality of the T2 TOP camera degraded over five months of deployment from August 2016 to January 2017. The progress of biofouling depends on the location of the camera, and appears to be accelerated during periods of poor water quality, which could be linked to increased biomass suspended in the water, and to periods of increased sunshine. Figure 2 mostly covers autumn and winter months when Shetland receives little sunshine. It is possible that biofouling will progress more quickly during the summer.

In the image from January the top of the turbine can still be clearly seen in gaps between fouled areas. However, scanning these pictures to identify interesting events becomes much harder as biofouling progresses. The contrast between objects in the water and the image background is significantly reduced, and it becomes harder to determine what a picture shows without taking the time to look at it closely. In addition, the biofouling on the camera moves when the tide flows, triggering thousands of additional "noise" events. With tens of thousands of pictures to review for every month of deployment, the probability of correctly identifying interesting events reduces significantly as biofouling increases.

Figure 2 T2 TOP: Biofouling at the beginning (August, left) and the end (January, right) of the analysis period

Source: Copyright © Nova Innovation 2017

3.1.5 Software performance

The trigger is designed to reset after 15 minutes of recording. This means that no footage should last longer than 15 minutes, which typically limits video sizes to less than 20 MB. However, on occasion the trigger failed to reset, and the file size grew up to several GB in size. These large files were corrupted, and useful video could not be captured from them, leading to gaps of a few days in the video record. While the root cause of this issue has not yet been identified, an operational work-around has been put in place to frequently check the size of video files and restart the recording system if a file grows too big.

3.1.6 Sample footage

Screenshots are provided below of interesting events captured on the cameras. All events where birds or mammals have been observed are included.

3.2 T1 SIDE Camera

Figure 3 and Figure 4 show shoals of fish, believed to be saithe, observed on 10th and 19th October 2015. These fish were observed frequently on all cameras; they are a reliable indicator of flow speed; they rise up from the seabed to the nacelle as the tide goes slack, and to sink back towards the seabed as tidal flow increases. Fish are rarely seen at the nacelle once flow speeds reach the cut-in speed of the turbine.
The species in these images was provisionally identified as saithe using the following features: elongated body with white stripes on the side; pointed snout; protruding lower jaw; small barbel on the chin (occasionally visible); forked tail; three dorsal fins; and large eyes. With two exceptions noted below, this was the only species of fish observed in the video analysis.

Figure 3 T1 SIDE: shoal of fish, 4_2015-10-10_16-23-10.mp4

Source: Copyright © Nova Innovation 2017

Figure 4 T1 SIDE: Diving school of fish, 4_2015-10-19_09-11-58.mp4

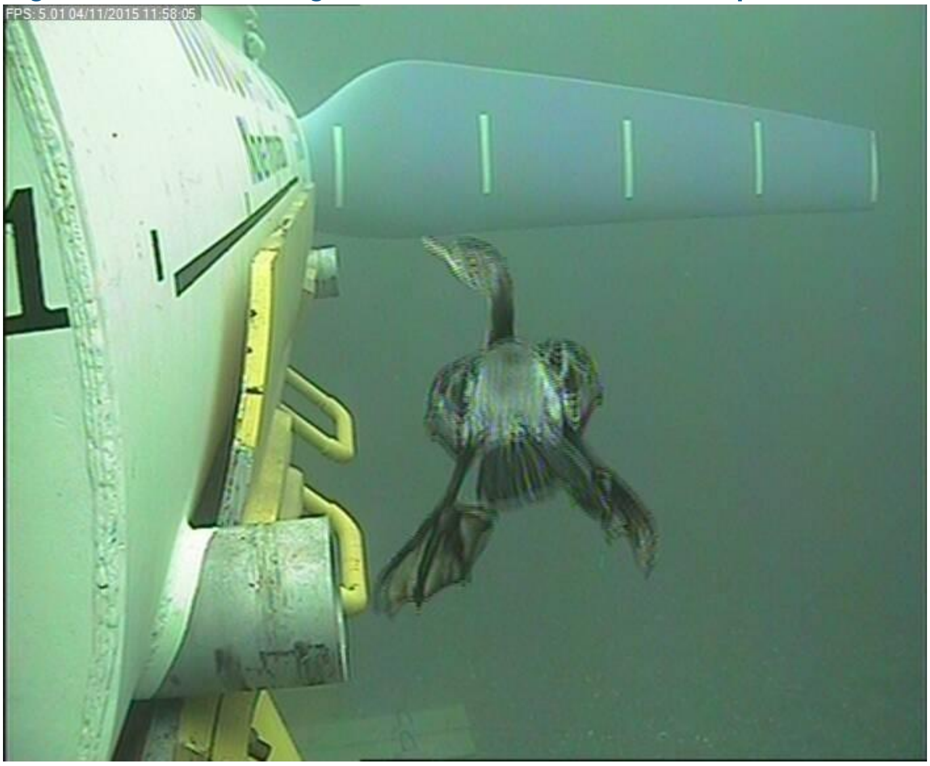
Source: Copyright © Nova Innovation 2017

On 4th November, the large shoal of fish shown in Figure 5 attracted the predator shown in Figure 6, believed to be a European Shag. Birds were only observed during slack or slow tidal speeds, and were never observed when the turbine was in operation.

Figure 5 T1 SIDE: large shoal of fish, 4_2015-11-04_11-42-04.mp4

Source: Copyright © Nova Innovation 2017

Figure 6 T1 SIDE: diving bird, 4_2015-11-04_11-58-01.mp4



Source: Copyright © Nova Innovation 2017

The behaviour of the fish during tidal flow is observed in Figure 7, where a large shoal forms a dark patch close to the seabed. The fish appeared to be sheltering in the lee of the turbine. This behaviour was also observed in the downward pointing cameras.

Figure 7 T1 SIDE: shoal of fish on the seabed, 4_2015-11-07_10-25-45.mp4

Source: Copyright © Nova Innovation 2017

A seal was caught on camera on 8th November, as shown in Figure 8 and Figure 9. A similar looking seal was observed the following day, shown in Figure 10, and a week later, show in Figure 11. As with birds, seals were observed rarely, and only during slack tide or low tidal speeds – never when the turbine was in operation. The mottled pattern and short snout suggest that this is a common seal (also known as a harbour seal).

Figure 8 T1 SIDE: seal observed 8th November 2015, 4_2015-11-08_15-09-14.mp4

Source: Copyright © Nova Innovation 2017

Figure 9 T1 SIDE: diving seal observed 8th November 2015, 4_2015-11-08_15-10-15.mp4

Source: Copyright © Nova Innovation 2017

Figure 10 T1 SIDE: seal observed 9th November 2015, 4_2015-11-09_15-08-08.mp4

Source: Copyright © Nova Innovation 2017

Figure 11 T1 SIDE: seal observed 17th November 2015, 4_2015-11-17_09-09-34.mp4

Source: Copyright © Nova Innovation 2017

Figure 12 shows a diving bird, believed to be a European Shag, observed on 24th November 2015.

Figure 12 T1 SIDE: diving bird, 4_2015-11-24_08-29-39.mp4

Source: Copyright © Nova Innovation 2017

The T1 nacelle was removed in December 2015 and redeployed in March 2016. Figure 13 and Figure 14 were captured just after redeployment. Schooling (i.e. coordinated motion of the shoal) was observed on occasion, and appears to be a response by the fish to a real or perceived threat. A few hours after the school was first observed, the threat was revealed in Figure 15 below. The diving bird in this case is believed to be a European shag.

Figure 13 T1 SIDE: Schooling fish, 4_2016-03-17_12-23-34.mp4

Source: Copyright © Nova Innovation 2017

Figure 14 T1 SIDE: Schooling fish, 4_2016-03-17_12-40-18.mp4

Source: Copyright © Nova Innovation 2017

Figure 15 T1 SIDE: Diving bird and schooling fish, 4_2016-03-18_14-01-59.mp4

Source: Copyright © Nova Innovation 2017

A diving bird was observed again a few weeks later, on the same camera; again, this is again thought to be a European shag.

Figure 16 T1 SIDE: Diving bird, 4_2016-04-01_18-28-47.mp4

Source: Copyright © Nova Innovation 2017

Figure 17 shows a more typical video image. Seaweed has snagged next to the camera, and triggers a recording when it moves in the tide. This kind of event will be very difficult to filter out automatically, since the shape, colour and movement of the seaweed can change from event to event. The vast majority of recorded footage in this period, amounting to thousands of hours of video and well over 100 GB of data, consists of events like this.

The change in image clarity and colour from the previous events is due to a combination of water quality, sunlight conditions, biofouling on the camera window and the colour filter applied to the image. Water quality and sunlight have a strong impact on the clarity of the image.

Figure 17 T1 SIDE: Seaweed caught next to the camera: 4_2016-04-04_09-30-37.mp4

Source: Copyright © Nova Innovation 2017

Fish were not observed frequently on this camera until after the turbine redeployment in August, after which they became a regular feature at slack tide, as can be seen in Figure 18. This again creates an issue when filtering the data, since the camera triggers constantly in the presence of fish. The trigger event – a picture of which is used in the first level filter of the data – will not necessarily include a bird or a mammal, even if one were present.

In order to identify birds and mammals, searches can be focused on events where schooling is observed in the trigger image, which indicates the presence of a predator. It is relatively easy to identify schools in the trigger images, though this happens infrequently – most of the observed schooling events are shown in this report. A more thorough search would involve reviewing by eye thousands of hours of video of milling fish, which is impractical for a human, even at 10x speed. It should be possible to accelerate this process using (for example) machine learning. We would welcome the opportunity to work with Marine Scotland on this dataset to develop improved video scanning tools.

Figure 18 T1 SIDE: Fish observed during slack tide: 4_2016-08-26_17-47-56.mp4

Source: Copyright © Nova Innovation 2017

In addition to fish, other creatures were occasionally observed on camera. Figure 19 shows a jellyfish swimming with fish during slack tide. Jellyfish were also observed being carried past the camera by the flowing tide.

Figure 19 T1 SIDE: Jellyfish observed with fish: 4_2016-09-06_13-53-31.mp4

Source: Copyright © Nova Innovation 2017

From October, biofouling began to affect the quality of image on this camera. This made it difficult to filter the images for interesting events, and recordings were increasingly triggered by movement of the biofouling itself.

Figure 20 T1 SIDE: Biofouling begins to affect the camera view from October: 4_2016-10-04_10-05-32.mp4

Source: Copyright © Nova Innovation 2017

3.3 T1 TOP camera

As with the T1 SIDE camera, fish were observed frequently on this camera, including the day after deployment as shown in Figure 21.

Figure 21 T1 TOP: shoal of fish, 3_2015-10-10_10-13-31.mp4

Source: Copyright © Nova Innovation 2017

A diving bird was seen on 23rd October 2015, believed to be a Black Guillemot in its winter (non-breeding) plumage.

Figure 22 T1 TOP: diving bird, 3_2015-10-23_10-12-02.mp4

Source: Copyright © Nova Innovation 2017

Figure 23 shows a seal observed on 25th October; as with all other observations, this is believed to be a common seal, and it was observed during slack tide when the turbine was not rotating.

Figure 23 T1 TOP: seal observed 25th October 2015, 3_2015-10-25_14-52-02.mp4

Source: Copyright © Nova Innovation 2017

A diving bird, believed to be a European shag, was observed on 4th November (Figure 24). A seal, believed to be a common seal, was also observed on this date (Figure 25).

Figure 24 T1 TOP: diving bird, 3_2015-11-04_11-58-10.mp4

Source: Copyright © Nova Innovation 2017

Figure 25 T1 TOP: diving seal, 3_2015-11-04_15-55-32.mp4

Source: Copyright © Nova Innovation 2017

A diving bird, believed to be a black guillemot, was observed on 7th November 2015 (Figure 26).

Figure 26 T1 TOP: diving bird, 3_2015-11-07_07-53-08.mp4

Source: Copyright © Nova Innovation 2017

A seal, believed to be a common seal, was observed three times on 9th November 2015 (Figure 27). A seal was also observed on the side camera on this date (Figure 10).

Figure 27 T1 TOP: seal, 3_2015-11-09_07-33-30.mp4, 3_2015-11-09_08-00-30.mp4, 3_2015-11-09_15-05-50.mp4

Source: Copyright © Nova Innovation 2017

A seal, again believed to be a common seal, was observed on 12th November 2015 (Figure 28)

Figure 28 T1 TOP: seal, 3_2015-11-12_16-05-16.mp4

Source: Copyright © Nova Innovation 2017

A particularly large shoal was observed on 24th November 2015 (Figure 29).

Figure 29 T1 TOP: large shoal, 3_2015-11-24_08-38-41.mp4

Source: Copyright © Nova Innovation 2017

The turbine nacelle was removed in December 2015 and redeployed in March 2016. In Figure 30, the top camera on T1 captured the same school of fish seen on the side camera on 17th March (see Figure 13). A single bird was again observed on this footage, seen to the lower right of Figure 31, believed to be a European shag.

Figure 30 T1 TOP: School of fish: 3_2016-03-17_12-41-55.mp4

Source: Copyright © Nova Innovation 2017

Figure 31 T1 TOP: Bird with schooling fish: 3_2016-03-18_14-02-05.mp4

Source: Copyright © Nova Innovation 2017

Soon after deployment some kelp was snagged next to the camera, leading to hundreds of triggered events and many hours of recorded data, typified by the picture below. As for the other cameras, this was a common occurrence which contributed significantly to “noise” in the data.

Figure 32 T1 TOP: Kelp snagged on camera: 3_2016-04-07_11-45-40.mp4

Source: Copyright © Nova Innovation 2017

As with other cameras, the fish observed appeared to almost exclusively consist of the species shown in Figure 33, which is believed to be a saithe.

Figure 33 T1 TOP: Saithe, 3_2016-08-31_15-47-59.mp4

Source: Copyright © Nova Innovation 2017

Figure 34 illustrates a difficulty in identifying diving birds in the video footage. The left image shows a diving bird (thought to be a European shag) which looks a bit like a piece of kelp, whilst the right image shows some kelp that looks a bit like a diving bird. The two can be easily distinguished in the associated video footage, which could be used to form the basis of a more sophisticated automatic filtering method: e.g. one that considers the speed and direction of passage of the object, and the flow and direction of the tide (birds were only observed during slack tide).

Figure 34 T1 TOP: (left) diving bird, 3_2016-08-25_14-42-00.mp4 (right) kelp, 3_2016-08-31_17-24-22.mp4

Source: Copyright © Nova Innovation 2017

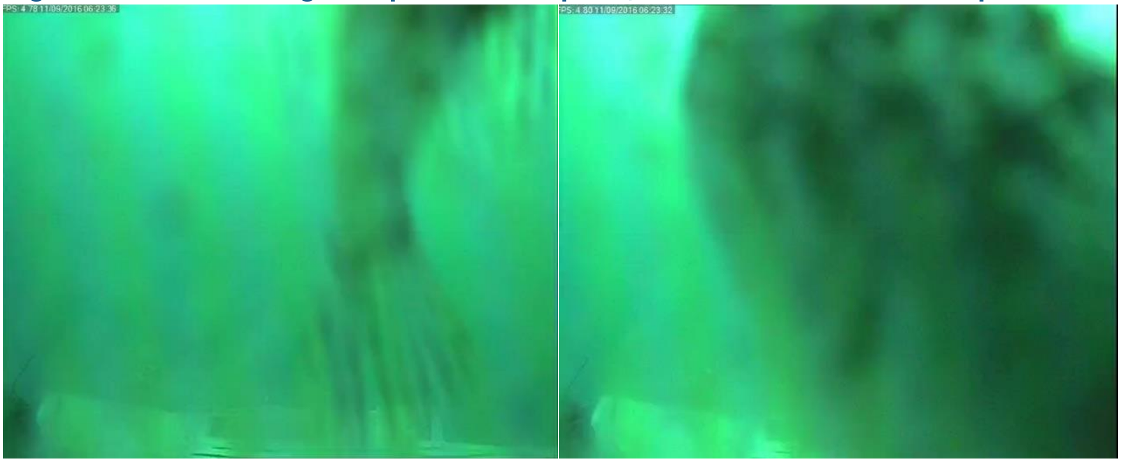
Figure 35 shows a school of fish moving quickly as if fleeing a predator. However, no predator was observed on the footage from this or other cameras around this time.

Figure 35 T1 TOP: schooling fish moving rapidly, 3_2016-09-01_10-33-03.mp4

Source: Copyright © Nova Innovation 2017

Whilst almost all of the observed fish appear to be of the same species, a different species of fish was observed on T1 in September, as shown in Figure 36. This is tentatively identified as a species of lumpfish; the video is not clear, but the image on the right could show the adhesive pelvic dish on the underside of the fish. The fish was observed to sit on the housing above the camera, which is consistent with the behaviour of a lumpfish. A similar fish was found during one of the recovery operations and is shown in Figure 37.

Figure 36 T1 TOP: images of possible lumpfish, 3_2016-09-11_06-23-31.mp4



Source: Copyright © Nova Innovation 2017

Figure 37 Possible lumpfish recovered during offshore operations

Source: Copyright © Nova Innovation 2017

3.4 T1 DOWN camera

This camera points downward from the nacelle to the sea floor. During the first deployment in October 2015, the camera became misaligned and so no useful footage produced. Figure 38 shows the view from the camera during this period.

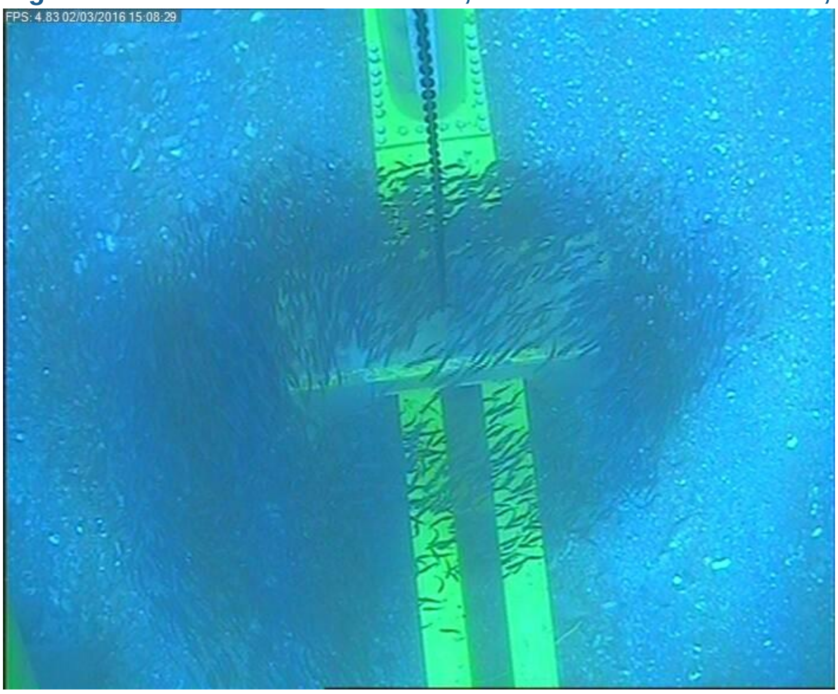
Figure 38 T1 DOWN: Obstructed view from camera Oct-Dec 2015, 5_2015-12-01_11-55-55.mp4

Source: Copyright © Nova Innovation 2017

The camera alignment was corrected before the next deployment in March 2016. The chain connecting the nacelle to the base moves when the tide flows, which causes the camera to trigger, leading to a large amount of footage. The presence of the seabed as a background to the image also makes it more difficult to identify interesting events using the trigger photos. However, a number of interesting events were observed on this camera.

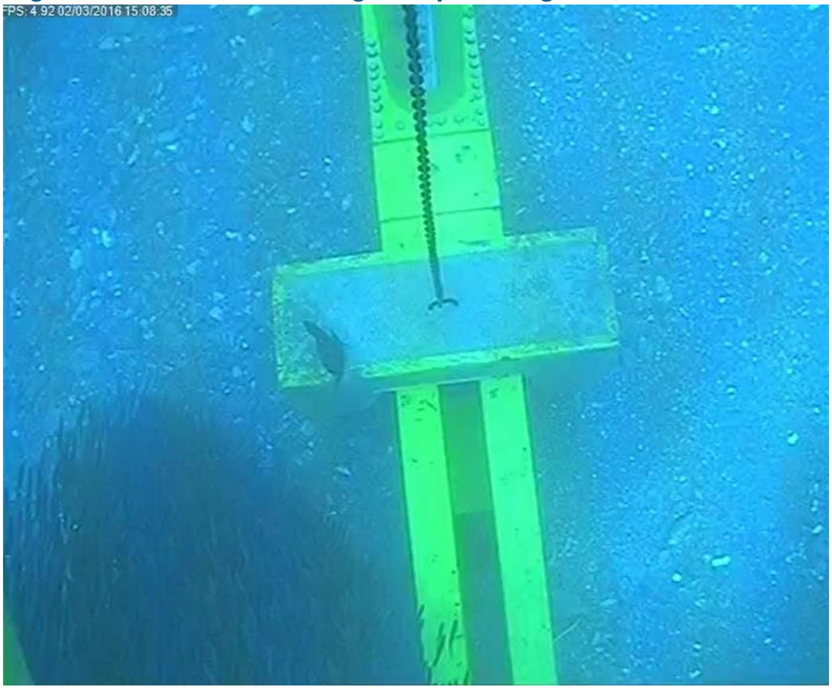
Figure 39 shows a school of fish circling beneath the turbine on 2nd March. The apparent cause of this behaviour is shown in Figure 40, and is thought to be a European Shag.

Figure 39 T1 DOWN: school of fish, as seen on other cameras, 5_2016-03-02_15-03-46.mp4



Source: Copyright © Nova Innovation 2017

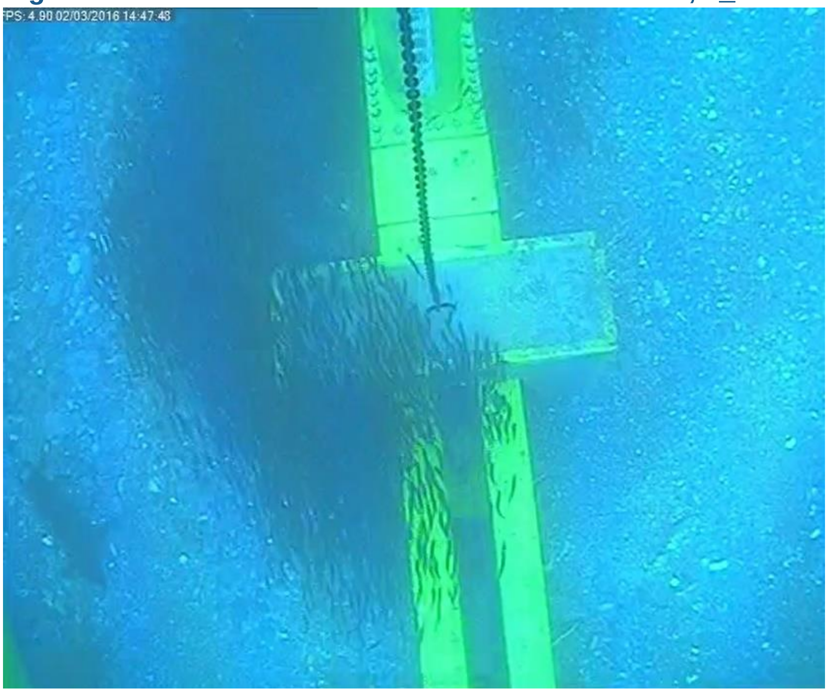
Figure 40 T1 DOWN: Diving bird pursuing fish, 5_2016-03-02_15-03-46.mp4



Source: Copyright © Nova Innovation 2017

This large school also attracted another predator; Figure 41 shows an unidentified species of seal. As with other seal observations, the tide was almost completely slack at this time – as can be verified by the motion of the chain, the fish, and passing flotsam in associated video. On this occasion, the trigger image showed only the school; the seal was spotted by visually inspecting the associated video. The schooling behaviour of the fish was again a good indicator of the presence of a predator.

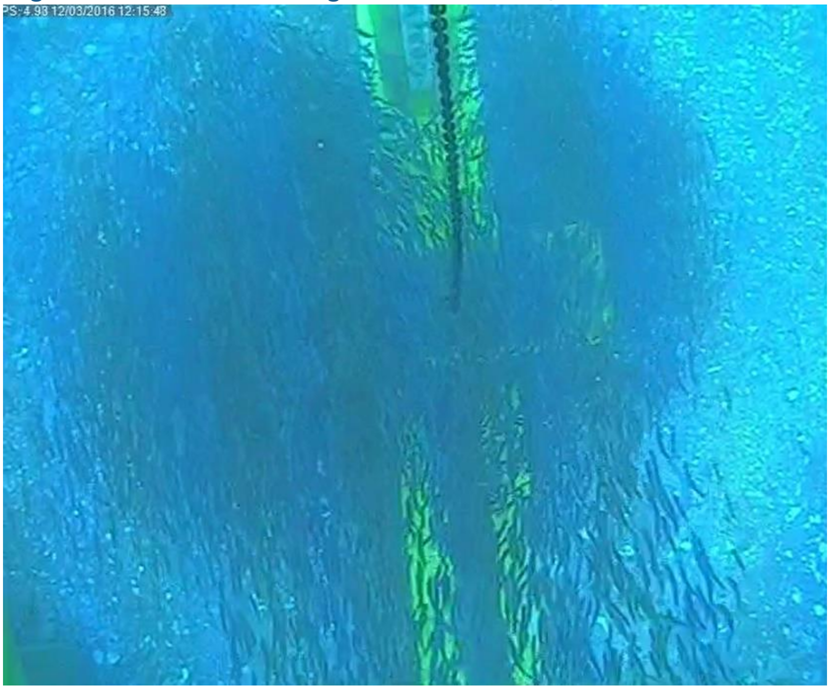
Figure 41 T1 DOWN: School with seal at bottom-left, 5_2016-03-02_14-33-42.mp4



Source: Copyright © Nova Innovation 2017

Another large school was observed ten days later, as shown in Figure 42. On this occasion, no predators were seen on the video footage.

Figure 42 T1 DOWN: Large school of fish, 5_2016-03-12_12-15-46.mp4



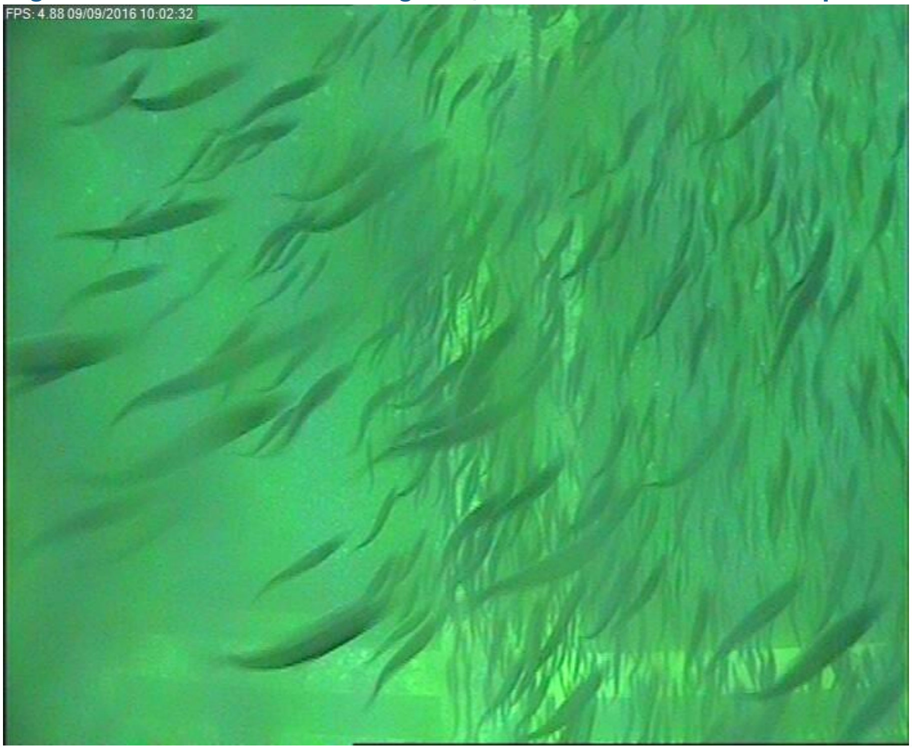
Source: Copyright © Nova Innovation 2017

A fault was encountered on this camera a few days after this picture was taken in March 2016, which put this camera out of action until after T1 redeployment in August 2016. Following that deployment, fish were frequently observed on this camera, as illustrated in Figure 43. Occasional schooling was observed, as shown in Figure 44, however no further predators were observed on this camera in this analysis.

Figure 43 T1 DOWN: milling fish, 5_2016-08-14_07-43-35.mp4

Source: Copyright © Nova Innovation 2017

Figure 44 T1 DOWN: schooling fish, 5_2016-09-09_10-02-22.mp4



Source: Copyright © Nova Innovation 2017

3.5 T2 SIDE camera

Fish were frequently observed on this camera, as illustrated in Figure 45. An occasional jellyfish was also captured, as in Figure 46. However, the camera became affected by biofouling, and from mid-September 2016, biofouling on the camera window was causing the camera to trigger continuously during daylight. Whilst objects could still be seen in the water, the poor image quality made it impossible to pick out interesting events by filtering video images. No birds or mammals were observed on this camera.

Figure 45 T2 SIDE: milling fish, 7_2016-08-19_05-13-35.mp4

Source: Copyright © Nova Innovation 2017

Figure 46 T2 SIDE: Jellyfish, 7_2016-09-06_17-19-17.mp4

Source: Copyright © Nova Innovation 2017

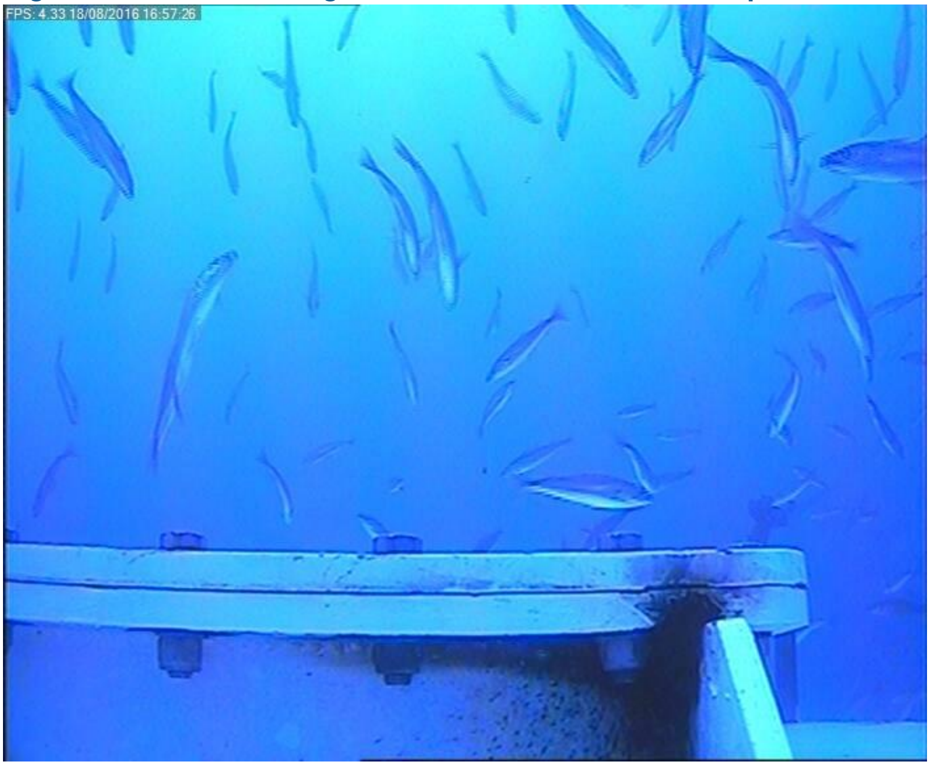
Figure 47 T2 SIDE: Poor visibility due to biofouling: 7_2016-10-02_10-08-23.mp4

Source: Copyright © Nova Innovation 2017

3.6 T2 TOP camera

Figure 48 shows a shoal of fish captured soon after deployment. As with the T1 turbine, a suspected lumpfish was also observed on the top of the T2 turbine, as shown in Figure 49 (pictured from below looking towards the head of the fish).

Figure 48 T2 TOP: Milling fish, 8_2016-08-18_16-57-27.mp4



Source: Copyright © Nova Innovation 2017

Figure 49 T2 TOP: Suspected lumpfish, 8_2016-10-03_06-15-03.mp4

Source: Copyright © Nova Innovation 2017

Three diving birds, believed to be European Shags, were observed on 5th October 2016, as shown in Figure 50, Figure 51 and Figure 52 ((a third bird not shown could be seen in video footage closer to the surface).

Figure 50 T2 TOP: Diving bird, 8_2016-10-05_06-41-36.mp4

Source: Copyright © Nova Innovation 2017

Figure 51 T2 TOP: Diving bird close-up, 8_2016-10-05_06-44-45.mp4

Source: Copyright © Nova Innovation 2017

Figure 52 T2 TOP: Two diving birds, 8_2016-10-05_06-42-02.mp4

Source: Copyright © Nova Innovation 2017

As with the other cameras, image quality degraded through September. However, the uncluttered visual field for the TOP cameras makes it easier to continue to identify interesting events. Figure 53 shows a seal, thought to be a common seal, passing over the turbine during slack tide.

Figure 53 T2 TOP: seal passing during slack tide, 8_2016-10-14_15-34-54.mp4

Source: Copyright © Nova Innovation 2017

On 25th October a diving bird was observed, as shown in Figure 54 and Figure 55. The bird is thought to be a black guillemot in its winter plumage. This coincided with a bird and mammal survey, where black guillemots were observed on the surface above the array.

Figure 54 T2 TOP: Diving bird, 8_2016-10-25_13-44-19.mp4

Source: Copyright © Nova Innovation 2017

Figure 55 T2 TOP: Diving bird, 8_2016-10-25_13-49-56.mp4

Source: Copyright © Nova Innovation 2017

Another bird, again thought to be a Black Guillemot, was observed on the same camera on two further occasions in the following weeks, as shown in Figure 56 and Figure 57.

Figure 56 T2 TOP: diving bird, 8_2016-11-18_12-54-56.mp4

Source: Copyright © Nova Innovation 2017

Figure 57 T2 TOP: diving bird, 8_2016-11-24_13-50-51.mp4

Source: Copyright © Nova Innovation 2017

3.7 T2 DOWN camera

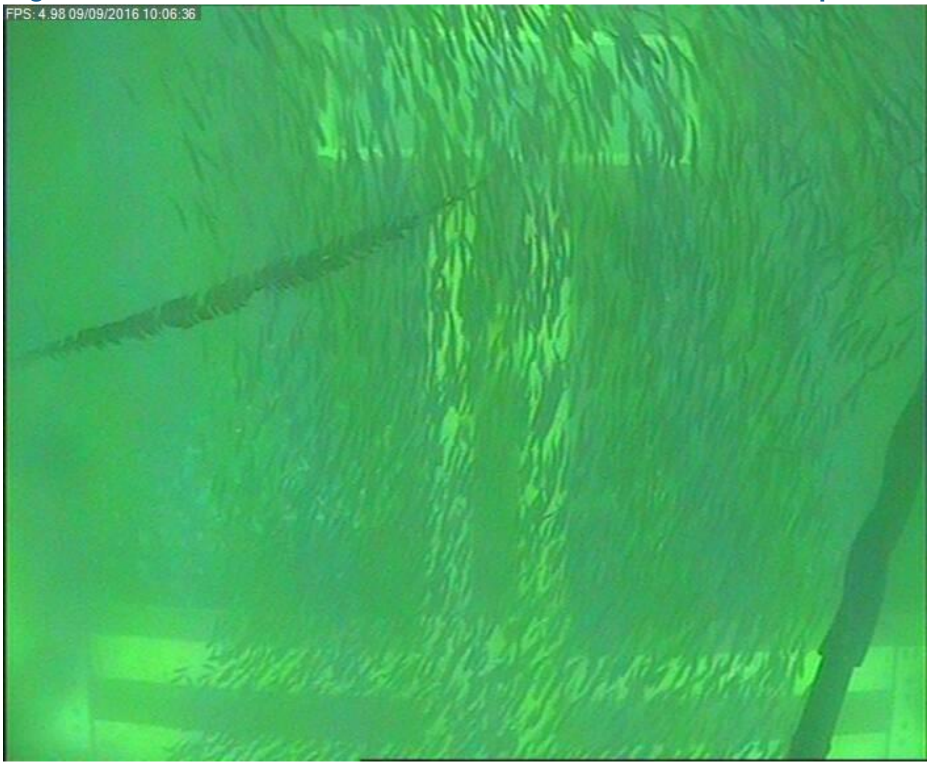
Fish were also observed on this camera on numerous occasions, as shown in Figure 58.

Figure 58 T2 DOWN: shoal of fish, 6_2016-08-30_15-48-37.mp4

Source: Copyright © Nova Innovation 2017

Interesting behaviour was observed on only one occasion on this camera, with a school of fish shown in Figure 59 (again during slack water). It was not possible to get a clear image of any predator from the video, but Figure 60 shows what appears to be a seal, visible on the lower right of the consecutive images. The images show one side flipper (left image), and two tail flippers (right image).

Figure 59 T2 DOWN: School of fish: 6_2016-09-09_10-06-34.mp4



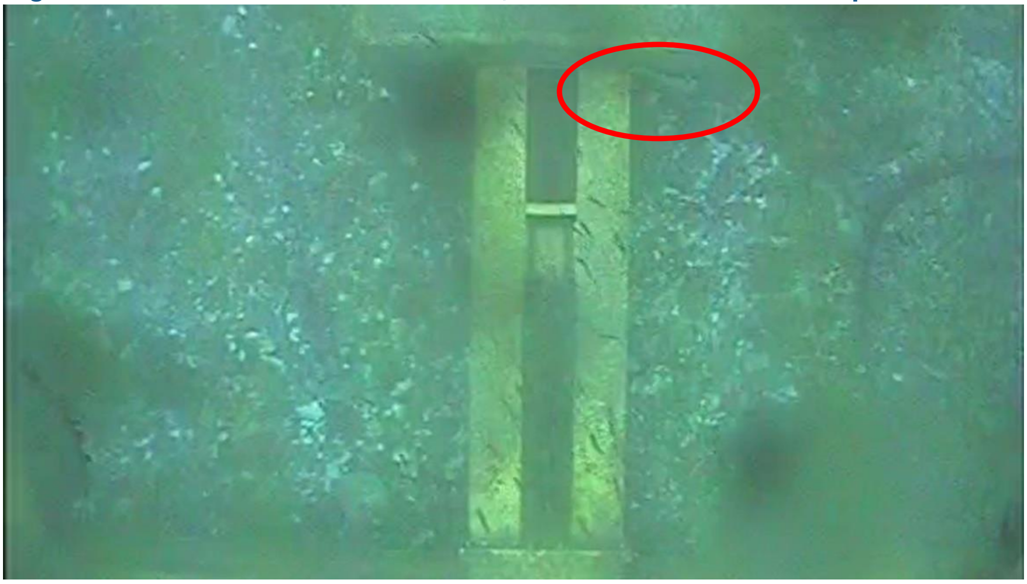
Source: Copyright © Nova Innovation 2017

Figure 60 T2 DOWN: Possible seal (bottom right of picture), 6_2016-09-09_10-11-05.mp4

Source: Copyright © Nova Innovation 2017

An unidentified species of fish was observed on 18th November. Whilst it is difficult to make out in the image below, the video reveals a fish with light colouration approximately 1m in length, possibly a dogfish, swimming close to the base of the turbine.

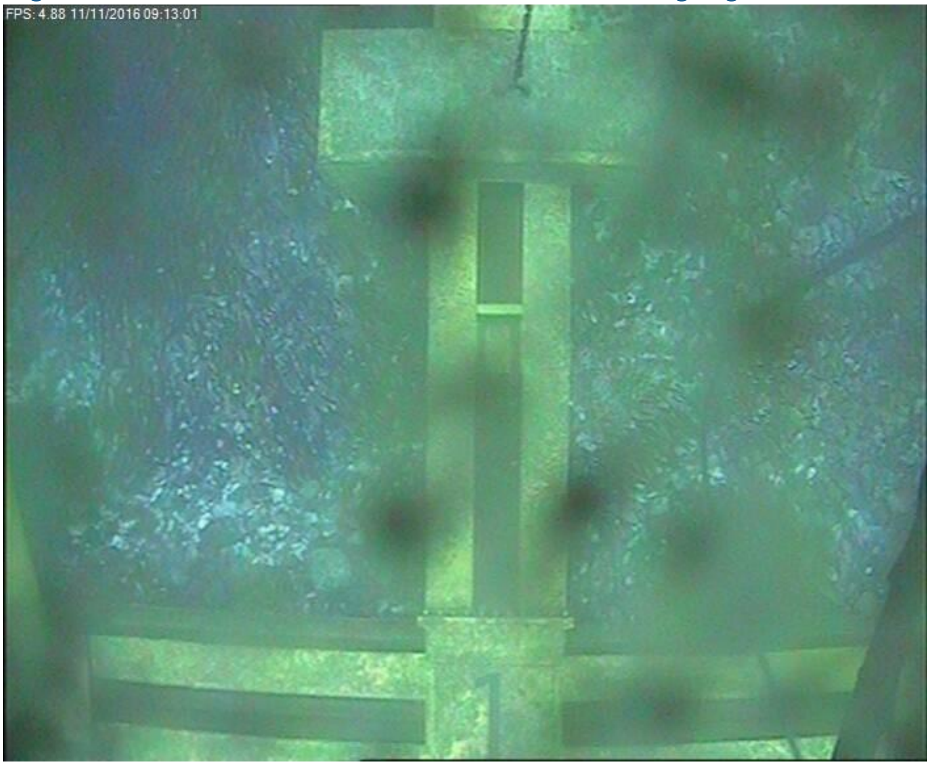
Figure 61 T2 DOWN: Unidentified fish, 6_2016-11-18_12-44-27.mp4



Source: Copyright © Nova Innovation 2017

The view from this camera supports the theory that the fish sink to the seabed when the tide flows and rise into the water column during slack tide. In Figure 62 a shoal of fish can be clearly seen on the seabed to the left of the structure, with a second shoal visible on the right. In this and on other occasions, the shoal remains close to the seabed while the flow speed high; swimming in the lee of the structure below the height of the support beams which are approximately 2m from the seabed.

Figure 62 T2 DOWN: Shoal of fish on seabed during high flow, 6_2016-11-11_09-08-47.mp4



Source: Copyright © Nova Innovation 2017

3.8 Video analysis – conclusions

The video cameras provided frequent sightings of fish, and birds and mammals. Shoals of saithe appear to shelter on the seabed behind the in the turbine base when the tidal flow is strong, and rise into the water column when the tide goes slack. The fish attract predators: common seals, European shags and black guillemots were observed. No cetaceans or basking sharks were observed in the video footage.

Birds and seals were only observed during slack water, which supports the theory that both fish and predators avoid regions of strong tidal flow. The strong tide would make it more difficult for birds and seals to spot the fish, due to turbulence in the water and the increased depth of the shoal. It would also make it more difficult for birds or seals to swim down to reach the fish, and to see and hear predators, since flow turbulence causes a significant increase in acoustic noise.

In summary:

- Fish were only observed to rise from the seabed during periods of slack tide.
- Birds and seals were also only observed occasionally, again during periods of slack tide.
- No cetaceans or basking sharks were observed.
- No interactions between birds or seals and the turbine blades were observed.