Scottish Government
Riaghaltas na h-Alba
gov.scot

Short-Term Behavioural Responses of Wintering Waterbirds to Marine Activity

Scottish Marine and Freshwater Science Vol 9 No 7

D Jarrett, A S C P Cook, I Woodward, K Ross, C Horswill, D Dadam and E M Humphreys

marine scotland

Short-Term Behavioural Responses of Wintering Waterbirds to Marine Activity (CR/2015/17)

Scottish Marine and Freshwater Science Vol 9 No 7

D Jarrett, A S C P Cook, I Woodward, K Ross, C Horswill, D Dadam and E M Humphreys

Published by Marine Scotland Science
ISSN: 2043-7722
DOI: 10.7489/12096-1

Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland's seas. Marine Scotland Science (formerly Fisheries Research Services) provides expert scientific and technical advice on marine and fisheries issues. Scottish Marine and Freshwater Science is a series of reports that publishes results of research and monitoring carried out by Marine Scotland Science. It also publishes the results of marine and freshwater scientific work that has been carried out for Marine Scotland under external commission. These reports are not subject to formal external peer-review.

This report presents the results of marine and freshwater scientific work carried out for Marine Scotland under external commission.

BTO Research Report No. 695

Quantifying the Sensitivity of Waterbird Species during the Non-Breeding Season to Marine Activities in Orkney and the Western Isles

SHORT-TERM BEHAVIOURAL RESPONSES OF WINTERING WATERBIRDS TO MARINE ACTIVITY

Authors

David Jarrett, Aonghais S. C. P. Cook, Ian Woodward, Kathryn Ross, Cat Horswill, Daria Dadam & Elizabeth M. Humphreys

Report of work carried out by the British Trust for Ornithology
on behalf of the Marine Scotland

April 2018

Contents

Figures

Tables

Short-Term Behavioural Responses of Wintering Waterbirds to Marine Activity (CR/2015/17)

D Jarrett, A S C P Cook, I Woodward, K Ross, C Horswill, D Dadam and E M Humphreys

British Trust for Ornithology

1. Executive Summary

1. Waterbirds are subject to a range of pressures on their wintering grounds, with disturbance and pollution being potentially the most significant. In the British Isles, significant populations of waterbirds winter in the seas including around Orkney and the Western Isles.

2. Increased marine activity associated with exploitation of the abundant wind, wave and tidal resources around Orkney and the Western Isles, in addition to increased aquaculture activity and existing shipping and shellfishing activity, has the potential to negatively impact wintering waterbird populations through increased disturbance.

3. The scope of this research project was to compare the relative sensitivities to marine activity of eleven target waterbird species during the non-breeding season. This was achieved by gathering data during a single winter fieldwork season on Orkney.

4. The research was focused on the following species: Common Eider, Long-tailed Duck, Velvet Scoter, Common Goldeneye, Red-breasted Merganser, Red-throated Diver, Black-throated Diver, Great Northern Diver, European Shag, Slavonian Grebe and Black Guillemot.

5. Data were collected using three complementary survey methodologies: Vantage Point (VPs) surveys, focal flock watches and ferry surveys. The methods were designed to gather systematic data on the target species' short term behavioural responses to marine activity, and environmental variables considered likely to affect those responses.

6. The VP surveys indicated that Common Eider, Long-tailed Duck and European Shag were all significantly more likely to fly in the presence of

marine activity. The numbers of Common Eider, Long-tailed Duck, European Shag and Great Northern Diver within a pre-defined study area all declined following marine activity, whereas Black Guillemot numbers appeared unaffected.

7. The focal flock watch methodology involved recording the behaviour of target species flocks in the presence and absence of marine activity. Long-tailed Duck flock size was likely to decrease in the five minute period following a disturbance event, and this species was also the most frequently recorded flying in the absence of marine activity. Great Northern Diver and Black-throated Diver were very unlikely to fly either in the presence or absence of marine activity.

8. The ferry survey methodology involved gathering data on regular island ferry services and recorded target species' responses to the passing ferry. Red-throated Diver, Black-throated Diver and Slavonian Grebe were the most likely species to exhibit a response (flight, evasive swim, or dive) to the passing ferry, and Red-throated Diver was most likely to show a flight response.

9. Whilst data were successfully gathered for nine of the target species across the three survey methodologies, too few data were collected for Common Goldeneye and Velvet Scoter to be able to draw conclusions.

10. Combining data gathered across the three methodologies, we categorised the sensitivity of nine target species (excluding Velvet Scoter and Common Goldeneye) as follows: **very high** (Red-throated Diver, Black-throated Diver, Slavonian Grebe and Red-breasted Merganser); **high** (Long tailed Duck and Great Northern Diver); **medium** (Common Eider and European Shag) and **low** (Black Guillemot). These sensitivities are assessed only in relation to the other target species, and are based solely on the data on short-term responses to marine activity gathered during this project.

11. Prior to this research little information on sensitivity to disturbance was in the public domain for Great Northern Diver, Slavonian Grebe and Black-throated Diver. The results presented here address important knowledge gaps which will help inform the marine planning process.

12. Gathering robust data on the effect of marine disturbance on waterbirds is challenging. Whichever methodological approach is followed there are likely

to be significant practical challenges in data collection and analyses, and limitations on the conclusions which can be drawn. Furthermore, the spatial and temporal scales at which data is collected and analysed can significantly influence the results obtained.

13. Although all the fieldwork took place in Orkney, it is likely that the findings presented here are also applicable to the Western Isles. However, we would advise against conclusions made here being applied to the larger estuarine ports of mainland Britain, where marine activity is likely to be of a different scale and intensity.

14. It should be borne in mind that the results and assessments presented in this report are based on short-term behavioural responses. Research is needed to better understand the mechanisms by which short-term behavioural responses might translate into demographic effects and the relative significance of the disturbance effects on habitat loss and energetic expenditure should be considered.

15. Recommendations for future research include suggestions to carry out a before-after-gradient study on the effect of new marine developments to assess long-term displacement effects, tracking studies of waterbird use of the marine environment in relation to marine activity, and trial disturbance tests using chartered boats.

2. Introduction

Waterbirds are subject to a range of pressures on their wintering grounds, with disturbance and pollution identified as potentially being most significant (see WP1, Appendix 2). Scottish Natural Heritage (SNH) and Joint Nature Conservation Committee (JNCC) have recently proposed nine new Special Protection Areas (pSPAs) for wintering waterbirds, including two new pSPAs in Orkney (Scapa Flow and North Orkney) and a further pSPA in the Western Isles to Scottish Government (SG) for the protection of inshore aggregations of wintering divers, grebes and seaduck. However, increased marine activity around Orkney associated with exploitation of the abundant wave and tidal resources, in addition to major expansion of aquaculture activities, as well as existing shipping and shellfish activities, has the potential to negatively affect the qualifying features of the pSPAs (SNH 2016a, SNH 2016b). The challenge for marine spatial planning is to ensure that the likely impacts of proposed licenced activities on SPA qualifying features are estimated accurately and decisions are based by the best available data (Scottish Government, 2016).

To inform this process, the aim of this research project was to gather data on short term behavioural responses of marine birds to marine activity. The research was focused on the species for which wintering populations are qualifying features of the Orkney pSPAs (Table 1): Common Eider *Somateria mollissima*, Long-tailed Duck *Clangula hyemalis,* Velvet Scoter *Melanitta fusca*, Common Goldeneye *Bucephala clangula*, Red-breasted Merganser *Mergus serrator*, Black-throated Diver *Gavia arctica*, Great Northern Diver *Gavia Immer*, European Shag *Phalacrocorax aristotellis and* Slavonian Grebe *Podiceps auritus*. Black Guillemot *Cepphus grylle*, is not a qualifying feature, but is included as part of this project as it occurs in large numbers in the region. Red-throated Diver *Gavia stellata* was included because it is a qualifying feature of two Orkney SPAs on Orkney during the breeding season. Hereafter in this report these 11 species are referred to as the ‘target species’.

While for some of these species existing research on sensitivity to disturbance had been carried out (see WP1, Appendix 2), there were important knowledge gaps for some of these target species. A recent review by Wade et al. (2016) ranked the level of uncertainty around our understanding of vessel displacement effects for ten of the target species of this report as follows: Great Northern Diver (very high); Black-throated Diver, Red-throated Diver, European Shag, Long-tailed Duck, Slavonian Grebe, Common Goldeneye (high); Velvet Scoter, Common Eider (moderate) and Black Guillemot (very low). This project aims to reduce the uncertainty around our understanding of the sensitivities of these species to marine activity.

Disturbance can also result in physiological or hormonal responses (Fowler 1999; Soldatini et al. 2015) and repeated exposure to stressful events could ultimately have population level effects (Müllner et al. 2004, Hau et al. 2010). Before considering long-term impacts of marine activity, however, it is necessary first to establish the extent to which disturbance is taking place, and identify those species most sensitive to disturbance. Disturbance effects of marine activity have previously been assessed by boat based recording of responses carried out in open sea areas (Larsen and Laubek 2005, Schwemmer et al. 2011) using the distance at which birds respond as a proxy of relative sensitivity to disturbance, described as Flight Initiation Distances (FIDs). These previous studies did not cover all of the target species of this piece of research, and there may be considerable variation in how wintering populations in different geographic areas respond to marine activity. Response to marine activity may also be influenced by habitat – the narrow channels and relatively enclosed areas of sea typical to many areas around the Orkney Isles are distinctive, so results from studies carried out in the open sea may not be applicable.

Factors which may affect responses to marine activity and therefore the extent to which species can habituate to such events (see Ross et al. 2015 for further details) include: a) Bird related variables including species, flock size, moult state and behaviour prior to disturbance; b) Environmental factors such as time of day/year, tidal cycle, weather and marine habitat; c) Characteristics of the marine activity taking place.

While multiple years of data are required to investigate whether displacement can be directly associated with patterns of marine activity (Grecian et al. 2010), the fieldwork for this research took place over one winter. Therefore, the focus was on short-term behavioural responses to marine activity, which are likely to be the best available proxy for sensitivity to displacement in the absence of long-term data (Furness et al. 2012; Furness et al. 2013).

This project aims to reduce the uncertainty around our understanding of the relative sensitivities of the target species to better inform impact assessments, habitats regulation appraisal, licencing decisions and strategic marine planning. The work was commissioned by Scottish Government, with work carried out under four main work packages (WPs):

WP1: A literature review of the sensitivity of the target waterbird species during the non-breeding season to marine activities in Orkney and the Western Isles (see Appendix 2).

WP2: A summary of all existing survey data (bird and marine activity) for wintering inshore waterbirds and licensed activities in Orkney and the Western Isles (see Appendix 3).

WP3: Data collection and subsequent analysis of the short term behavioural responses of the target species to marine activities around Orkney during the winter of 2016/2017.

WP4: The development of a simple tool to help with marine spatial planning and consenting issues (available as a separate excel spreadsheet). The information provided by this project will be incorporated into the Feature Activity Sensitivity Tool (FEAST) administered by Marine Scotland.

WP3 forms the basis of this main report, with WP1 and WP2 attached as appendices to this report.

We used three complementary survey methodologies (summarised below) to gather systematic data on the target species' responses to marine activity in order to assess and compare the relative sensitivities of these species.

i) Vantage Point Surveys

This methodology was designed to determine the extent to which the frequency and intensity of marine activity affected target species' movements and abundance within a pre-defined study area. Seven different study areas were used for Vantage Point (VPs) surveys, featuring different disturbance and habitat characteristics, and differing assemblages of the target species.

ii) Focal Flock Watches

This methodology was designed to determine whether the behaviour of target species' flocks visibly altered following marine disturbance events**.** The focal flock watch survey methodology also allowed some data to be gathered on those species which were largely absent from the areas where the vantage point surveys and the ferry surveys were carried out.

iii) Ferry Surveys

This methodology was designed to compare the likelihood of target species responding to regular ferry traffic and to investigate the effect of environmental parameters on responses. The design of the ferry survey methodology allowed large datasets to be gathered on the target species.

Table 1: Qualifying features for Orkney and Western Isles pSPAs outside the breeding season (reproduced from WP1).

		Qualifying feature for SPAs		
Common name	**Scientific name**	**North Orkney**	**Scapa Flow**	**West coast of Outer Hebrides**
Common Eider	*Somateria mollissima*	✓	✓	✓
Long-tailed Duck	*Clangula hyemalis*	✓	✓	✓
Velvet Scoter	*Melanitta fusca*	✓		
Common Goldeneye	*Bucephala clangula*		✓	
Red-breasted Merganser	*Mergus serrator*	✓	✓	✓
Black-throated Diver	*Gavia arctica*		✓	✓
Great Northern Diver	*Gavia Immer*	✓	✓	✓
European Shag	*Phalacrocorax aristotellis*	✓	✓	
Slavonian Grebe	*Podiceps auritus*	✓	✓	✓

3. Methodology - Site Selection

Vantage Point Surveys

Vantage Point (VP) surveys were carried out from seven fixed locations around the mainland of Orkney between 2 December 2016 and 7 March 2017. The selection of sites was based on a number of reconnaissance visits which looked at the suitability of different areas in terms of the range and abundance of target species and the level of marine activity present. VP locations were also informed by the knowledge of local fieldworkers who had spent many years surveying the target species around Orkney, and had up to date knowledge on where marine activity was likely to take place during the survey period. Because the objective of the study was to gather data on how birds respond to disturbance, areas which were subject to very low levels of disturbance were not considered suitable, this included much of the north and west coast of Mainland.

Figure 1: Location of all VPs on mainland Orkney

All of the selected VPs looked out across bays or channels - none looked out across open sea (see Figure 1, Table 2). This was because target species tended to be more numerous in sheltered areas, and in addition there was limited marine activity (for example passenger ferries, creel boats and maintenance visits to aquaculture cages) at the open sea sites. No VPs were located on the smaller isles as a reduced ferry service was in place during the fieldwork period and all the fieldworkers were based on the mainland. Across the seven VPs there was a range of species, coastal topography and disturbance types present. Variation in the sea depth at the different VPs can be seen in the bathymetry maps in Appendix 1. Because marine activity varied with the day of the week and the time of day, surveys at each VP were carried out on different days of the week, at different times of day and also across different tidal states.

The effects of glare and prevailing winds were also considered in the selection of VPs; only one of the VPs faced west (Kirkwall Harbour), which was in a relatively sheltered location, and only two of them faced south (Houton and The Breck). The south facing VPs were normally completed in periods of cloudy weather to reduce the effect of glare. Because of the absence of high cliffs in the areas we identified as being suitable for vantage point surveys, the height above sea level of most of the VPs was relatively low. The low altitudes ruled out the possibility of using a clinometer to measure distances. Current strength, which is known to affect absolute abundance counts of water birds in tidal areas (Robbins 2017), was not considered likely to affect responses to marine activity, although we were aware that the movements of birds at high tidal energy sites may be affected by the state of the tide.

Table 2: Vantage point sites.

VP	Grid reference	Habitat	Height above sea level (m)	Tidal energy level*
Broch of Gurness	HY38500 26837	Channel	6	High
Quanterness	HY42372 14020	Bay	8	Low
Bay of Kirkwall	HY45885 13244	Bay	4	Low
Head of Work	HY47690 14064	Channel	8	Low
The Breck	HY35016 03851	Wide channel	13	Low
Houton	HY32096 03354	Wide channel	3	Variable
Stromness	HY25652 07939	Channel / Bay	3	High

* Pers.comm, David Wolff

Focal Flock Watches

Flock watches were carried out from the seven VP sites (Section 2.1) and opportunistically from other locations (when travelling to and from VPs and ferry terminals) from 2 of December to 11 March (see Figure 2). Field workers located a single flock of birds taking into account the need for a range of target species and flock sizes. Fieldworkers prioritised those species which were less abundant on the vantage point surveys, to ensure some data was gathered on all species during the project. Watches were preferentially carried out in areas where there was likely to be marine activity taking place (http://www.marinetraffic.com/).

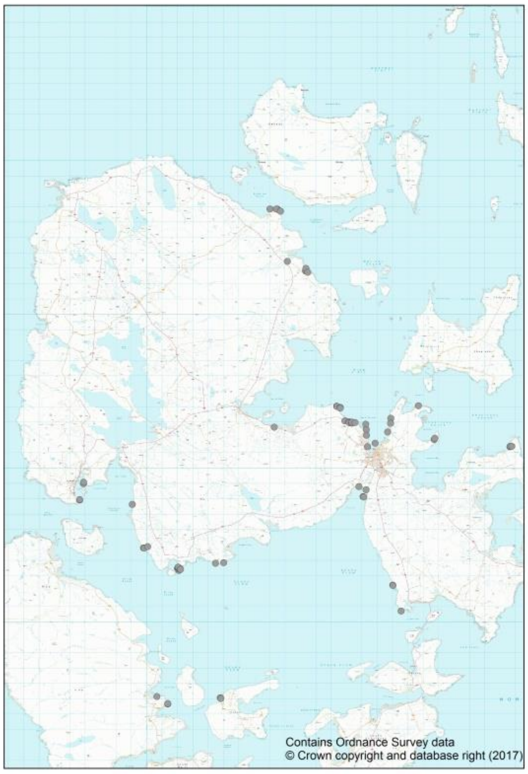


Figure 2: Location of focal flock watches**.**

Ferry Surveys

Surveys were carried out on board regular passenger ferry services between 28 November 2016 and 7 March 2017. These journeys were relatively short ferry trips (the longest journey being around 35 minutes) between small piers and harbours on Mainland Orkney and nearby islands (Table 3, Figures 3, 4 and 5). As such most of the time the ferries were relatively close to land and not in areas of open sea.

Table 3: Ferry and route details (information from Orkney Ferries website http://www.orkneyferries.co.uk/).

Name	Hoy Head	m.v. Eynhallow	Shapinsay
Route	Figure 3	Figure 4	Figure 5
Top Speed (knots)	11	11	10
Length (m)	53.3	29.0	35.0
Beam* (m)	10	7	9
Draft (m)**	2.5	1.5	1.45

* width of ferry, ** extent of ferry below waterline.

Figure 3: Route of the Hoy Head (Houton - Lyness - Flotta).

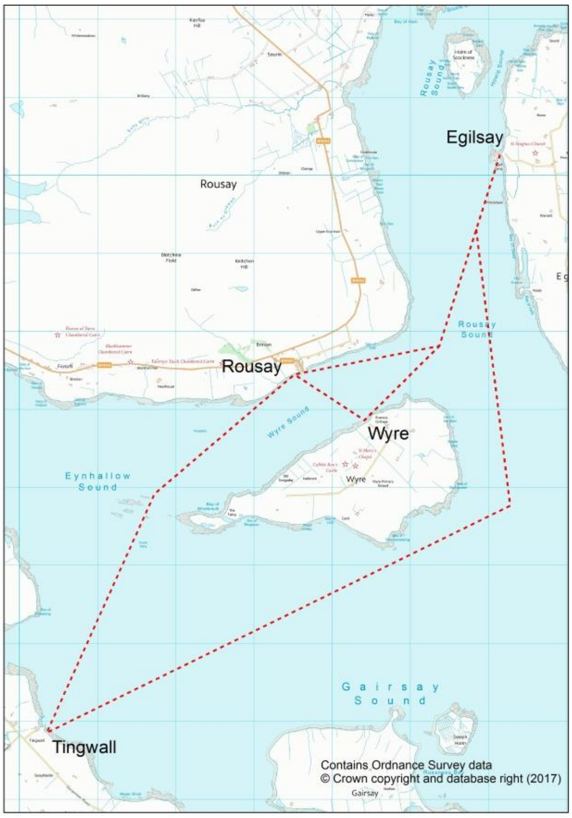


Figure 4: Route of the m.v. Eynhallow (Tingwall - Rousay - Egilsay - Wyre).

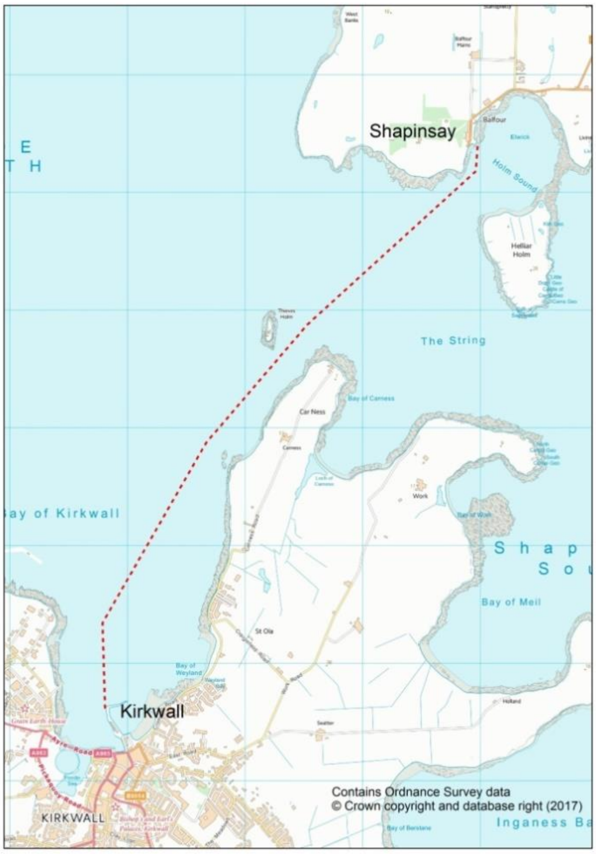


Figure 5: Route of the Shapinsay (Kirkwall – Shapinsay).

4. Methodology - Data Collection

Vantage Point Surveys

At each VP, the study area was a 90^0 arc in which four distance bands were defined (0-250 m, 250-500 m, 500-1000 m and 1000-2000 m) and divided with a centre line into eight sectors (Figure 6). Fieldworkers used OS 1:25,000 maps and satellite imagery to identify the distance to reference landmarks (navigation markers, navigation routes, skerries, islands, aquaculture sites etc.) within and near the study area. These were used to delineate the distance bands and the division between the 'left' and 'right' sectors. This approach was only possible because none of the VPs looked out at open sea and was the most accurate method of calculating distance given the relative abundance of reference landmarks within the study sites. The use of a range finder stick (Camphuysen et al. 2004) was not appropriate because this approach only works when looking out to the horizon or to an opposing shoreline a constant distance away. Neither of these criteria were met by any of the selected VPs. Similarly laser range finders were impractical to use for measuring distances to birds on water due to a combination of the oblique angle of view, the effect of swell and wave action, and the large distances involved.

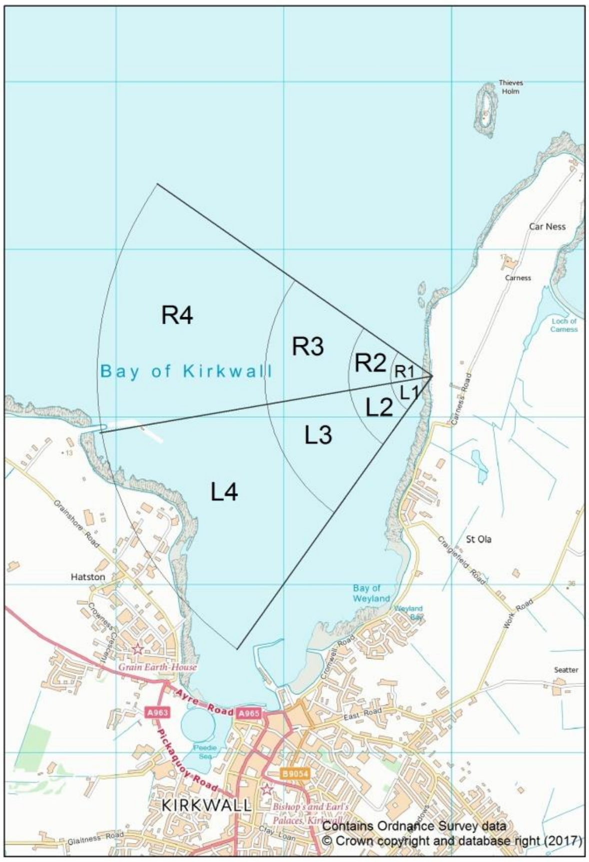


Figure 6: Example of a study area with sector divisions.

The vantage point surveys were structured as follows:

- Count 1 (10-25 minutes duration);
- Record marine activity and target species' flight activity (60 minutes duration);
- Count 2 (10-25 minutes duration);
- Record marine activity and target species' flight activity (60 minutes duration);
- Count 3 (10-25 minutes duration)/

Each one hour recording period of marine activity and flight activity was preceded and followed by a count. On some occasions, for practical reasons fieldworkers continued and did a third hour recording marine activity and flight activity, and then carried out a fourth count.

Counts of Birds

The total number of each target species within each sector was counted (L1, L2, L3, L4, R1, R2, R3, R4). Since the sea conditions and numbers of target species were highly variable there was no specified time for counting. In practise counts typically took between 10-25 minutes. Where Shags or other target species were roosting on barges/rocks/salmon cages this was also recorded, in case this affected the likelihood of birds responding to marine activity. There were insufficient data on roosting birds to be able to carry out meaningful analyses however. Any significant flocks (n >20) just outside the study area were noted as such in case there were large variations in numbers caused by large flocks drifting in and out of the edge of the study area. It was not necessary to use this data in the analyses.

During each count the following additional data was recorded - wind direction: (N, NE, E, SE, S, SW, W, NW); wind speed on the Beaufort Scale (0, 1, 2, 3, 4, 5); sea state on the Beaufort Scale: (0, 1, 2, 3, 4, 5); Weather: (fair, rain, snow); Glare: (none, moderate, strong). The tidal cycle for data recording purposes was split into four periods of approximately three hours: the period one and a half hours either side of high water was recorded as 'high'; and the period one and half hours either side of low water was recorded as 'low'. The intermediate periods between the 'high' and 'low' recording periods were recorded as 'falling' or 'rising'. The 'rising' and 'falling' tidal periods were in practise slightly longer than three hours because of the length of the tidal cycle (12 hours 25 minutes), but this was considered unlikely to affect the results of data analysis. Tide times were obtained from tidetimes.org.uk.

Recording of Marine Activity

Marine activity was allocated to one of the following categories: Creel boat, fishing boat, work boat, barge, tug, pilot boat, pleasure craft, large commercial, yacht, ferry, lifeboat, powerboat <10, powerboat >10, airplane, helicopter, drone, canoe/row-boat, and predator (e.g. bird of prey). The time the marine activity entered and left each one of the eight the study sectors (L1, L2, L3, L4, R1, R2, R3, R4) was recorded.

Recording of Flight Activity

Scanning for bird flights was carried out either with the naked eye or with binoculars, not with telescopes because this reduces the field of vision too much. The fieldworker was positioned facing the centre line dividing the left and right sectors. Time spent scanning between the left segment and the right segment was equal. Scanning effort remained constant whether disturbance events were taking place or not.

Target species' flights into, out of, or between the study sectors were recorded along with the time the flight was detected. The study sectors that the flights started from and ended in (e.g. L2 to R3) were recorded and flights that started and ended in the same sector were recorded as such (e.g. L2 to L2). Flights that started or ended out of the study sectors were recorded as such (e.g. Out to L2, R3 to Out). Flights across the study area where the bird didn't land or take off in the study area were not recorded. Flights which were obviously a response to vessels/disturbance were recorded in the same way as flights which were not.

Alterations from the Proposed Methodology

Initially it was proposed that for the vantage point surveys, fieldworkers would be required to count all birds within an arc of 180^0 every 15 minutes. In practise, counting this area could take up to 45 minutes (depending on sea state and number of birds present). The initial methodology also specified that while counting birds, the fieldworker would also be recording marine activity. It was not possible, however, for fieldworkers to be simultaneously counting birds (using a telescope) whilst also recording the movement of marine activity within the study area.

In light of these practical restrictions, we reduced the counting area to a 90^0 arc, and separated the counting of birds and the recording of marine activity into separate parts of the vantage point watch as described above.

Focal Flock Watches

Recording was carried out for up to one hour on the same target species' flock. Flock species composition, flock size, the coastal topography (narrow channel, wide channel, open sea, bay, harbour), and any permanent structures (piers, aquaculture cages, barges, platforms, renewable devices) near the flocks were recorded. The distance from the fieldworker to the flock was estimated using reference points and a 1:25,000 Ordnance Survey map. Weather variables were also recorded (precipitation, glare, cloud cover, sea state, wind speed - see Section 4.1).

For each five minute period of the watch, the fieldworker observed the flock and recorded flock activity as follows:

(i) Flock behaviour was recorded in **one** of the following general categories: all diving; more than half the flock diving; fewer than half diving; loafing (no diving or displaying taking place); displaying (displaying activity amongst males within flock);

(ii) the cumulative amount of non-disturbance flights (not a response to marine activity) undertaken by birds within the flock – including short flights and repeat flights by the same birds;

(iii) whether the fieldworker judged the flock to be 'tight' (birds in flock 'overlapping' with neighbour) or not (this was a subjective assessment);

(iv) Number of birds leaving or joining the flock.

Any marine activity which occurred during each five-minute period was recorded – using the same categories used for the vantage point surveys (Section 4.1). The closest pass of the marine activity to the focal flock within the five-minute period was again estimated using reference points and 1:25,000 OS maps. Laser range finders were not appropriate (see Section 4.1 for further details). It was challenging to assess how close the marine activity was to the flock when both were a long way from the shore, whereas judging whether birds were responding to marine activity was relatively straightforward if the fieldworker was watching a flock closely and aware of the location, speed and direction of any marine activity taking place.

The bird's response to the marine activity was captured in the recording of evasive behaviour in terms of number of flights, dives and swimming away events within the five-minute period. The time in seconds of the birds' evasive flight was recorded to distinguish between 'get out the way' flights and flights where the birds flew some distance to a different location (when evasive flights went out of the observers field of view this was recorded with the time the birds had been in the air before leaving the field of view). Absence of evasive action was not recorded specifically, but could be determined from the data where there were no instances of evasive action corresponding to a recorded marine activity event.

Ferry Surveys

Fieldworkers were positioned at the front of the ferry either on the bridge or next to the bridge, at a height of 5-7 m above the waterline. Fieldworkers worked in pairs - one identified and observed the behaviour of the target species with binoculars and the second fieldworker completed the survey forms. Weather conditions including glare, precipitation, cloud cover, wind speed, sea state and tidal state were recorded (see Section 4.1). Surveys were carried out in sea states up to force five; while ESAS (European Seabirds at Sea) survey methods recommends surveys are carried out in sea states up to a force 4, because the purpose of this work was to gather behavioural data rather than abundance data, carrying out surveys at sea state 5 was not problematic. Fieldworkers aimed to collect data from a range of sea states, so the effect of sea state on behavioural responses could be tested, following initial observations indicating that sea state influenced responses.

Birds were allocated to distance bands perpendicular to route of the ferry (Figure 7). When birds were picked up far ahead of the ferry (e.g. >1 km) this proved to more challenging and on occasion there was a need for the initial assessment to be revised. Fieldworker estimation of distance was periodically tested and calibrated against various landmarks a known distance from the path of the ferry using a GPS device with preloaded Ordnance Survey maps. The GPS device also recorded the routes that the ferries took, which assisted with calibration of distances. The rangefinder stick method (which uses trigonometry to estimate the distance to an object at sea) was not used because it can only be used effectively in open water or when the opposing shoreline is a constant distance away. For the ferry surveys, the distance to the opposing shoreline on each ferry leg varied significantly - as can be seen from Figures 3, 4 and 5. Recording of those target species which had been recorded on fewer occasions during the surveys previously were prioritised during busy periods when multiple flocks were in view. The objective of the work was not to generate population estimates, only to sample behavioural responses, so this did not introduce any biases into the data.

Each individual/flock which was recorded was observed until the ferry had passed. Behaviour was categorised as either: ‘no response’, ‘swim away’, ‘evasive dive’, or ‘flight’. Where birds exhibited two types of response, for example ‘swim away’ then ‘flight’, only the ‘highest’ response type was recorded (flight > dive > swim away).

This hierarchy was used to exclude short ‘swims’ which often preceded other responses from the analysis. Where individual birds within the same flock exhibited different responses, the different responses were all recorded. Where birds had moved from one distance band to another in response to the approach of the ferry, this was also recorded.

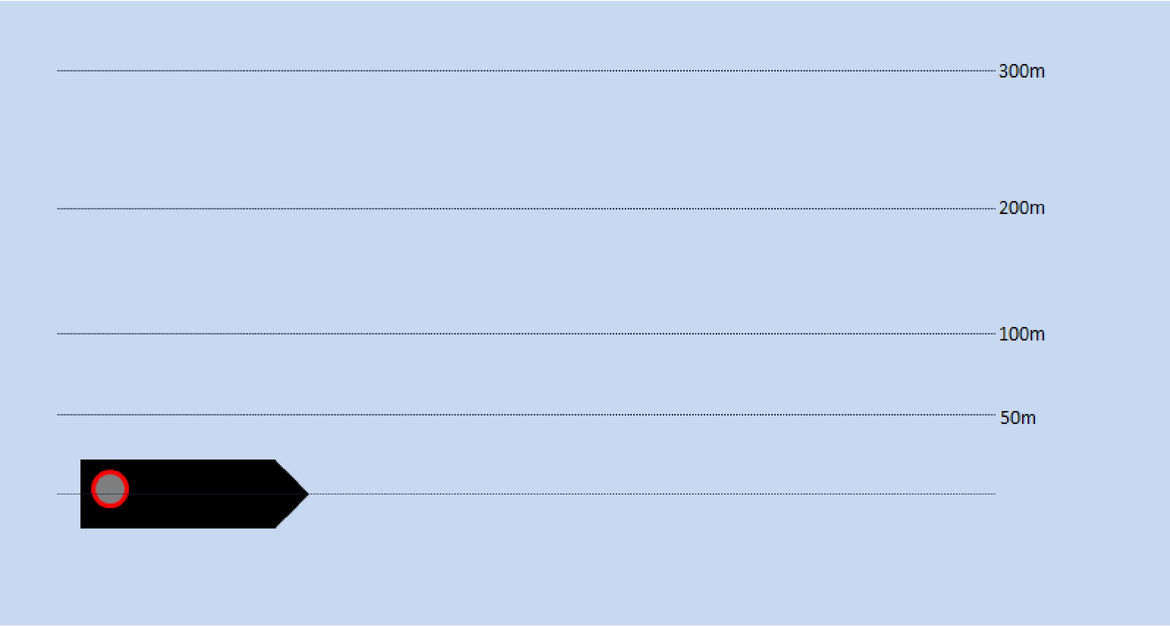


Figure 7: Distance band recording categories.

5. Methodology – Data Analyses

Unless stated otherwise, all analyses were carried out using R version 3.4.0 (R Core Team, 2017).

Vantage Point Surveys

5.1.1. Analysis of Birds in Flight

We used odds ratios (Equation 1) in order to compare the number of flights of each target species originating in a sector in the presence and absence of marine activity (Szumilas 2010).

Equation 1

$$Odds\ Ratio\ = \frac{n\ flying\ after\ activity\ event\ /\ n\ flying\ independent\ of\ activity}{n\ not\ flying\ after\ activity\ event\ /\ n\ not\ flying\ independent\ of\ activity}$$

Where the odds ratio is greater than one, this indicates that a bird is more likely to fly following marine activity than would be expected in the absence of marine activity. If the confidence intervals don't cross one, then the effect is significant. These confidence intervals are estimated using the Delta method, a technique which can be used to summarise the variance associated with ratios (Dorfman 1938; Powell 2007).

As part of our initial, exploratory analysis we plotted summaries of the frequency of birds taking flight in relation to marine activity within a count sector. We found a clear peak in the number of birds recorded taking flight from one minute before marine activity to five minutes afterwards (Figure 8). Consequently, we used this as the basis of our definition of a disturbance event. We summarised the data in order to determine the number of six minute periods within each hour in which there were and were not disturbance events in each sector. We also then summed flights from each of the 11 target species within each six minute period. We tested the sensitivity of our conclusions to these assumptions by considering a range of alternative time periods. It should be noted that this approach treats each disturbance event as independent and does not allow us to investigate the cumulative impact of multiple disturbance events over the space of an hour.

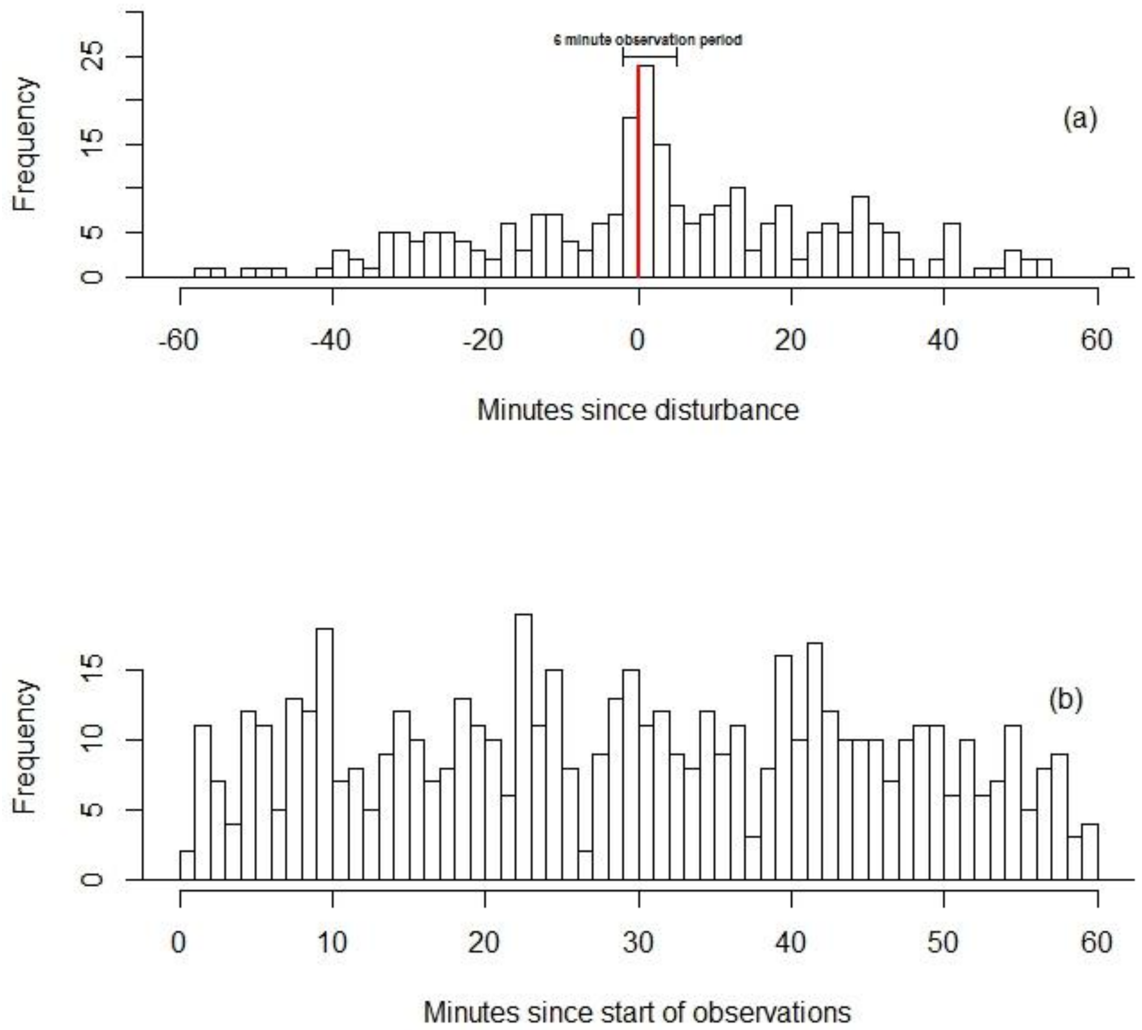


Figure 8: Number of flights for Common Eider in relation to (a) the time since a disturbance event red line indicates the disturbance event (each bar reflects two minutes); and (b) the time since the start of the recording period (each bar reflects one minute).

5.1.2. Analysis of Change in Abundance

Mixed models with site as a random effect and sector as a nested random effect were used to analyse variations in target species abundance in relation to marine activity. Distance sampling, where data are adjusted to take into account reduced detectability at greater distance from the fieldworker, was not used in the analysis because this method assumes that birds are randomly distributed across space. In our VP data, the distribution of target species was influenced by ecological gradients associated with distance from shore, so distance analysis would not have been appropriate. Imperfect detection at greater distance from the fieldworker was accounted for by treating the number of birds in each sector as deviations from a mean population, and thus modelling relative abundance rather than absolute abundance. Closer examination of the count data was suggestive of a zero-inflated Poisson distribution. Consequently, mixed models with a zero-inflated Poisson distribution were fitted using the R package glmmADMB (Fournier et al. 2012).

We considered the impact of time since sunrise, sea state and the presence or absence of disturbance on the number of birds recorded during the vantage point counts. The inclusion of state of tide did not improve models for any species. In order to assess the temporal scale of disturbance effects, we modelled the impact of the presence or absence of disturbance in the previous 10, 15, 30 and 60 minutes separately. Each model was then compared and hierarchically ordered using Akaikes Information Criterion (AIC), a statistic method that rewards parsimony by penalizing the maximum likelihood for the number of model parameters (Akaike, 1973).

Analyses were initially run for all eight sectors and then repeated for the middle four sectors (L2, R2, L3, R3) only, to investigate the effect that the size of the sectors had on our ability to detect significant changes in abundance (the effect of sector size is discussed in more detail in Section 7.4). There were insufficient data to test the effect of different types of marine activity.

Focal Flock Watch Surveys

Initial summaries of the flock watch data were produced to show the number of flock watches for each species and the frequency with which different types of marine activity were recorded. However, analyses were carried out using each five minute recording period (hereafter referred to as '5-minute period') as a separate record. As several different marine activity events can occur during each flock watch, this approach ensures that the analysis assesses the immediate effects of the marine activity. However, it should be borne in mind that: (1) this approach does not take into account the possible cumulative effects of two or more marine activity events happening in a short timescale; (2) as each flock watch comprises up to twelve 5-minute periods, the individual 5-minute periods during each flock watch are not independent of one other. As a result caution should be applied when interpreting the results of significance tests. In order to remove this problem of pseudoreplication, we considered carrying out the analyses at flock level, however, this was discounted because of the effect on sample sizes for each species (see Tables 9 and 10).

Marine activities were grouped into four different categories for the purposes of the analyses (Table 4). In a small number of instances (three flock watches), the vessel recorded was immobile for part or all of the flock watch. These instances were categorised separately from moving vessels and the marine activity was re-coded to "Immobile vessel". A vessel was assumed to be immobile if the recorded distance to the flock did not change for three or more consecutive 5-minute periods.

Table 4: Categories used to group marine activity types.

Category	Marine activity event types included in this level
Static/Shorebound	• Aquaculture activity • Shorebound activity • Immobile vessel[1]
Slow vessel/craft	• Canoe[2] • Yacht • Creel boat • Barge • Ferry • Large Commercial • Pilot boat • Pleasure craft • Work boat
Fast vessel	• Powerboat < 10 m • Powerboat > 10 m

[1] Vessels were assumed to be immobile, if the recorded distance to the flock did not change for three or more consecutive 5-minute periods. Two work boats and one barge were reclassified accordingly.
[2] Canoe was only recorded once. It has been included in this category as it represents a moving rather than a static activity, although of a different scale to the other marine activities included in this category.

To investigate the effects of marine activity, we compared the following responses against the three marine activity categories and also (where appropriate) against 5-minute periods when no marine activity events were recorded, as described below:

5.2.1 Evasive Behaviour

Where the evasive behaviour recorded involved more than one type of response to the same marine activity (for example an evasive swim followed by flight or a dive), only the highest level of evasive behaviour was considered (i.e. the most energetically expensive), with evasive swim being considered the lowest level of evasive behaviour, followed by evasive dive, and evasive flight the highest level. For each species and marine activity category, we calculated the percentage of 5-minute periods during which each type of evasive behaviour was recorded.

5.1.2. Flight

All records of flight were included in the analysis whether they were recorded by the fieldworker to be evasive or not. For each species and marine activity category (including no marine activity), we calculated the percentage of 5-minute periods during which flight activity was recorded.

Chi-squared tests were carried out to assess whether the percentage of 5-minute periods in which flight activity was recorded, differed between 5-minute periods when marine activity events (of any category) occurred and 5-minute periods with no marine activity.

5.1.3. Flight Distances

We investigated how distance between the marine activity and the flock affected the likelihood of flight. Because the number of data points was small for most species, we only produced graphs for Common Eider, Long-tailed Duck, Red-breasted Merganser and Slavonian Grebe, the species for which an (arbitrary) minimum of ten 5-minute periods with marine activity was recorded. Whilst Great Northern Divers were also exposed to the minimum level of marine activity, they were excluded because no flight activity was recorded. A single local polynomial regression line was fitted to each graph along with standard error lines using the R-function 'loess' within the "stats" package in base R version 3.4.0 (R Core Team, 2017). Due to the low number of sample points, each regression line was fitted using the combined points from all three marine activity categories. The regression line was fitted for visualisation only, and no statistical tests were carried out to assess the significance of the relationship. This was for two reasons: (1) due to the low sample sizes; (2) fieldworkers had noted that estimating the distance between the marine event and the flock was extremely challenging (see Section 4.2), and, therefore, the distances are considered to be subject to substantial uncertainty.

5.1.4. Changes in Flock Size

The mean change in flock size as a proportion of the overall size of the flock for a particular 5-minute period was calculated in response to exposure to the three different marine activity categories (Table 4) and compared with mean change in the absence of marine activity. Recorded changes in flock size could be either positive (birds joining the flock) or negative (birds leaving the flock).

Because the data were skewed, Wilcoxon rank sum tests were carried out to assess whether there was a significant difference in the change in flock size due to marine activity. The tests compared the changes in flock size (as a proportion of flock size) during 5-minute periods when marine activity was taking place with 5-minute periods with no marine activity.

In order to assess whether or not tests had sufficient statistical power, we ran a Wilcoxon power test, using R-package ‘samplesize’ version 0.2-4 (Scherer 2016) to identify the minimum sample sizes required, setting power = 0.8 and the error level to 0.05

5.1.5. Changes to Flock Behaviour and Flock Compactness

We carried out exploratory analyses of the flock watch data to investigate whether marine activity was causing changes in flock behaviour (whether birds were diving or loafing) and flock compactness (whether the flock was recorded as “tight” or “dispersed”). We compared the occurrence of changes in flock behaviour or flock compactness following 5-minute periods with marine activity events with changes following periods with no such events.

We investigated two different potential methods for assessing changes in the flock behaviour and flock compactness:

(1) Comparing each 5-minute period with the next 5-minute period only, i.e. whether or not an immediate change had been recorded;

(2) Comparing changes occurring during the subsequent three 5-minute periods following each 5-minute period, i.e. the number of changes recorded during an (arbitrary) 15-minute period.

We were unable to detect any significant increases in the occurrence of changes in flock behaviour or flock compactness following marine activity events, and so did not carry out any further analyses of these variables.

Ferry Surveys

Generalised Linear Models (GLMs, McCullagh and Nelder 1989) were used to analyse the factors affecting the responses (flight, swim, dive and no response) of the target species to the ferries. GLMs were fitted using the ‘glm’ package, and analysis of explanatory variables was carried out using the ‘effect’ packages (Fox 2003). ‘ggplot2’ and ‘ternplot’ were also used for some additional plotting.

Each distinct flock recorded during the data collection was regarded as an individual data point in the analyses, regardless of flock size. There were very few flocks, approximately 1%, where some birds within the flock exhibited a response (flight, dive or swim) whilst other birds within the flock did not. Similarly in less than 1% of flocks the responses of individual birds were mixed within a flock (for example some birds diving and others swimming). In these instances the flocks were considered to be exhibiting more than one response. We chose this flock-level approach because once one bird within a flock has exhibited a response, the responses of other birds within the flock are no longer independent. Finally, for flocks where all birds exhibited no visible response, this flock was a ‘no response’ data point.

Separate fitted models were run for each of the different response categories for each species. Each model was then compared and hierarchically ordered using Akaikes Information Criterion (AIC) (Akaike 1973). The models were simplified by a process of stepwise removal of explanatory terms from the model to obtain the model with the lowest AIC value.

The explanatory terms which were initially tested in all models were flock size, ferry/route, tidal state, sea state, time of day, and time of year.

Data were collected over six different sea states: 0 (101 minutes of data gathering), 1 (775 minutes), 2 (715 minutes), 3 (664 minutes), 4 (798 minutes), 5 (25 minutes). Because there were relatively few data gathered at sea states 0 and 5, to improve sample sizes we combined sea states 0-1, 2-3, and 4-5, giving three different sea state levels used as categorical explanatory terms in the models. To account for the rapidly changing day lengths, we used a time of day index, with 0 as dawn and 1 as sunset. The time of year variable was represented by the number of days passed since 1 November 2016 (the first month during which surveys were carried out).

Following the identification of the best fitting model for each species and response, the effect of significant explanatory variables was analysed and plotted using the ‘effect’ function in R.

6. Results

Vantage Point Surveys

Across the surveys, a total of 499 marine activity events were recorded (Table 5). Kirkwall was the most heavily disturbed site reflecting its use as a key port for the islands. Stromness and Head of Work were also subject to high levels of disturbance. The most frequent type of marine activity was commercial vessels and ferries, with high numbers of fishing vessels and powerboats also recorded.

Table 5: Number of hourly watches carried out and the number and type of marine activity events observed at each vantage point.

	N Hourly Watches	Aircraft	Creel Boat[1]	Commercial/ Ferry[2]	Powerboat	Yacht	Predator	Total
Broch of Gurness	28	0	15	1	1	0	1	18
Quanterness	30	1	21	4	0	1	3	30
Bay of Kirkwall	34	3	37	85	20	8	1	154
Head of Work	31	1	38	39	9	2	1	90
The Breck	32	2	2	28	14	0	0	46
Houton	26	0	7	46	18	1	1	73
Stromness	33	0	20	42	23	0	3	88

[1] Also includes one larger trawler boat.
[2] Includes vessel types: barge, Ferry, Large commercial, Pilot boat, Work boat.

During the vantage point surveys, 34,135 registrations of the 11 target species were recorded (Table 6). European Shag, Common Eider, Long-tailed Duck, Great Northern Diver and Black Guillemot were the most frequent species recorded, being present at all VPs and relatively abundant in areas with marine traffic. Red-breasted Merganser were frequently observed at all the VPs, however because they typically stay close to the shore (per field obs.) they were less frequently in areas affected by marine activity. Slavonian Grebes and Red-throated Divers were present at most of the VPs. Common Goldeneye was very rarely recorded across all surveys. There were only two reliable sites on Orkney for Velvet Scoter of which Quanterness (one of the VP sites) was the only site where marine activity was expected. Black-throated Diver was recorded very sporadically from the VPs, most frequently from Kirkwall Bay.

Table 6: Median (+ range) number of individuals of each species recorded during each vantage point count.

	Common Eider	**Long-tailed Duck**	**Velvet Scoter**	**Common Goldeneye**	**Red-breasted Merganser**	**Red-throated Diver**	**Black-throated Diver**	**Great Northern Diver**	**European Shag**	**Slavonian Grebe**	**Black Guillemot**
Broch of Gurness	2 (0 - 17)	16 (0 - 67)	0 (0 - 0)	0 (0 - 3)	0 (0 - 16)	0 (0 - 5)	0 (0 - 0)	0 (0 - 5)	36 (0 - 281)	0 (0 - 1)	5.5 (0 - 38)
Quanterness	32 (0 - 510)	37 (0 - 200)	29 (0 - 59)	0 (0 - 0)	0 (0 - 23)	0 (0 - 2)	0 (0 - 5)	15 (0 - 49)	4 (0 - 83)	0 (0 - 14)	5 (0 - 46)
Bay of Kirkwall	29 (0 - 90)	37 (0 - 96)	0 (0 - 0)	0 (0 - 0)	3 (0 - 29)	0 (0 - 1)	0 (0 - 2)	2 (0 - 51)	4 (0 - 35)	1 (0 - 5)	9 (0 - 28)
Head of Work	9 (0 - 125)	6 (0 - 59)	0 (0 - 0)	0 (0 - 0)	0 (0 - 11)	0 (0 - 7)	0 (0 - 0)	1 (0 - 34)	17 (0 - 212)	0 (0 - 3)	6 (0 - 54)
The Breck	2 (0 - 23)	2 (0 - 61)	0 (0 - 0)	0 (0 - 0)	0 (0 - 7)	0 (0 - 4)	0 (0 - 32)	6 (0 - 55)	5 (0 - 123)	0 (0 - 13)	8 (0 - 54)
Houton	2 (0 - 9)	1 (0 - 17)	0 (0 - 0)	0 (0 - 2)	0 (0 - 5)	0 (0 - 4)	0 (0 - 1)	2 (0 - 11)	3 (0 - 22)	0 (0 - 2)	8 (0 - 23)
Stromness	14 (0 - 48)	5 (0 - 50)	0 (0 - 0)	0 (0 - 0)	0 (0 - 42)	0 (0 - 3)	0 (0 - 1)	0 (0 - 16)	53 (0 - 489)	0 (0 - 1)	9 (0 - 29)

6.1.1 Flight Activity

Our analyses indicate that Common Eider, Long-tailed Duck and European Shag were all significantly more likely to fly in response to marine activity events than would be expected by chance (Figure 9). Velvet Scoter also appear to show a strong response although it should be noted that this result was based on a small sample size, with the species only exposed to eight marine activity events. Similarly, whilst Red-throated and Great Northern Divers appeared to show a strong response to marine activity events, these effects were not significant. For Black Guillemot and Red-breasted Merganser, no significant effect on the likelihood of flight following marine activity were detected. No Common Goldeneyes or Slavonian Grebes were recorded flying following marine activity events although analyses of the Common Goldeneye data were based on a very limited sample size (n = 50 birds). Finally, since no Black-throated Divers flights were recorded at any time during any of the vantage point surveys, this analysis was not possible for this species.

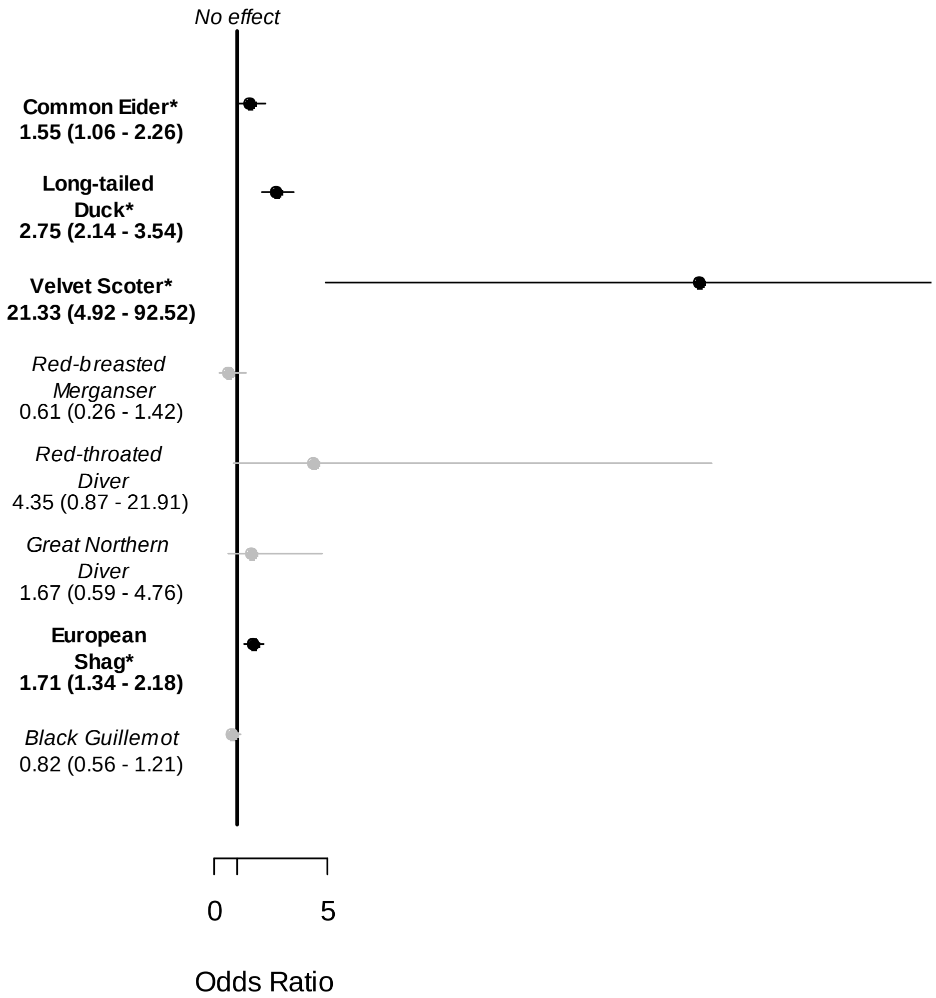


Figure 9: Odds ratios describing the likelihood of a species taking flight during a disturbance event, relative to the level of flight activity in the absence of disturbance. At the 'no effect' line, flight probability during disturbance events was equal to flight probability at other times. The further to the right of the line a species is, the more effect disturbance has on flight activity. Numbers given are the odds ratios and associated 95% CIs. For example, the ratio for Common Eider (1.55) shows that this species is 1.55 times more likely to take flight when a disturbance event is taking place, within confidence intervals of 1.06 – 2.26. Where confidence intervals overlap with 1, the effect is not significant. *Indicates those species for which a significant effect was found. Where the effect was significant, values are plotted in black, where the effect was not significant values are plotted in grey.

6.1.2 Change in Abundance

The best fitting model varied by species (Table 7). However, there was often little to choose between the different models. Generally, for each species, the same model was identified as the best fit for all four time periods. However, this was not the case for European Shag and Slavonian Grebe. In order to ensure that parameter estimates were comparable across time periods for these species, the model with the lowest AIC values across the most time periods was selected (Table 7).

Table 7: AIC Values for competing models to investigate changes in response to disturbance occurring least once in the previous 10, 15, 30 or 60 minutes within vantage point sectors L2, R2, L3 and R3. "Best" model (with the lowest AIC value) used for further analysis indicated in bold. Models which did not converge indicated by -.

	10 mins	15 mins	30 mins	60 mins
Common Eider				
~Disturbance + Time since Sunrise+ Sea State	2367	2369	2353	2366
~Disturbance + Time Since Sunrise	2398	2401	2389	2394
~Disturbance + Sea State	**2366**	**2369**	**2352**	**2366**
~Disturbance	2396	2399	2388	2393
Long-tailed Duck				
~Disturbance + Time since Sunrise+ Sea State	**3104**	**3113**	**3108**	**-**
~Disturbance + Time Since Sunrise	3112	3122	3121	-
~Disturbance + Sea State	3129	3129	3124	3131
~Disturbance	3130	3134		3136
Red-breasted Merganser				
~Disturbance + Time since Sunrise+ Sea State	-	498	-	-
~Disturbance + Time Since Sunrise	496	496	496	493
~Disturbance + Sea State	-	496	-	-
~Disturbance	**494**	**494**	**494**	**492**
Red-throated Diver				
~Disturbance + Time since Sunrise+ Sea State	275	275	-	-
~Disturbance + Time Since Sunrise	267	267	268	268
~Disturbance + Sea State	275	275	275	275
~Disturbance	**267**	**267**	**267**	**267**
Great Northern Diver				
~Disturbance + Time since Sunrise+ Sea State	-	1146	1116	-
~Disturbance + Time Since Sunrise	1143	1143	1113	1134
~Disturbance + Sea State	-	-	-	-
~Disturbance	**1141**	**1142**	**1112**	**1133**
European Shag				
~Disturbance + Time since Sunrise+ Sea State	3746	3745	3770	3723
~Disturbance + Time Since Sunrise	3806	3787	3775	
~Disturbance + Sea State	**3745**	**3737**	**3741**	**3728**
~Disturbance	3795	3795	3801	3781
Slavonian Grebe				

~Disturbance + Time since Sunrise+ Sea State	-	-	-	-
~Disturbance + Time Since Sunrise	397	397	396	398
~Disturbance + Sea State	388	-	-	-
~Disturbance	**396**	**396**	**395**	**397**
Black Guillemot				
~Disturbance + Time since Sunrise+ Sea State	2634	-	2635	2635
~Disturbance + Time Since Sunrise	2638	2640	2639	-
~Disturbance + Sea State	**2634**	**2636**	**2635**	**-**
~Disturbance	2637	-	2638	2639

Common Eider

For Common Eider, the most parsimonious model included an effect of marine activity and sea state with fewer birds being detected in sea states greater than three. When considering all eight sectors and including marine activity in the tne minutes prior to the count, there was a significant and strong effect of marine activity reducing abundance of Common Eider. However, at this spatial scale, no impact of marine activity could be detected over longer time periods (Figure 10). When analyses were restricted to only the middle four sectors, the size of the effect of marine in the ten minutes prior to the count was less pronounced. However, at this spatial scale, an effect of marine activity was evident for 15 and 30 minutes as well. It is also noticeable that there was less uncertainty surrounding the estimated effect sizes at this reduced spatial scale.

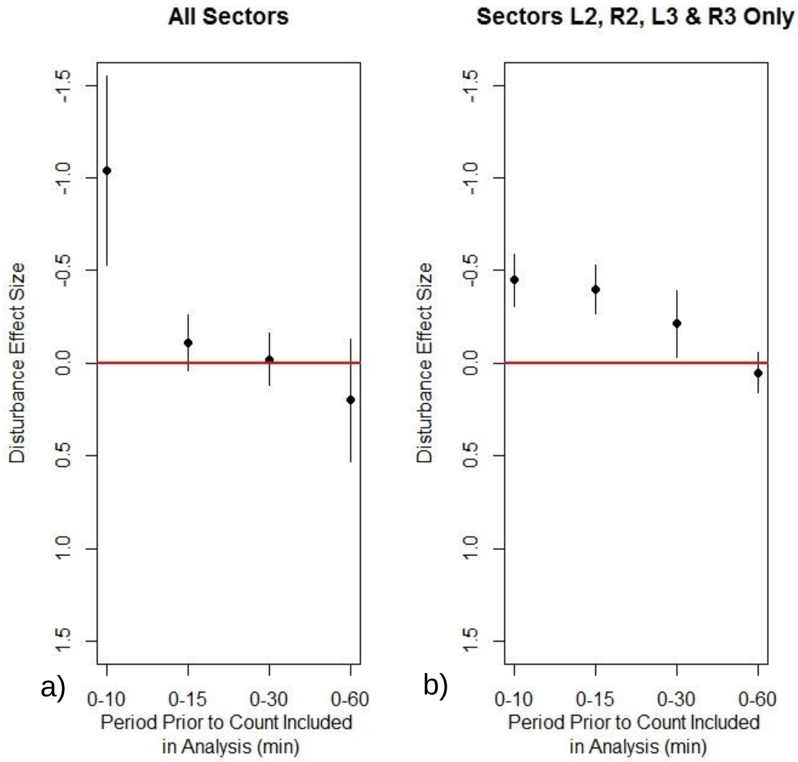


Figure 10: Change over time for effect size in relation to disturbance activity for Common Eider. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity.

Long-Tailed Duck

For Long-tailed Duck, the most parsimonious model included an effect of time since sunrise (fewer birds detected later in the day), sea state, (fewer birds detected in sea states greater than three) and marine activity. When considering all eight sectors, there was no significant effect of marine activity on the number of Long-tailed Ducks recorded (Figure 11). However, when analyses were restricted to the middle four sectors, and marine activity in the 10, 15, and 30 minutes prior to the count was included, there was a significant relationship between marine activity and reduced abundance of Long-tailed Ducks (Figure 11). The model including marine activity in the 60 minutes prior to the count did not converge.

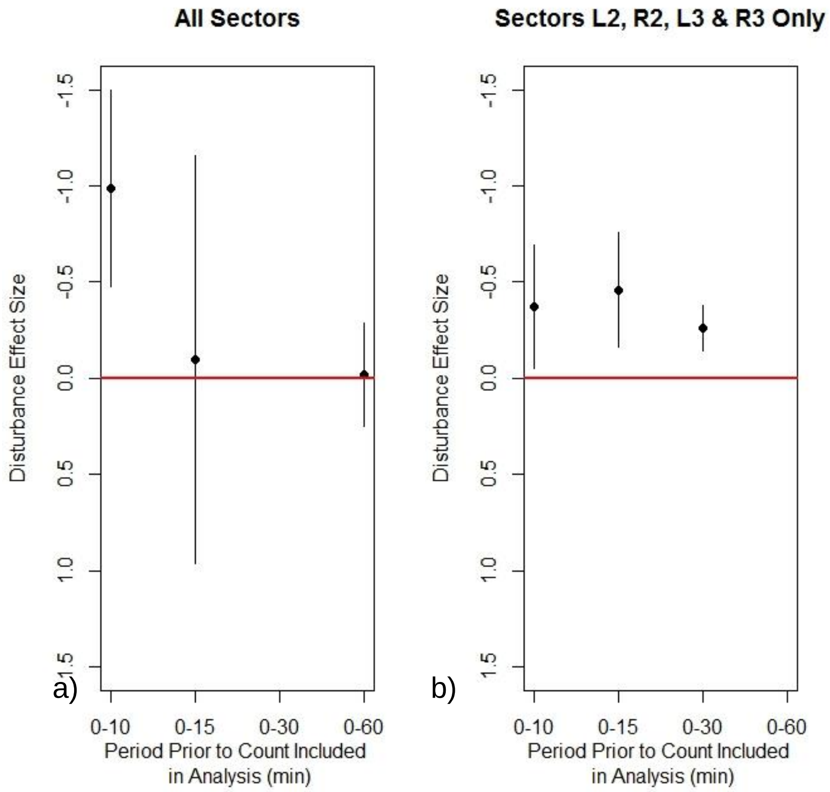


Figure 11: Change over time for effect size in relation to disturbance activity for Long-Tailed Duck. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity. Note that the models for the 0-30 minute time period for all sectors, and the 0-60 minute time period for the middle four sectors did not converge.

Red-Breasted Merganser

The most parsimonious model for Red-breasted Merganser only included an effect of marine activity. When considering all eight sectors, models only converged for marine activity recorded in the 60 minutes prior to the count. This effect was not significant (Figure 12). When assessing the middle four sectors only, and including marine activity in the 15, 30 and 60 minutes prior to the count, the effect appeared to be negative, although the relationships was not significant.

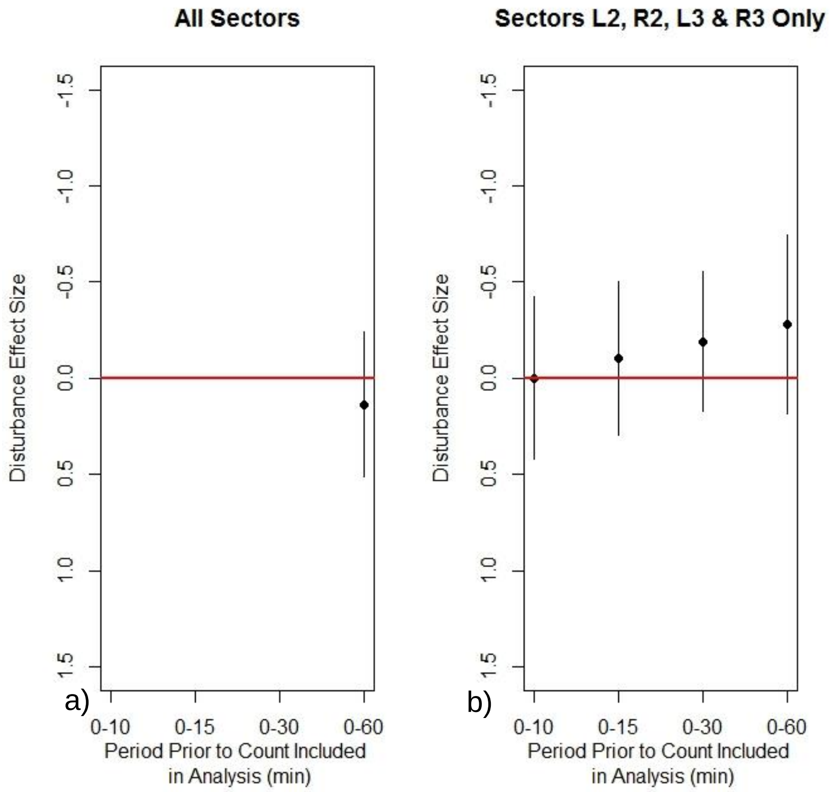


Figure 12: Change over time for effect size in relation to disturbance activity for Red-breasted Merganser. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity. Note that for all sectors, only the model for the 0-60 minute time period converged.

Red-Throated Diver

The most parsimonious model for Red-throated Diver only included an effect of marine activity. When considering all eight sectors, models only converged when considering marine activity in the 60 minute period prior to the count. This effect was not significant (Figure 13). When assessed for the middle four sectors only and including marine activity in the 30 minute period prior to the count, the effect appeared to be negative, although this relationship was not significant.

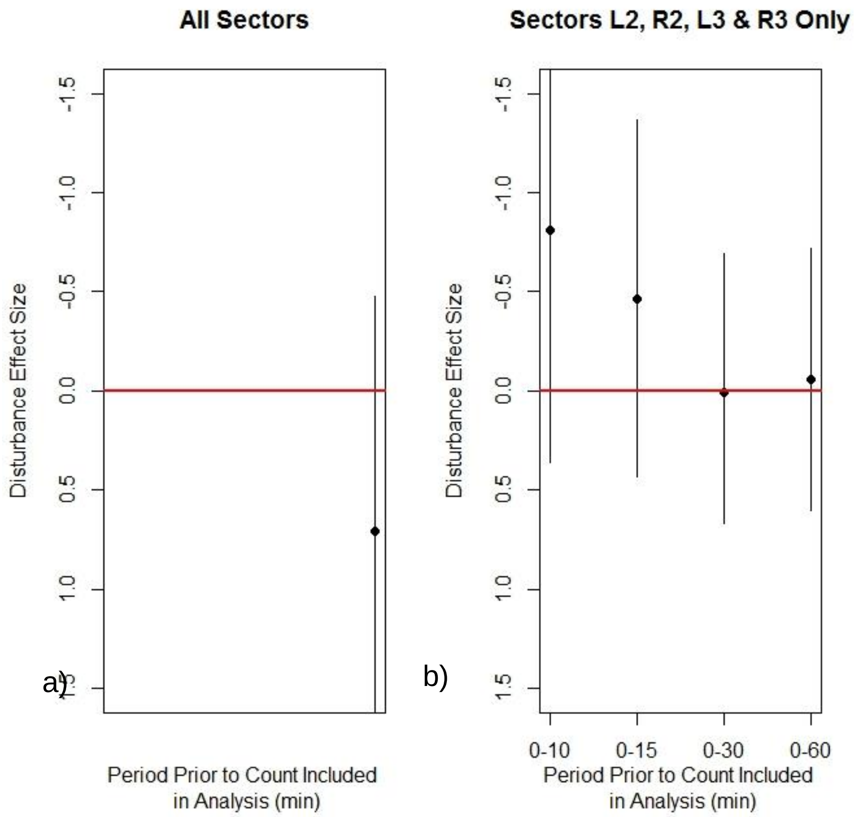


Figure 13: Change over time for effect size in relation to disturbance activity for Red-throated Diver. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity. Note that for all sectors, only the model for the 0-60 minute time period converged.

Great Northern Diver

The most parsimonious model for Great Northern Diver only included an effect of marine activity. When considering all eight sectors, there was a significant effect on abundance when including marine activity in the 10 and 15 minute periods prior to the count (Figure 14).

When only the middle four sectors were considered, there was a significant effect on abundance when including marine activity in the ten minute period prior to the count (Figure 14), although the standard error was larger when the sectors were restricted to the middle four sectors. This is likely to be a result of the high detectability of Great Northern Divers (because they are the largest of the target species) resulting in better quality data in the L4/R4 sector, and the usual distribution of this species further from shore.

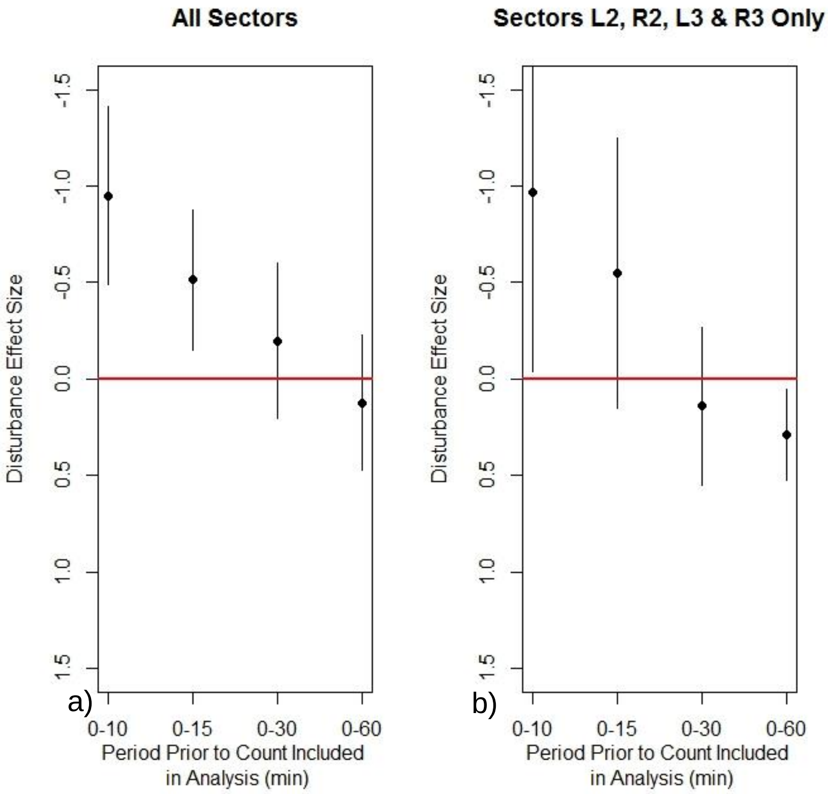


Figure 14: Change over time for effect size in relation to disturbance activity for Great Northern Diver. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity..

European Shag

The most parsimonious model for European Shag included effects of sea state and marine activity. Fewer birds were recorded at both spatial scales at sea state three or higher. No effect of marine activity could be detected when all eight sectors were considered. However, when only the middle four sectors were considered, there appeared to be a reduction in the number of birds recorded when analysing marine activity in 10 and 15 minute periods prior to the count. (Figure 15)

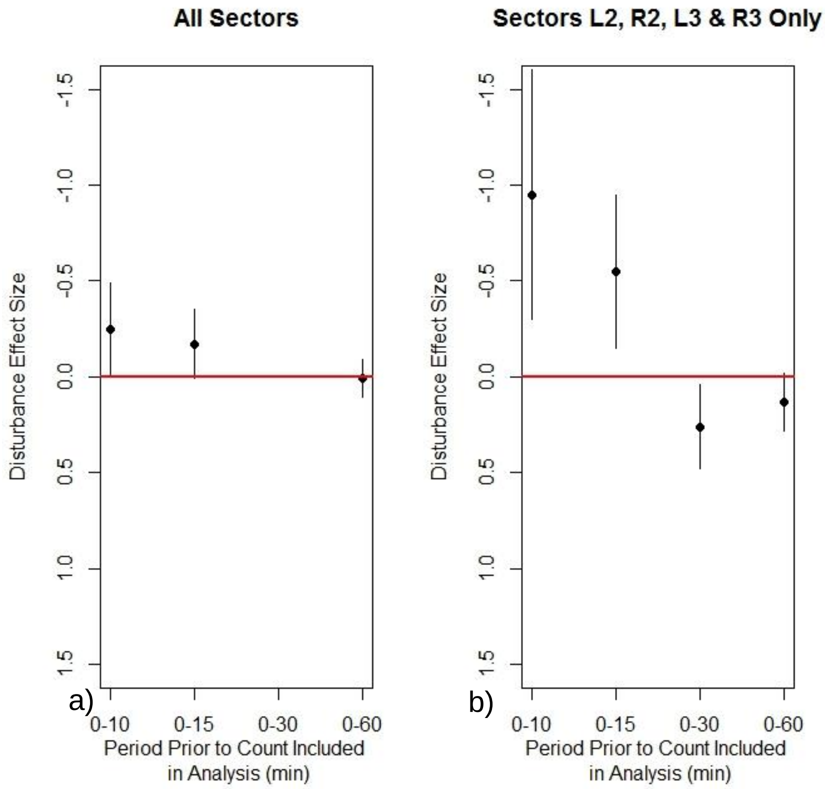


Figure 15: Change over time for effect size in relation to disturbance activity for European Shag. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity. Note that the model for the 0-30 minute time period for all sectors did not converge.

Slavonian Grebe

The most parsimonious model for Slavonian Grebe only contained an effect of disturbance. However, this effect was not significant, with no clear effect of disturbance on the number of birds recorded at either spatial scale (Figure 16).

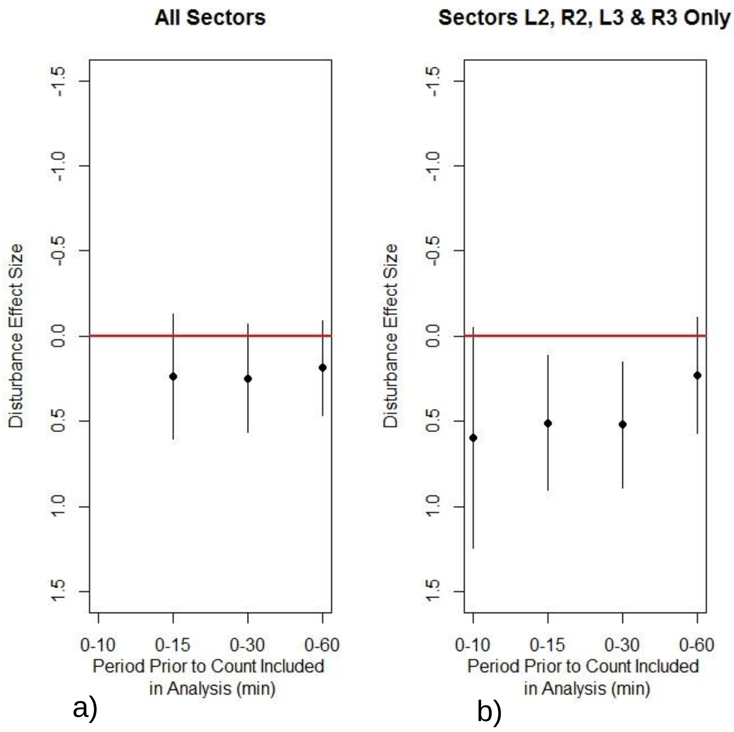
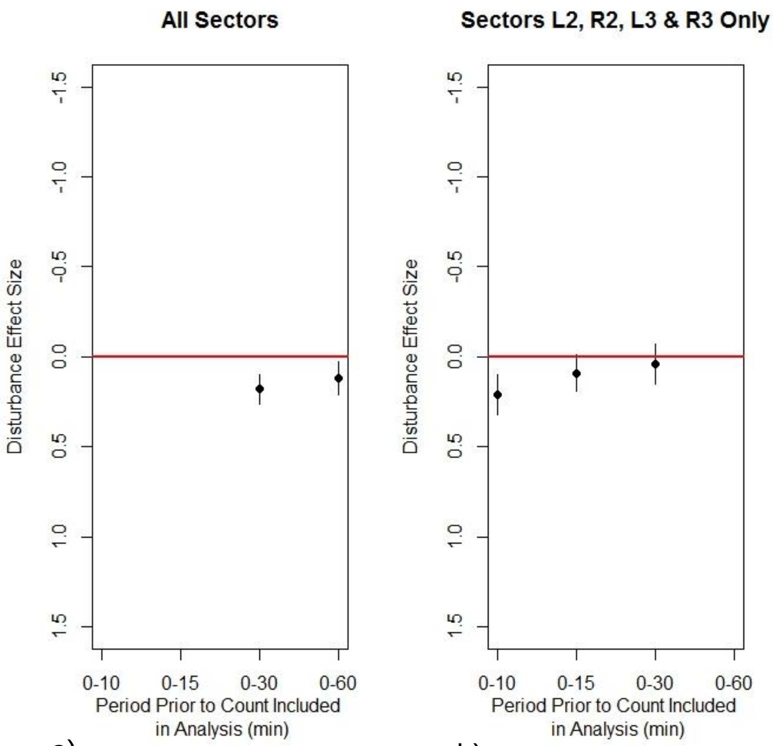


Figure 16: Change over time for effect size in relation to disturbance activity for Slavonian Grebe. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity. Note that the model for the 0-15 minute time period for all sectors did not converge.

Black Guillemot

The most parsimonious model for Black Guillemot included effects of sea state (less birds recorded in higher sea states) and marine activity, but marine activity did not appear to impact the number of Black Guillemots recorded at either spatial scale, in fact more birds were recorded in counts following marine activity (Figure 17).



a) b)

Figure 17: Change over time for effect size in relation to disturbance activity for Black Guillemot. Assessed for all eight sectors (a) and middle four sectors only (b). Where confidence intervals cross the red line this indicates no significant effect of marine activity. Where effect size is negative (above the red line) this indicates that abundance was reduced following marine activity. Note that the models for the 0-15 and 0-30 minute time period for all sectors, and 0-60 minute time period for the middle four sectors did not converge.

6.1.3 Summary of Vantage Point Survey Results

The analysis of the vantage point survey abundance data shows that the size and significance of the effect of disturbance for each species depends on the scale at which the analysis is carried out. This may be a consequence of the size of the datasets per species, or variation in the abundance, distribution and detectability of target species, as well as differences in behavioural responses to disturbance. As such, the results do not lend themselves easily to the making of comparisons between the sensitivities of the target species. However the key results from the vantage point surveys are summarised in Table 8, showing the significance of the effect of marine activity on flight activity and changes in abundance detected for the target species.

The results for Great Northern Diver should be highlighted – even though Great Northern Divers very rarely fly in response to marine activity, preferring to swim or dive, their abundance in an area can be significantly reduced following marine activity. This suggests that when considering the disturbance effects of marine activity, it may not be appropriate to consider flight response more significant than evasive swimming or evasive diving in predicting displacement effects.

Table 8: Summary of results from the vantage point surveys. For species marked as NA there was not enough data to draw any conclusions. Colours indicated magnitude of response to disturbance from black (strongest) to pale grey (weak/no response).

Species	**Flight response**[1]	**Change in Abundance**[2]
Common Eider		
Long-tailed Duck		
Velvet Scoter		**NA**
Common Goldeneye	**NA**	**NA**
Red-breasted Merganser		
Red-throated Diver		
Black-throated Diver	**NA**	**NA**
Great Northern Diver		
European Shag		
Slavonian Grebe	**NA**	
Black Guillemot		

Colours assigned as follows: [1]Effect size >1 & CI's do not overlap with 1 (black), Effect size >1 & CI's overlap with 1 (dark grey), Effect size <1 (light grey); [2] Numbers of birds present significantly reduced 30 minutes or more after disturbance (black), Numbers of birds present significantly reduced for less than 30 minutes following disturbance (dark grey), no significant reduction in the number of birds present (light grey).

Focal Flock Watches

A total of 139 flock watches were carried out, covering all 11 target species. Of these, 47 were carried out at the VP locations, with the others carried out at 56 additional locations (Table 9; Figure 2).

Table 9: The number of flock watches carried out at the seven VP locations, by species, and the total number carried out at other locations.

	Common Eider	Long-tailed Duck	Velvet Scoter	Common Goldeneye	Red-breasted Merganser	Red-throated Diver	Black-throated Diver	Great Northern Diver	European Shag	Slavonian Grebe	Black Guillemot	Total
Gurness	0	1	0	0	1	0	0	0	0	0	0	2
Head of Work	4	0	0	0	0	0	0	0	1	0	1	6
Kirkwall Harbour	5	8	0	0	3	0	0	2	1	4	0	23
Quanterness	0	0	1	0	0	0	0	0	1	0	0	2
Houton	1	0	0	0	0	0	0	1	0	1	1	4
The Breck	0	0	0	0	0	0	1	1	0	0	0	2
Stromness	1	1	0	0	2	1	0	0	2	0	1	8
Other sites	16	16	5	2	22	2	2	14	3	10	0	92
Total	27	26	6	2	28	3	3	18	8	15	3	139

A total of 119 flock watches (86%) lasted for a full hour; the remaining counts were cut short after the flock left the area or moved out of view (Table 10). In total, the flock watches captured data covering 1,555 five minute periods.

During the flock watches, a total of 274 marine activity related events were recorded, occurring across 269 different 5-minute periods (i.e. there were six instances where two such events occurred during a 5-minute period). This equates to 17% of the total recording time. Three additional potential disturbance events related to aerial predators were noted but did not appear to illicit a response from the observed flock.

In around 60% of flock watches, motorised boat or ship traffic was recorded at least once during the watch, with a total of 14% of watches recording activity by powerboats. Forty-two flock watches (30%) had no marine activity events during the 1-hour watch, including all three watches on Black-throated Divers.
The duration of the marine activity events was also variable, with some events being very brief, and others occurring continuously over multiple 5-minute periods within

the same flock watch, or re-occurring on more than one occasion during the same watch. Generally, marine activity by fast vessels and the majority of activity by slow moving vessels tended to be of short duration, whereas static activity tended to be longer and often lasted for most or all of the flock watch. The longer incidents of marine activity related to aquaculture activity, immobile vessels, or work boats or creel boats which were moving but remained within the area.

6.2.1 Evasive Behaviour

A total of 106 instances of evasive behaviour (evasive flights, dives or swims made by one or more bird within the flock) were recorded during the flock watches. These are summarised in Table 11.

Table 10: Summary of flock watches. The flock size details are based on the mean flock size for each watch and the category of marine activity which occurred – note in some flock watches, more than one category of marine activity was recorded.

Species	Number of complete (and incomplete) flock watches	Total number 5-minute periods	Flock Size			Number of flock watches with marine activity recorded (or not)			
			Med.	Min.	Max.	No activity recorded	Static/ Shore-bound*	Slow vessel/ Craft*	Fast vessel*
Common Eider	24 (3)	313	20	2	500	6	3	18	3
Long-tailed Duck	22 (4)	282	12	2	160	5	2	19	7
Velvet Scoter	6 (0)	72	15	1	27	4	0	1	1
Common Goldeneye	1 (1)	15	2	1	2	0	0	2	0
Red-breasted Merganser	22 (6)	303	5	2	32	7	4	17	4
Red-throated Diver	2 (1)	30	2	1	3	1	0	2	1
Black-throated Diver	3 (0)	36	4	3	6	3	0	0	0
Great Northern Diver	18 (0)	216	4	1	30	6	2	12	1
European Shag	7 (1)	87	64	3	293	6	0	2	0
Slavonian Grebe	11 (4)	165	3	1	10	3	1	10	2
Black Guillemot	3 (0)	36	4	1	8	1	0	1	1
Total	119(20)	1555	-	-	-	42	12	84	20

* See Table 4 for definitions

Table 11: The percentage of five min periods in which an evasive behaviour was recorded when flock was exposed to different types of marine activity. Where more than one evasive behaviour was recorded in the same 5-minute period, only the *highest* level recorded is shown (see text for further details). The total percentage of 5-minute periods during which each type of evasive behaviour was recorded is also shown.

Species	**Marine activity events**														
	Static/Shorebound*					**Slow vessel/craft***					**Fast vessel***				
	% evasive swim	**% evasive dive**	**% evasive flight**	**% any evasive behaviour***	**No. 5-minute periods**	**% evasive swim**	**% evasive dive**	**% evasive flight**	**% any evasive behaviour***	**No. 5-minute periods**	**% evasive swim**	**% evasive dive**	**% evasive flight**	**% any evasive behaviour****	**No. 5-minute periods**
Common Eider	9	0	0	9	23	20	6	12	39	49	0	0	50	50	4
Long-tailed Duck	0	0	0	0	13	5	2	31	38	42	0	0	89	89	9
Velvet Scoter	-	-	-	-	0	33	0	33	67	3	0	0	100	100	1
Common Goldeneye	-	-	-	-	0	0	33	33	67	3	-	-	-	-	0
Red-breasted Merganser	0	0	0	0	7	23	6	23	52	31	25	0	50	75	4
Red-throated Diver	-	-	-	-	0	50	17	33	100	6	0	0	100	100	1
Black-throated Diver	-	-	-	-	0	-	-	-	-	0	-	-	-	-	0
Great Northern Diver	0	0	0	0	13	7	33	0	41	27	0	0	0	0	1
European Shag	-	-	-	-	0	0	50	50	100	2	-	-	-	-	0
Slavonian Grebe	0	0	0	0	2	0	13	21	33	24	0	0	50	50	2
Black Guillemot	-	-	-	-	0	0	0	100	100	1	0	100	0	100	1

*** See Table 4 for definitions. ****As a result of rounding, some totals do not equal the sum of the individual behaviour types.

6.2.2 Flight Responses

For most species, flight activity was recorded more frequently during the 5-minute periods when marine activity events occurred. Great Northern Diver was a notable exception as it was never recorded taking flight (Figure 18).

Chi-squared tests can only be reliably carried out when the expected frequencies are >5 (Gardener 2017). As a result, tests were only carried out for three species, and were highly significant for all: Common Eider (test value 33.9, df = 1, p<0.0001); Long-tailed Duck (test value 19.9; df = 1, p < 0.0001); Red-breasted Merganser (test value 27.6, df = 1, p < 0.0001). In all instances, flight activity occurred more often during 5-minute periods during which a marine activity event occurred.

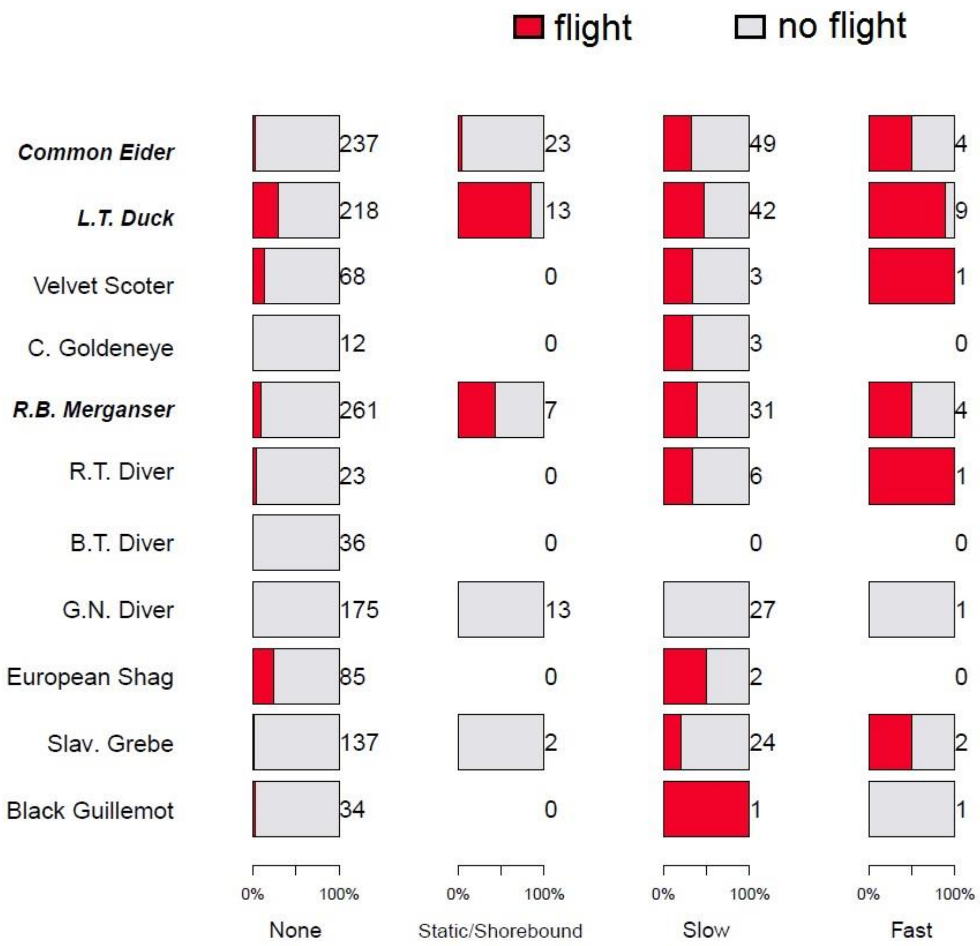


Figure 18: Percentage of 5-minute periods with flight activity by one or more birds within the flock by marine activity category and species. The number after each bar shows the total number of records. The species shown in bold showed significantly greater flight activity during periods when marine activity occurred.

6.2.3 Flight Distances

Figure 19 shows flight initiation distances in the presence of different types of marine activity. The regression lines have been added for visualisation only, but fit the data well for Common Eider and Slavonian Grebe, suggesting responses to marine activity drop off at around 200 m for both species (although this is based on a low number of data points for Slavonian Grebe, and on only one data point for Eider beyond 500 m). The fit is poorer for Long-tailed Duck, for which it is difficult to interpret responses at distances greater than 400 m. The regression line for Red-breasted Merganser also cannot be interpreted due to variable flight responses across all distances and may reflect the relatively low number of data points (Figure 19).

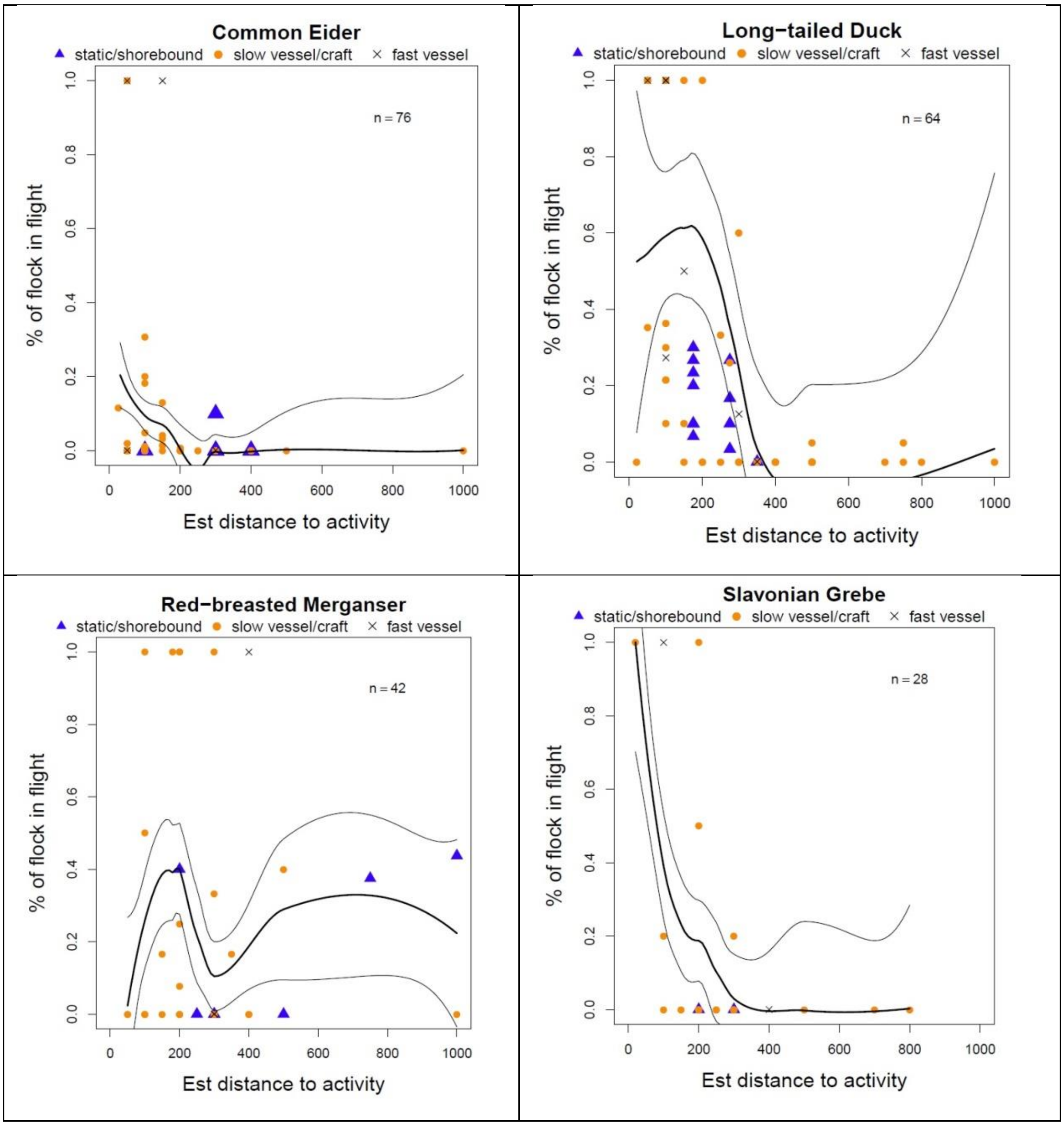


Figure 19: Estimated distance from marine activity at which flight activity occurred, showing the % of the flock recorded in flight. A fitted local polynomial regression line is shown on ach graph (in bold) along with standard error lines. This is for visualisation only and the lines not necessarily indicate any statistically significant relationship.

6.2.4 Changes in Flock Size

Wilcoxon rank sum test results were significant for Long-tailed Duck, for which significantly larger reductions in flock size occurred during 5-minute periods when marine activity events occurred, than in 5-minute periods when no marine activity events occurred. The analyses suggest larger reductions in flock size may also occur for other species when marine activity events occur, in particular Red-breasted Merganser (Table 12). However, results were not found to be significant for any other species, (Table 13). A test could not be run for Black-throated Diver because there were no flock watches during which a marine activity occurred.

Table 12: Mean percentage change in flock size during 5-minute periods in which different categories of marine activity event occurred.

Species	Category of Marine activity							
	None		Static/Shore bound*		Slow vessel*		Fast vessel*	
	No. 5-minute periods	Mean % change in flock size	No. 5-minute periods	Mean % change in flock size	No. 5-minute periods	Mean % change in flock size	No. 5-minute periods	Mean % change in flock size
Common Eider	237	-1	23	-1	49	0	4	-25
Long-tailed Duck	218	0	13	0	42	-5	9	-33
Velvet Scoter	68	1	0	-	3	0	1	0
Common Goldeneye	12	-3	0	-	3	-33	0	-
Red-breasted Merganser	261	0	7	8	31	-9	4	-41
Red-throated Diver	23	-1	0	0	6	-17	1	0
Black-throated Diver	36	0	0	0	0	-	0	-
Great Northern Diver	175	2	13	0	27	0	1	0
European Shag	85	3	0	-	2	-50	0	-
Slavonian Grebe	137	1	2	0	24	1	2	-50
Black Guillemot	34	-1	0	-	1	0	1	0

*See Table 4 for definitions

Table 13: Wilcoxon test results comparing the change in flock size (as a proportion of flock size) during periods in which a marine activity event was recorded with the change in flock size during periods when no marine activity event was recorded. The number of records in each group are shown next to the test value (w). Significant results (p-value<0.05) are shown in bold. Results are shown in italics indicate where the test did not have sufficient statistical power as one or both sample sizes too low (power <0.8).

Species	**Test results**
Common Eider	$W_{237,76}$=9223, p=0.59
Long-tailed Duck	**W218,64=7724,p=0.01**
Velvet Scoter	$W_{68,4}$=140,p=0.76
Common Goldeneye	*$W_{12,3}$=23,p=0.40*
Red-breasted Merganser	$W_{261,42}$=6155,p=0.09
Red-throated Diver	*$W_{23,7}$=89,p=0.37*
Great Northern Diver	$W_{175,41}$=3793,p=0.15
Shag	$W_{85,2}$=128,p=0.06
Slavonian Grebe	$W_{137,28}$=1961,p=0.64
Black Guillemot	$W_{34,2}$=33,p=90

Ferry Surveys

Data were recorded on the three routes shown in Figures 3-5. In total there were nine different journey legs (there were multiple stops on some routes) as shown in the first column of Table 14. A total of 6,094 registrations of target species were made, the most common being Common Eider (1,784) and Black Guillemot (1,650), and the rarest being Velvet Scoter (1) and Common Goldeneye (11). Table 14 shows the total number of registrations made of flocks of target species on each journey leg (outward journeys and return journeys are summed together). For those species rarely recorded, Velvet Scoter did not frequent the areas the ferry routes took, and Common Goldeneye were very scarce offshore. However, for Slavonian Grebe and Black-throated Diver, though both species are also relatively scarce, it is possible that these species were avoiding areas with regular marine activity because of their likely sensitivity to marine activity.

Table 14: Summary of registrations by species on each section of the three ferry routes.

Journey leg (number of trips on leg in brackets)	Common Eider	Long-tailed Duck	Velvet Scoter	Common Goldeneye	Red Breasted Merganser	Red Throated Diver	Black-Throated Diver	Great Northern Diver	European Shag	Slavonian Grebe	Black Guillemot	Total
Lyness-Flotta (22)	320	166	0	2	27	4	3	45	61	1	202	**831**
Lyness-Houton (30)	416	254	0	5	44	18	15	224	146	25	633	**1,780**
Houton-Flotta (14)	56	67	0	0	23	4	3	138	74	7	212	**584**
Rousay-Tingwall (36)	791	128	1	4	25	40	0	31	756	1	336	**2113**
Rousay-Wyre (22)	43	24	0	0	11	2	0	4	23	0	49	**156**
Shapinsay-Kirkwall (4)	7	34	0	0	2	0	0	3	18	0	40	**104**
Egilsay-Wyre (8)	57	31	0	0	3	8	0	14	32	0	80	**225**
Rousay-Egilsay (7)	70	17	0	0	3	10	0	13	28	0	77	**218**
Wyre-Tingwall (1)	24	6	0	0	0	2	0	3	27	0	21	**83**
Total (144)	**1784**	**727**	**1**	**11**	**138**	**88**	**21**	**475**	**1165**	**34**	**1650**	**6094**

6.2.5 Comparison of Evasive Responses Between Species

Slavonian Grebe, Red-throated Diver and Black-throated Diver were the most likely species to respond to the passing ferry, and Black Guillemot the least likely, with over 75% of Black Guillemot registrations being ‘no response’ records (Figure 20). There was also variation in the types of responses recorded across the target species. The highest propensity to fly in response to marine activity was shown by Long-tailed Duck, Red-throated Diver and Slavonian Grebe, whilst the least likely species to fly were Great Northern Diver, Black-throated Diver and Black Guillemot. Great Northern Diver and Black-throated Diver were more likely to swim away in response to the ferry, which in combination with diving accounted solely for the evasive behaviour of the latter species.

Figure 20 is likely to be a reasonable representation of relative sensitivities of the target species to marine activity (or at least to regular ferry services) – the larger the ‘no response’ section of column, the less sensitive the species is likely to be. The small sample sizes for Black-throated Diver and Slavonian Grebe should also be borne in mind when considering this figure.

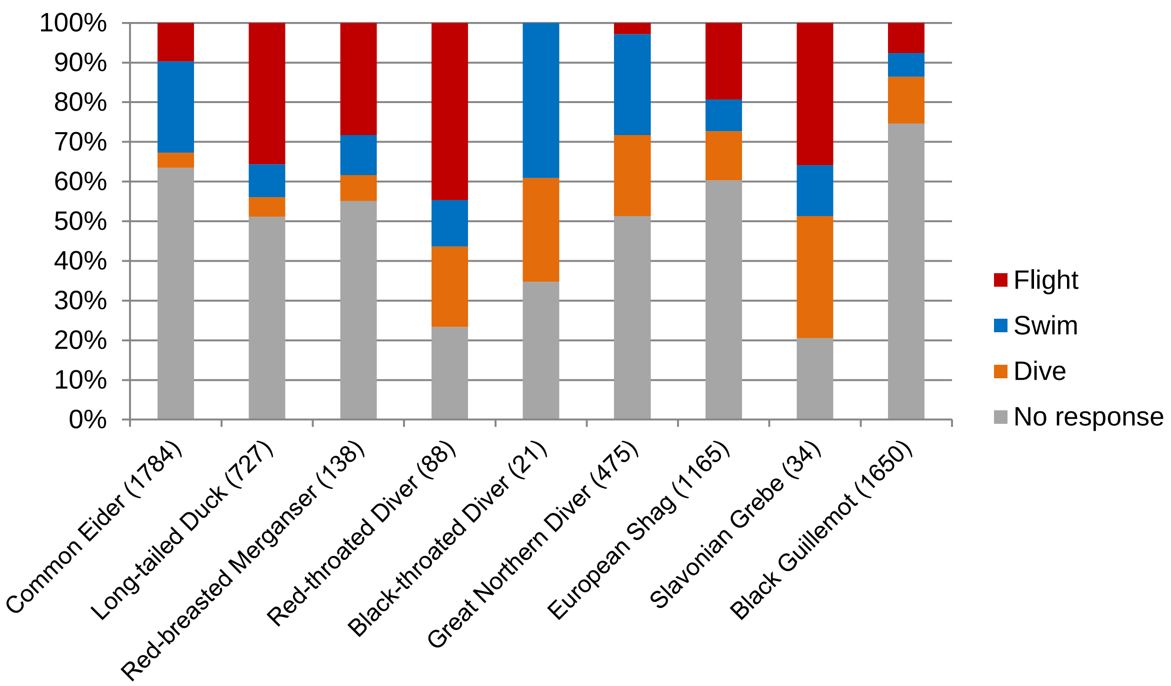


Figure 20: Summary of responses in relation to ferry traffic by species (summed over all distance bands). Velvet Scoter (1 record) and Common Goldeneye (11 records) are not shown because of the low number of records. Sample sizes are shown in parentheses.

Within the 0-50 m distance band, where an evasive response to the approaching ferry is likely to be unavoidable for most species, differences in evasive strategies are more marked. Figure 21 shows the evasive strategies (flight, swim or dive) for the target species with >20 records in the 0-50 m band. Long-tailed Duck have a very strong preference for flight (76% of responses), while Great Northern Diver, in contrast, had a strong aversion to flight (3%). Common Eider showed a strong preference for swimming away (63%). Shag had a more mixed strategy, favouring flight (43%) and Black Guillemot also had a mixed strategy but favouring evasive dives (46%).

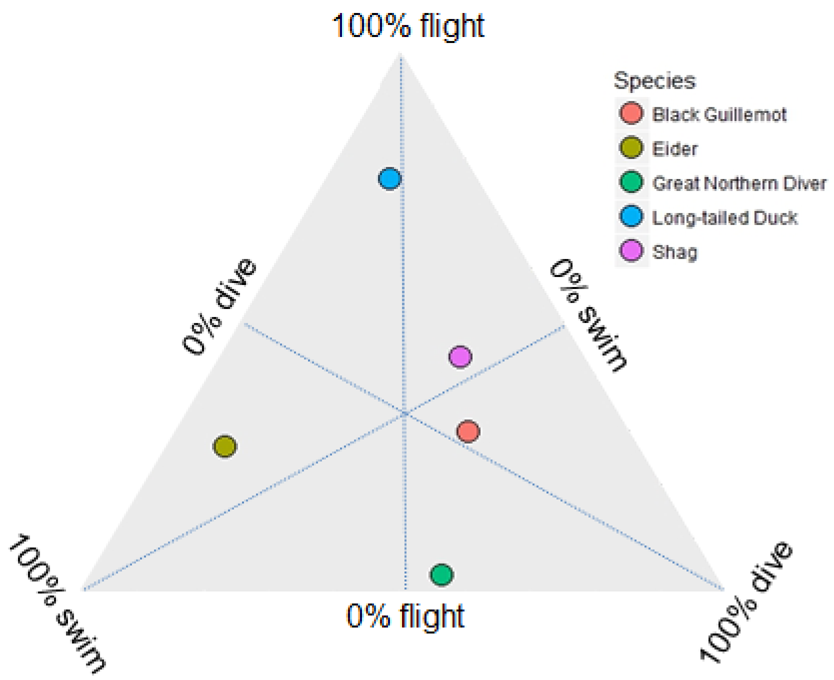


Figure 21: Evasive strategies of five waterbird species to ferry passes within 50 m (0-50 m distance band). The position on the plot shows the percentage of responses for each species that were categorised as either flight, swim or dive, excluding 'no response'. At the point when the three axes meet in the centre of the chart, responses would be split 33:33:33 between swim, dive and flight.

Given the challenges associated with recording on ferries in sometimes challenging weather conditions, we considered what biases may be present in the data, including the effect of distance band and the effect of sea state. There were notable declines in recording rates of some species in the further distance bands, particularly Black Guillemot (Table 15). For larger species such as divers, there was much less effect of distance band on recording. Given that propensity to fly declines with increasing distance from the ferry, under-recording of Black Guillemot in the further distance bands would suggest the relative number of flights (Figure 20 and Table 15) is slightly over-reported for Black Guillemot compared to the other target species. Given the low numbers of flights recorded anyway for this species, this doesn't affect the overall picture.

In contrast, Red-breasted Merganser recording rates increased noticeably as distance from the ferry increased (Table 15). This is because Red-breasted Mergansers often frequent areas of sea relatively close (<100 m) to the shore (per field obs), and the ferry routes were often through channels with land approximately 200-400 m away from the ferry route, where Red-breasted Mergansers were most frequently encountered. Given that Red-breasted Mergansers may be more limited spatially by this preference for coastal habitats than the other species, it is possible that disturbance may be more significant for Red-breasted Merganser, either in restricting availability of preferable habitat, or forcing birds to move further following disturbance. It's also important to note that Red-breasted Mergansers were frequently recorded flying in response to the sudden loud noise generated by the ferry engine manoeuvring into the pier - there were often other species nearer to the ferry than the Mergansers which did not respond to the noise.

As can be seen in Table 15, all species with the exception of Black Guillemot show a high response rate in the 0-50 m distance band (all other target species responding at least 63% of the time). However in the 200-300 m distance band in Table 15 there is a wide variation between species' response rates. Some species such as Common Eider (5%), European Shag (7%) and Black Guillemot (5%) are very unlikely to respond, while Red-throated Divers (54%), Black-throated Diver (56%) and Slavonian Grebe (43%) still have relatively high response rates. The propensity to respond in the 200-300 m distance may also be a reasonable proxy for estimating sensitivity to marine activity (discussed more in section 7.3).

Table 15: The percentage of flock registrations for which a response (evasive flight, swim or dive) was recorded, and the number of flock registrations for each species by distance band.

Distance Band (m)	Common Eider	Long-tailed Duck	Red-breasted Merganser	Red-throated Diver	Black-throated Diver	Great Northern Diver	European Shag	Slavonian Grebe	Black Guillemot
0-50	68% n=556	85% n=178	69% n=16	100% n=16	100% n=3	83% n=106	63% n=429	100% n=3	39% n=746
50-100	31% n=477	57% n=208	71% n=24	87% n=31	100% n=5	64% n=114	35% n=336	100% n=14	18% n=462
100-200	15% n=406	36% n=167	38% n=40	60% n=15	0% n=4	36% n=107	19% n=230	80% n=10	7% n=276
200-300	5% n=345	17% n=174	33% n=58	54% n=26	56% n=9	18% n=148	7% n=170	43% n=7	7% n=166
All	34% n=1784	47% n=727	45% n=138	75% n=88	62% n=21	47% n=475	38% n=1165	85% n=34	25% n=1650

Encounter rates (the number of encounters with a given species per minute) for the target species were not negatively affected by rougher sea conditions. Encounter rates for Common Eider, Black Guillemot and European Shag are shown in Table 16 – these were the species for which flight responses changed most significantly in higher sea states. While there may be confounding effects where in different weather conditions different areas of sea are favoured, sea state had no effect on detectability of target species. Table 16 also shows the much increased recording of ‘flight’ responses in rougher sea states for these species, which is discussed in more detail in the next section.

Table 16: Comparing encounter rates with target species at different sea states. The registrations/minute rate provide assurance that there was no bias associated with recording rates of three target species in rougher seas.

Sea State	Common Eider		Black Guillemot		European Shag	
	Encounters / minute	Flights / minute	Encounters / minute	Flights / minute	Encounters / minute	Flights / minute
0-1	0.52 (n=456)	0.02 (n=20)	0.54 (n=475)	0.02 (n=14)	0.42 (n=370)	0.03 (n=25)
2-3	0.60 (n=826)	0.06 (n=82)	0.54 (n=742)	0.04 (n=61)	0.31 (n=434)	0.06 (n=84)
4-5	0.68 (n=562)	0.09 (n=75)	0.54 (n=442)	0.06 (n=51)	0.48 (n=393)	0.15 (n=122)

6.2.6 Modelling the Effect of Environmental Variables on Responses

There were sufficient data to run GLM models for seven of the eleven species: Common Eider, Long-tailed Duck, Red-breasted Merganser, Red-throated Diver, Great-northern Diver, European Shag and Black Guillemot. Variables considered for the models were distance band, sea state, number of birds in flock, time of year, time of day, ferry, and tidal state. Separate models were run for the response variables ‘flight’, ‘no response’, ‘dive’ and ‘swim’. Coefficients and standard error terms for significant variables are shown in Tables 17-20 in bold.

Table 17: Results of GLMs with 'flight' as the response variable. Coefficients and standard error terms (in brackets) are shown for each explanatory term. Only variables from the final, fitted models are shown in the table and those variables which were excluded from each model are left blank in the tables. The reference levels used in the model are: distance band: 0-50 m, sea state: 0-1, tide: falling, ferry: Eynhallow (this was the ferry used on the Tingwall – Rousay – Egilsay – Wyre route). Those variables shown in bold were statistically significant in the models.

Explanatory Term	Common Eider	Long-tailed Duck	Red-breasted Merganser	Red-throated Diver	Great Northern Diver	European Shag	Black Guillemot
50-100m	**-1.15** (0.20)	**-0.98** (0.21)	**-1.03** (0.67)	**-1.88** (0.78)	-0.69 0.73	**-0.48** (0.18)	**-0.68** (0.22)
100-200m	**-1.74** (0.26)	**-2.14** (0.26)	**-1.48** (0.64)	**-2.11** (0.87)	-0.29 0.78	**-1.37** (0.25)	**-1.71** (0.43)
200-300m	**-2.65** (0.41)	**-2.86** (0.30)	**-1.46** (0.60)	**-2.03** 0.78	**-1.53** (1.17)	**-2.09** (0.38)	**-2.91** (1.01)
Sea state 2-3	**0.88** (0.27)	-0.0060 (0.23)		0.32 (0.57)		**1.23** (0.25)	**0.96** (0.31)
Sea state 4-5	**1.29** (0.27)	**0.40** (0.25)		**1.62** 0.63		**1.81** (0.24)	**1.29** (0.31)
Number of birds in flock	**0.012** (0.0056)		**-0.28** (0.21)			**0.0081** (0.0045)	
Time of year	**0.011** (0.0055)						
Time of day					**-3.07** (1.33)		**-1.58** (0.44)
Ferry: Hoy Head							
Ferry: Shapinsay							
Tide:High							
Tide:Low							
Tide: Rising							

Table 18: Results of GLMs with 'no response' as the response variable. All variables and reference levels are the same as described for Table 17, and those variables shown in bold were statistically significant in the models.

Explanatory Term	Common Eider	Long-tailed Duck	Red-breasted Merganser	Red-throated* Diver	Great Northern Diver	European Shag	Black Guillemot
50-100m	**1.66** (0.14)	**1.50** (0.26)	-0.01 (0.70)		**1.04** (0.33)	**-1.22** (0.16)	**-1.10** 0.14
100-200m	**2.60** (0.17)	**2.82** (0.28)	**1.30** (0.63)		**2.30** (0.34)	**2.09** (0.20)	**2.33** 0.26
200-300m	**4.04** (0.28)	**3.46** (0.30)	**1.51** (0.61)		**3.53** (0.37)	**3.29** (0.33)	**2.29** 0.32
Sea state 2-3	**0.41** (0.15)					**-0.68** (0.18)	
Sea state 4-5	**0.63** (0.17)					**-0.89** (0.18)	
Number of birds in flock	**-0.014** (0.005)					**-0.009** (0.004)	**0.42** (0.15)
Time of year	**-0.0078** (0.0035)					**0.013** (0.0042)	**0.015** (0.0026)
Time of day	**-1.00** (0.27)				**-1.94** (0.55)		
Ferry: Hoy Head		**-0.45** (0.20)			**1.43** (0.36)		**-0.25** (0.13)
Ferry: Shapinsay		**-1.11** (0.45)			**1.73** (1.49)		**-0.78** (0.39)
Tide: High						**-0.20** 0.18	
Tide: Low						**0.81** 0.25	
Tide: Rising						-0.12 0.19	

*No model could be fitted for Red-throated Diver

Table 19: Results of GLMs with 'evasive dive' as the response variable. All variables are the same as described for Table 17, and those variables shown in bold were statistically significant in the models.

Explanatory Term	Common Eider	Long-tailed Duck	Red-breasted Merganser	Red-throated Diver	Great Northern Diver	European Shag	Black Guillemot
50-100m	**-0.84** 0.30	**-0.41** 0.40			**-1.17** 0.31	**-1.50** 0.24	**-0.92** 0.19
100-200m	**-1.13** 0.36	**-1.05** 0.53			**-1.91** 0.35	**-1.77** 0.31	**-2.22** 0.38
200-300m	**-2.57** 0.73	**-1.21** 0.65			**-3.43** 0.48	**-3.32** 0.72	**-1.81** 0.39
Sea state 2-3				**-0.74** 0.58			
Sea state 4-5				**-2.57** 1.08			
Number of birds in Flock	**-0.082** 0.037	**-0.61** 0.21					**-0.66** 0.24
Time of year						**-0.014** 0.0048	**-0.021** 0.0030
Time of day			**0.007** 0.003		**1.09** 0.61		**0.97** 0.34
Ferry: Hoy Head							
Ferry: Shapinsay							
Tide: High	**0.60** 0.33	0.29 0.58			**1.04** 0.35		
Tide: Low	0.32 0.40	**1.76** 0.48			0.28 0.59		
Tide: Rising	**0.39** 0.33	0.30 0.48			**-0.54** 0.32		

Table 20: Results of GLMs with 'evasive swim' as the response variable. All variables are the same as described for Table 17, and those variables shown in bold were statistically significant in the models.

Explanatory Term	Common Eider	Long-tailed Duck	Red-breasted Merganser	Red-throated Diver*	Great Northern Diver	European Shag	Black Guillemot
50-100m	**-1.26** 0.15	-0.10 0.33	**1.33** 1.15		-0.02 0.28	**-0.52** 0.25	**-1.16** 0.28
100-200m	**-2.30** 0.20	**-0.60** 0.38	0.69 1.14		**-0.92** 0.31	**-1.56** 0.39	**-1.94** 0.47
200-300m	**-4.25** 0.43	**-1.39** 0.48	-1.04 1.32		**-1.70** 0.34	**-2.74** 0.70	**-3.24** 1.03
Sea state 2-3	**-0.71** 0.15	**-0.76** 0.30				-0.08 0.24	**-0.36** 0.24
Sea state 4-5	**-1.21** 0.18	**-1.45** 0.43				**-0.88** 0.30	**-0.93** 0.31
Number of birds in Flock	**0.028** 0.007				**0.19** 0.07	**0.018** 0.005	**0.21** 0.11
Time of day	**0.72** 0.28				**1.12** 0.51	**0.84** 0.46	**1.33** 0.45
Time of year			**0.01** 0.004				
Ferry: Hoy Head							
Ferry: Shapinsay							
Tide: High							
Tide: Low							
Tide: Rising							

*No model could be fitted for Red-throated Diver

Distance band was a significant term in the flight models for all seven species (Table 17), with flight less likely to be recorded with increasing distance from the ferry. For Great Northern Diver, however, there were very few flights recorded, and only distance band 200-300 m was significantly different to the 0-50 m distance band. Swim and dive responses did, however, decrease significantly with distance from the ferry for Great Northern Diver (Table 19 and 20). There was significant variation in the degree to which the propensity to fly, represented by the distance band coefficients declines in the further distance bands (Table 17). For Long-tailed Duck (-2.86) and Black Guillemot (-2.91), the strength of the distance band effect in the 200-300 m band is strong, indicating sharp declines in likelihood of flight as distance from the ferry increases. In contrast, the effect is approximately half as strong for Red-breasted Merganser (-1.46). Red-throated Diver (-2.03) also showed a weaker effect of distance band. These two species (Red-breasted Merganser and Red-throated Diver) had the highest probability of flight in the 200-300 m distance band, indicating a higher degree of sensitivity to marine activity. Black Guillemot flight probability in the 200-300 m distance band was close to zero (Figure 20), and they showed the lowest propensity to fly of all target species. Common Eider and European Shag also show much reduced propensity to fly in further distance bands Long-tailed Duck showed a high probability of flight close to the path of the ferry, but probability of flight declines significantly in the further distance bands.

Sea state was a significant explanatory term in the flight response models for Common Eider, Long-tailed Duck, Red-throated Diver, European Shag and Black Guillemot, with rougher conditions increasing the likelihood of flight (Table 17). The effect was strongest for Common Eider, European Shag and Black Guillemot. Similarly sea state was a significant variable for the swim response for the same group of species - while flight response is more likely in higher sea conditions for these species, in calmer sea conditions swim response becomes more likely. The modelled effect of sea state on the likelihood of flight and swim responses is shown in Figure 23. For Long-tailed Duck, while sea state remained in the final model, there was no significant difference between sea conditions 0-1 and 2-3 (p value = 0.98) and the difference between 0-1 and 4-5 was weak (p value = 0.11), so sea condition was a weaker effect for this species (even though there was a large dataset).

Time of day was a significant explanatory term in the flight models for Black Guillemot and Great Northern Diver (though there were very few flights recorded in total for this species), with flight responses being more likely earlier in the day, as shown in Figure 24 for Black Guillemot. For Black Guillemot, the modelled probability of swim and dive responses was also significantly higher later in the day.

This indicates that Black Guillemot are less likely to be displaced from an area in response to marine activity later in the day.

Size of flock also affected the likelihood of flight response for European Shag, Common Eider and Black Guillemot, with flight more likely the larger the flock size. This is unsurprising because of the way the analysis was carried out - a response was treated as ‘flight response’ whenever at least one bird within the flock flew – the larger the flock, the more chance there is of at least one bird within the flock flying.

Time of year was a significant variable in response models for Common Eider (no ‘response’ and ‘flight’), Red-breasted Merganser (‘swim’), European Shag (‘no response’, ‘dive’), and Black Guillemot (‘dive’, ‘no response’), possibly giving some indication that species can become more habituated to disturbance on the non-breeding grounds over the course of the winter. However, in all these cases, the size of the effects were relatively small. While tidal state was significant for some species in the dive models, this is more likely to represent the effects of tide on birds’ feeding behaviour, rather than any effect on disturbance. For European Shag, tidal state was also significant in the ‘no response’ models, with ‘no response’ more likely at low tide, again this may also be linked to feeding patterns.

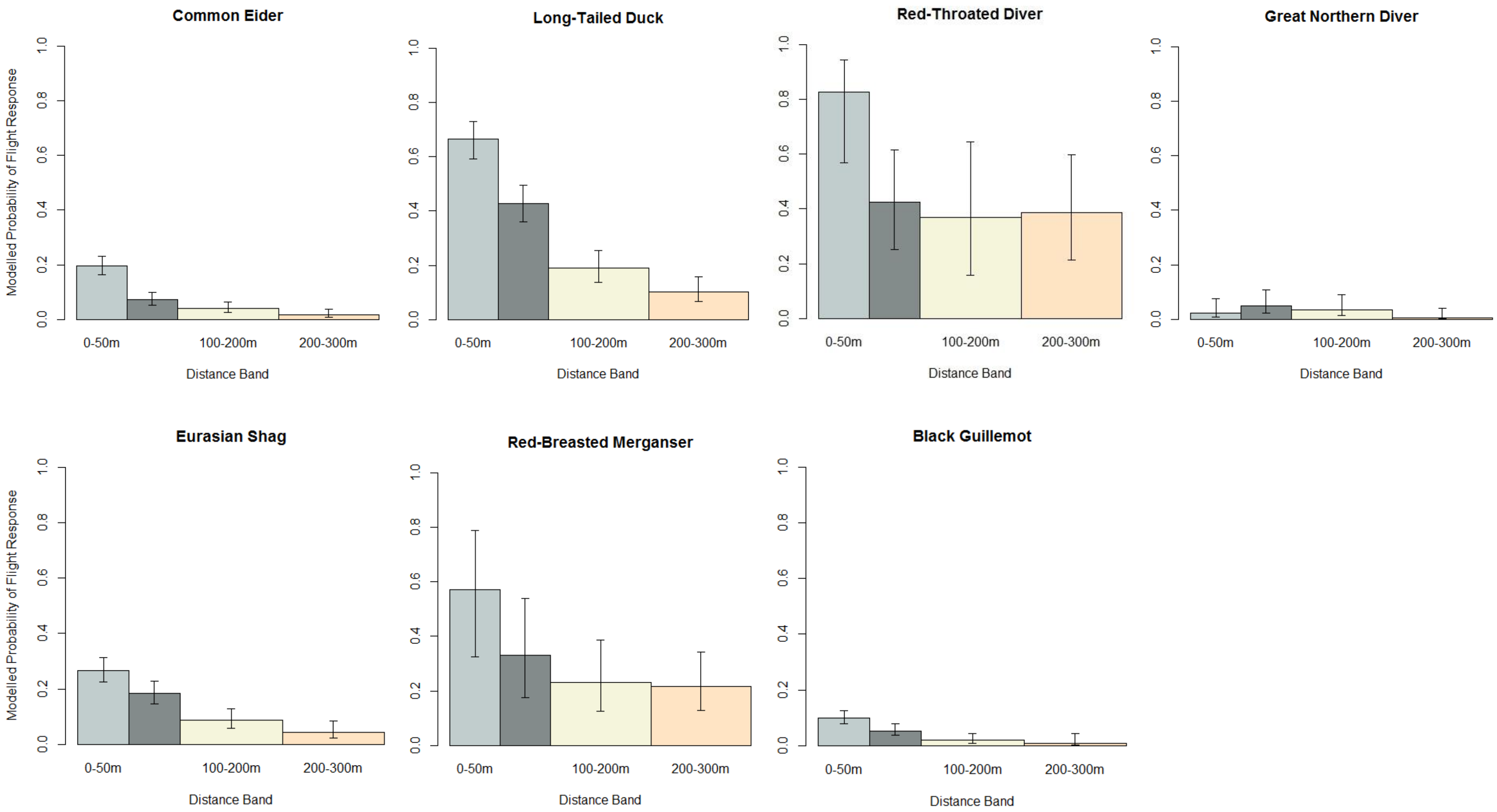


Figure 22: The effect of distance band on the probability of flight response for seven waterbird species. The Y-axis scale is the same for all species so the effect can directly be compared. The error bars represent 95% confidence intervals.

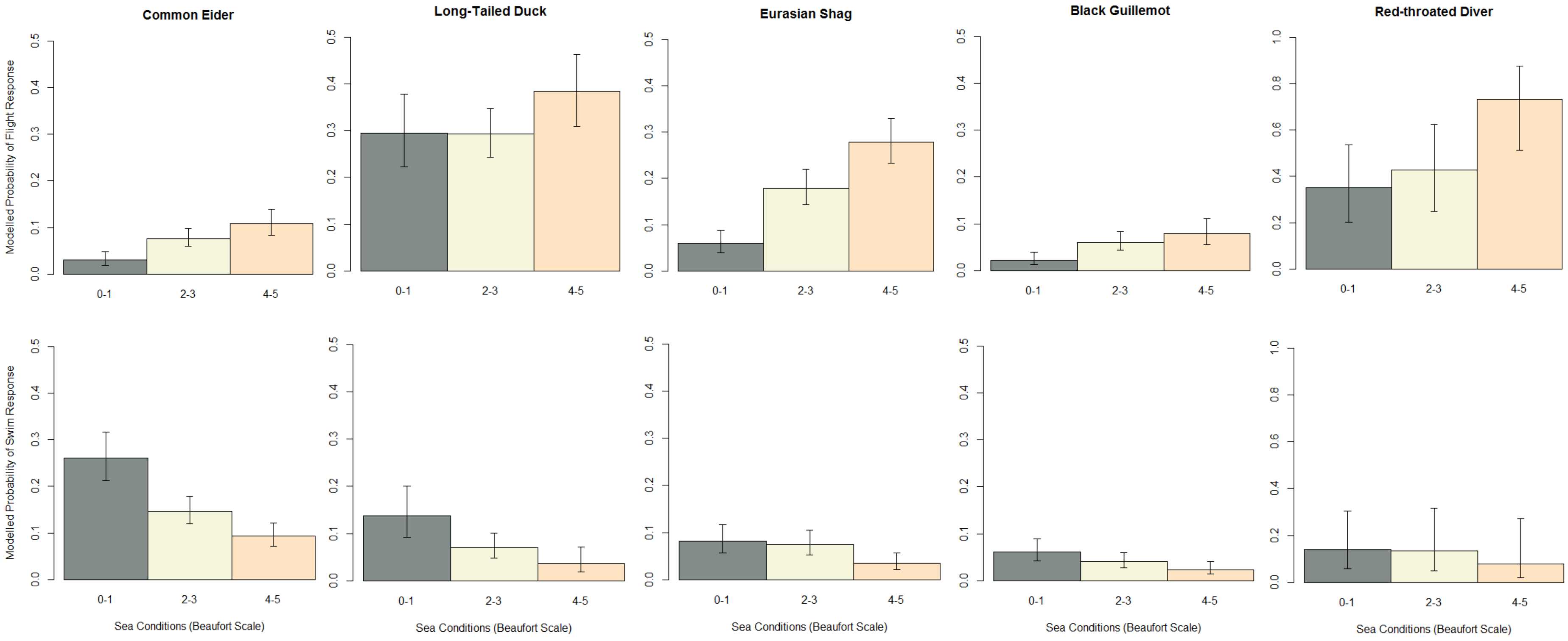


Figure 23: The effect of sea conditions on flight response (above) and swim response (below) for five waterbird species. The Y-axis scale is the same for the first four species, but note the different scale used for Red-throated Diver. The error bars represent 95% confidence intervals.

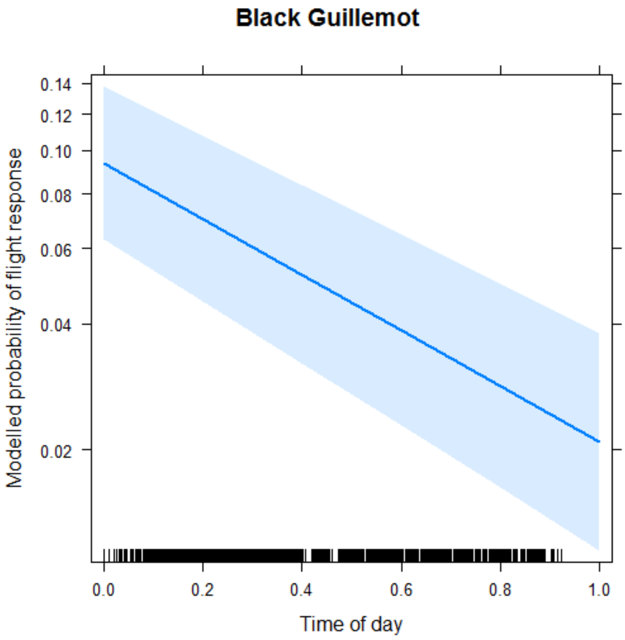


Figure 24: The effect of time of day on the probability of flight response for Black Guillemot. The shaded area around the line represents 95% confidence intervals. The x-axis represents a time of day index, with '0' representing one hour before sunrise, and '1' representing sunset. This index was used rather than time (GMT) because of the rapidly changing times of sunset and sunrise and changing day length in Orkney across the survey period.

6.2.7 Summary of Ferry Survey Data

A summary of the key results for the nine target species (excluding Goldeneye and Velvet Scoter for which few data were gathered) is shown in Table 21. The key variables which allow comparison across the target species which we have selected are: a) the overall response rate across all distance bands; b) the response rate in the 200-300 m distance band; and c) flight response rate in the 200-300 m distance band. We would recommend that b) is the best measure of relative sensitivity since it allows for the inclusion of all evasive behaviour, and the evidence from the vantage point surveys for Great Northern Divers (Section 6.1.1) shows that displacement (in the short-term) can take place even when a species very rarely flies in response to marine activity.

Sea state influenced the likelihood of flight response for Common Eider, Long-tailed Duck, Red-throated Diver, European Shag and Black Guillemot, as shown in the final column (Table 21). For Slavonian Grebe and Black-throated Diver we didn't run models due to the small sample sizes, so weren't able to test the effect of sea state on responses.

Table 21: Ferry survey response rates. The coloured bars represent responses as a % of total registrations. This table is based on the data in Figure 20, Table 15, and the results of the GLMs (Table 17-20). It should be noted that the data informing columns 1, 2 and 3 are not independent, for example, species with a higher overall response rate are likely to also have a higher response rate in the 200-300 m band. If the bar were to fill the whole cell, this would represent a 100% response rate.

Target Species	Overall response rate across all distance bands	Overall response rate in 200-300m distance band	Flight response rate in 200-300m distance band	Sea state effect on flight response
High sensitivity				
Red-throated Diver				Y
Black-throated Diver				
Slavonian Grebe				
Red-breasted Merganser				
Medium sensitivity				
Long-tailed Duck				Y
Great Northern Diver				
Low sensitivity				
Black Guillemot				Y
Common Eider				Y
Eurasian Shag				Y

7. Discussion

Over the course of the project we were successfully able to gather data on the relative sensitivity to disturbance of eleven target species across three different survey methodologies, although for some species (Common Goldeneye, Velvet Scoter), too few data were gathered to draw conclusions.

In Section 7.1, factors likely to affect responses to disturbance are discussed. In Section 7.2 short summaries of the findings by species, and in Section 7.3, a succinct comparison between our findings for all the target species are provided (Table 22). In Section 7.4 we review the methods used in this project and make recommendations for further research; final conclusions are presented in Section 7.5.

Factors Affecting Responses

7.1.1 Vessel Speed and Size

A previous study in the Kattegat Sea, Denmark (Larsen and Laubek 2005) using larger, faster ferries reported an 88% flight response rate (n = 230) for Common Eider flocks within 100 m of the ferry (comparable to the combined 0-50 m and 50-100 m bands in this study). The ferries used in the Danish study travelled at 36-37 knots, compared to 10-11 knots in this project, and were 23 m in width, compared to 7-10 m in this project. The equivalent figure for Common Eider flights within 100 m of the ferry in this research was much lower, at 18% (n = 882). While there may be other environmental factors affecting responses, it's reasonable to assume that the size and speed of the ferries is likely to be significant in explaining a large part of this difference.

The focal flock watches carried out in this research also indicated that birds were more likely to take flight in response to faster vessels. This agreed with anecdotal observations made during this project that the characteristics of the vessel were important in determining responses, with speedboats most likely to cause a response in target species, and creel boats, which travel very slowly, the least.

7.1.2 Sea State

We found that the likelihood of flight response increased in rougher sea states for five species: Common Eider, Long-tailed Duck, Red-throated Diver, European Shag and Black Guillemot. There was also an equivalent decrease in swim responses.

There are two factors which may be driving the interaction between sea state and flight responses. In rougher sea states, birds are likely to find it harder to spot approaching vessels, and because birds then have less time to respond to the approaching vessel, flight responses become more likely. In addition, the stronger winds associated with rougher sea states are likely to reduce the energetic costs of take-off, resulting in increased flight responses. Schwemmer et al. (2011) found that Common Scoter, Long-tailed Duck and Common Eider responded (by flushing) to approaching vessels later in rougher sea states – this would suggest that birds' ability to detect vessels is reduced in rougher sea states.

While sea state also influenced the number of Common Eider, Long-tailed Duck, European Shag and Black Guillemot recorded during the VP surveys, this is likely to be a consequence of reduced detectability in rougher sea conditions.

7.1.3 Moult Strategy

The likelihood of flight responses in waterbirds may also be affected by the moult strategy of target species. Most species of seaduck, as well as Red-throated Divers, aggregate in large post-breeding flocks in remote, undisturbed areas to moult primary feathers in relative safety (Mendel et al. 2008). In contrast, Great Northern and Black-throated Divers undergo a simultaneous moult of primary flight feathers in late winter on the wintering grounds. This leaves these individuals flightless for a period of approximately 3-4 weeks, beginning in late January or February (Appleby et al. 1986) which overlapped with the latter period of our fieldwork. We also found that these species were equally reluctant to fly in the earlier part of the study (when they were able to fly), and nearly always responded with diving or swimming. This may be a behavioural adaptation which allows them to carry out primary moult in areas where they may be subject to greater levels of disturbance and so must be capable of responding to disturbance or threats without taking flight. In contrast, Red-throated Divers, a closely related species, were the most likely of all 11 species to fly in response to the passing ferry (Table 21). Red-throated Divers have a different moult strategy and undergo primary moult immediately following the breeding season (Mendel et al. 2008); as such they are able to fly for the whole of the wintering period. It's likely that the moult strategies of the diver species are involved in the mechanisms driving the difference in avoidance strategies. It's also worth noting that Red-throated Divers are likely to have lower wing-loading than the other diver species making flight relatively less energetically costly (Pennycuik 2008).

7.1.4 Other Variables

We also investigated whether time of day would influence the probability of responses, and while there were some significant effects in the flight models, the only species for which a clear pattern emerged was Black Guillemot, which were less likely to fly and more likely to swim or dive later in the day, possibly indicating a greater reluctance to be displaced from an area later in the day. This may be because later in the day birds are more likely to be near to safe roosting areas. We also considered the possibility that changes in behaviour over the course of the wintering period might influence responses, but we didn't find much indication that this was the case; neither did Schwemmer et al. (2011), who carried out a similar analysis.

Summary of Findings by Species

The following accounts summarise the key findings for each of the target species. The criteria used to assign sensitivity categories are described in greater detail in Section 7.3, and are assigned relative to the other target species of this project.

7.2.1 Common Eider

Common Eider flocks were regularly recorded in high numbers at all VPs. In addition, 27 focal flock watches were carried out on this species. Common Eider were recorded on 1,784 occasions during the ferry surveys (highest across all species). Common Eider were frequently present in high numbers in areas where regular marine activity took place.

From the VP survey data we found a significant increase in flights within a sector following disturbance. There was also a significant reduction in numbers within a sector following marine activity, an effect which was noticeable when considering marine activity up to 30 minutes prior to a count. The focal flock watches also showed that Common Eider flight activity increases in the presence of marine activity, but no effect on flock size was be detected.

Common Eider favoured swim responses over flight or dive responses to the passing ferry. This species had the second lowest overall response rate to passing ferries, and a very low overall response or flight response rate in the 200-300 m distance band. The likelihood of Common Eider flights in response to passing ferries did show a strong and significant increase in rougher sea states.

Common Eider should be considered a **medium sensitivity** species based on the findings of this research.

7.2.2 Long-Tailed Duck

Long-tailed Duck flocks were regularly recorded at all VPs. A total of 26 focal flock watches were carried out on this species. In addition, Long-tailed Ducks were recorded on 727 occasions during the ferry surveys. Long-tailed Ducks were present in high numbers in areas where regular marine activity was taking place.

From the VP surveys we found that Long-tailed Duck abundance within sectors reduced significantly following marine activity and that the effect was noticeable when considering marine activity up to 30 minutes prior to a count.

From the focal flock watch surveys we found significant increases in flights in response to marine activity, and significant changes in flock size occurred during 5-minute periods when marine activity was taking place. High sensitivity to shore-bound activity was also recorded for this species from the focal flock watches.

Long-tailed Duck were far more likely to fly in response to the passing ferry compared to swim/dive responses. The likelihood of Long-tailed Duck flights in response to the passing ferry did increase significantly in rougher sea states, although the effect was not as marked as for European Shag, Black Guillemot and Common Eider. Long-tailed Duck were, relative to the other target species, more frequently recorded taking flight in the absence of marine activity during both the VP surveys and focal flock watches.

Long-tailed Duck should be considered a **high sensitivity** species based on the findings of this research.

7.2.3 Velvet Scoter

This species was only recorded at a single VP location (Quanterness). Six focal flock watches were carried out on this species with few records of responses to disturbance. Only one Velvet Scoter flock was recorded during the ferry surveys.

From the VP survey data gathered at Quanterness there was a suggestion that this species was highly likely to fly in response to marine activity, however due to the small sample size the effect was non-significant.

Due to the lack of data we can't make any conclusions about the sensitivity of this species.

7.2.4 Common Goldeneye

We were able to gather very few data on Goldeneye during the project. In Orkney, this species is largely present in very sheltered areas and inland lochs where marine activity is unlikely (per field obs). Therefore, they rarely come into contact with marine activity in Orkney.

Due to this lack of data, we can't make any conclusions about the sensitivity of this species and future research in areas where they are in more regular contact with marine activity may be useful.

7.2.5 Red-Breasted Merganser

Red-breasted Merganser were frequently recorded during the VP surveys, although they prefer habitat closer to shore and are rarely found in open water. This limited the amount of data gathered on disturbance from the VP surveys on this species, because regular marine traffic was usually some distance (>500 m) from shore. Twenty-eight focal flock watches were carried out on this species. In addition, Red-breasted Merganser flocks were recorded on 138 occasions during the ferry surveys.

Red-breasted Merganser response rate in the 200-300 m distance band was fourth highest of the target species, and the flight response rate in the 200-300 m distance band is second highest. During ferry surveys (and also from anecdotal observations before and after ferry surveys were carried out) and focal flock watches we observed that Red-breasted Merganser may be more sensitive than other species to noise. When ferries arrived at a pier and the engine was put into reverse (to manoeuvre the boat) the sudden loud noise often caused Red-breasted Merganser to flush. There were also often other species closer to the ferry which showed no sign of being affected by the noise. The focal flock watches showed sensitivity to shore-bound disturbance for this species, and also suggested that this species may be disturbed at greater distances than other target species.

Red-breasted Merganser should be considered a **very high sensitivity** species.

7.2.6 Red-Throated Diver

Small numbers of Red-throated Divers were recorded at all the VP surveys. Three focal flock watches were carried out on this species but there were too few data from the focal flock watches to draw any conclusions. In addition, Red-throated Diver flocks were recorded on 88 occasions during the ferry surveys.

There was not enough data gathered during the VP surveys to detect significant effects of disturbance on the abundance of this species, although there was a strong indication (though non-significant) that flights increased in the presence of marine activity.

The ferry surveys provided strong evidence that Red-throated Divers were highly sensitive to marine activity. They were the most likely target species to take flight as a response to passing ferries across all distance bands, and also in the 200-300 m distance band. They were second most likely (behind Black-throated Diver) to exhibit any response at 200-300 m.

The likelihood of Red-throated Diver flights did increase significantly in rougher sea states, although the effect was not as marked as for European Shag, Black Guillemot and Common Eider. However, the weaker effect may be a consequence of the smaller sample size for Red-throated Diver. Relative to the other two diver species, Red-throated Divers are much more likely to take flight in response to disturbance, but they were also recorded flying more in the absence of disturbance than the other two diver species across all surveys.

Section 7.1.3 describes how the different moult strategies of the diver species may be involved in driving differences in response strategies.

Red-throated Diver should be considered a **very high sensitivity** species based on the findings of this research.

7.2.7 Black-Throated Diver

Black-throated Diver were very rarely recorded at the VP surveys, and flocks were only recorded 21 times from the ferry surveys. In addition, three focal flock watches were carried out on this species, but this didn't yield any data on responses to disturbance because the flocks were not subject to any disturbance events. Black-throated Diver were very rarely recorded in areas where regular marine activity takes place.

Black-throated Divers were very unlikely to take flight in response to marine activity. Across all the ferry surveys, focal flock watches and VP surveys Black-throated Diver were never recorded taking flight or in flight; either in the presence or absence of disturbance.

Black-throated Diver were the most likely of all target species to respond to the passing ferry in the 200-300 m distance band, and had a high response rate across all distance bands. Black-throated Diver favoured swim or dive responses to the passing ferry, similar to Great Northern Diver.

It seems likely that Black-throated Divers avoid areas where marine activity takes place, making data gathering for this species difficult. Given also the likelihood that data gathering for this type of research may focus on flight responses, there is a risk that the sensitivities of species such as Black-throated Diver, which very rarely fly, but do respond to marine activity, are underestimated. We, therefore, feel that Black-throated Divers should be considered a priority for further research.

Section 7.1.3 describes how the different moult strategies of the diver species may be involved in driving differences in response strategies.

Black-throated Diver should be considered a **very high sensitivity** species, although this is based on a smaller dataset than other species.

7.2.8 Great Northern Diver

The data gathered during this research project is the only data we are aware of in the public domain on the sensitivity of Great Northern Divers to marine activity. Great Northern Divers were regularly recorded from all the VP surveys in reasonable numbers. Eighteen focal flock watches were carried out on this species. Great Northern Divers were also recorded in high numbers from the ferry surveys (475 records). Although they were recorded frequently, and often in areas where regular marine activity took place, they were rarely recorded close to shore.

Great Northern Divers showed a significant reduction in numbers within a sector following marine activity, when including marine activity in the 15 minutes prior to a count. However, there were very few Great Northern Diver flights recorded during any of the survey methods. This suggests that although this species very rarely flies in response to marine activity, they are still being temporarily displaced from areas by marine activity. During the 18 focal flock watches, 41 5-minutes periods with marine activity present were recorded, and no Great Northern Diver flights recorded.

Great Northern Divers ranked close to the middle across the target species for response rates in the 200-300 m distance band and in terms of overall response rate. They were the second least likely species to fly in response to the passing ferries (behind Black-throated Diver), with very few flights recorded. Swim and dive responses were frequent, however, and this species was recorded swimming out of the path of the ferries at great distance (up to 4 km).

Section 7.1.3 describes how the different moult strategies of the diver species may be involved in driving differences in response strategies.

Great Northern Diver should be considered a **high sensitivity** species based on the findings of this research project.

7.2.9 European Shag

European Shag were recorded in high numbers during the VP surveys and the ferry surveys. In addition, eight focal flock watches on this species were carried out. Shags were present in high numbers in areas where regular marine activity took place, including very close to piers and harbours.

From the VP surveys we found that Shags showed a significant increase in flights in response to marine activity, and a significant reduction in numbers within a sector following marine activity. The effect of disturbance was noticeable when marine activity from the 15 minutes prior to a count was included in analysis.

Shags had the third lowest overall response rate to ferry traffic, and had very low response and flight rates within the 200-300 m distance band. Shags typically take flight or dive in response to approaching vessels, and are less likely to swim evasively. The likelihood of Shag flight responses to the passing ferry increased strongly and significantly in rougher sea states.

Shags should be considered a **medium sensitivity** species based on the findings of this research.

7.2.10 Slavonian Grebe

Limited data were gathered on Slavonian Grebe from the VP surveys with very low counts recorded. In addition 15 focal flock watches were carried out on this species, but only 34 records were gathered from the ferry surveys. Slavonian Grebe appeared to rarely be present in areas of sea where regular marine activity took place.

The small sample sizes from the VP surveys meant no significant effect of marine activity could be detected. From the focal flock watches, a sample of timed evasive flights were collected which suggested that Slavonian Grebe evasive flights are longer/further than other species.

Slavonian Grebes had the third highest likelihood of responses in the 200-300 m distance band, and there was also a high likelihood of flight responses to ferry traffic.

Slavonian Grebe should be considered a **very high sensitivity** species based on the findings of this research, although this is based on a smaller dataset than other species.

7.2.11 Black Guillemot

Black Guillemot were frequently recorded at all VP surveys and were recorded on 1650 occasions from the ferry surveys. They were abundant in areas where regular marine activity took place, including close to active piers and harbours. Because of the abundance of data gathered from the VP surveys and ferry surveys, this species was not considered a priority for focal flock watches.

No effect of marine activity was found on the abundance of Black Guillemot within sectors from the VP surveys, despite a large dataset on this species, suggesting that this species is very unlikely to be displaced from areas by marine activity.

Black Guillemots were also the least likely target species to show a response to passing ferry traffic, and had very low response rates in the 200-300 m distance band. They were more likely to dive in response to the passing ferry compared to swim or flight responses.

The likelihood of Black Guillemot flights in response to the passing ferry did increase significantly in rougher sea states despite their apparent low sensitivity. If the driver of the increased flight responses in rougher sea states is reduced visibility, the small size of Black Guillemot would be expected to make them more susceptible to this effect. As discussed in Section 7.1.4, we also found that time of day influenced the likelihood of flight response in Black Guillemot, with flight less likely later in the day.

Based on the findings of this research Black Guillemot should be considered a **low sensitivity** species, and relative to the other target species, we consider them the the lowest sensitivity species.

Overall Comparisons Between Species

The objective of this project was to compare the relative sensitivities of the eleven target species during the winter to marine activity. In Table 22 the species are arranged in order of relative sensitivity, from very high sensitivity at the top, to low sensitivity at the bottom, with the two species in light blue at the bottom of the table data deficient. The assessments in Table 22 are based solely on data gathered during this project, and are made in relation to the other target species. As such these assessments cannot necessarily be simply compared with other reviews which consider a different suite of species (for example, Furness et al. 2013).

The species were initially assigned to groups based on response rates in the 200 - 300 m band from the ferry surveys (Table 21). This metric was chosen because of the following:

i) There is wide variation across the target species in terms of response rates in this distance band;

ii) At this distance evasive action is wholly unnecessary in terms of avoiding collision, so response rates in this distance band are likely to indicate sensitivity to the *presence* of marine traffic;

iii) We used response rate because this includes flight, swim and dive responses, rather than flight responses only. There is little evidence to suggest that flight responses should be considered a more accurate predictor of longer-term displacement and habitat loss than evasive diving or swimming. This decision is supported by the fact that Great Northern Diver abundance was reduced in areas following marine activity, even though this species very rarely flies in response to marine activity – indicating that short-term displacement effects can be seen even when a species is not taking evasive flights.

iv) Finally, for species where the focal flock watches, the VP surveys, or other information gathered from the ferry surveys indicated a higher or lower sensitivity, species were re-assigned.

The three lowest sensitivity species (Common Eider, European Shag and Black Guillemot) all responded to the passing ferry on less than 10% of passes in the 200-300 m band, and they also had very low flight response rates, and there was no evidence from the focal flock watches. For Black Guillemot there was also strong evidence from the VP surveys that marine activity had no effect on the abundance of this species within a sector, and combined with the very low response rates from the ferry and focal flock watches for this species, we assign Black Guillemot to **low** sensitivity, and consider Common Eider and European Shag **medium** sensitivity species.

Great Northern Diver and Long-tailed Duck were both mid-ranking species for overall response rates in 200-300 m distance band. As such, Great Northern Diver and Long-tailed Duck, are both considered **high** sensitivity species. Red-breasted Merganser also had a similar response rate at 200-30 0m but we re-assigned Red-breasted Merganser to the **very high** sensitivity category because i) this species had a very high flight response rate in 200-300 m band; ii) the instances of Red-breasted Merganser showing high sensitivity to ferry noise, and iii) the fact that they may be more limited in terms of habitat availability than the other target species (restricted to areas close to the coast).

The three species which had the highest response rates in the 200-300 m distance band were Red-throated Diver, Black-throated Diver and Slavonian Grebe (Table 21), and so these species are also allocated to the **very high** sensitivity category (Table 22).

Table 22: Summary of main findings by species. Arranged with highest sensitivity species at top to lowest sensitivity species at bottom (the colour gradient also indicates relative sensitivity). For the final two species (highlighted in light blue) there were too few data to draw conclusions. The species accounts in Section 7.2 describe the basis for these assessments and the strength of evidence. Overall sensitivities are assessed only in relation to the other target species, and are based solely on the data on short-term responses to marine activity gathered during this project.

Species	VP surveys	Focal flock watches	Ferry surveys	Overall sensitivity
Red-throated Diver	Probable (but non-significant) increased likelihood of flight following marine activity	Limited data	Second highest response rate at 200-300m; highest flight response rate at 200-300m; flight responses more likely in rougher seas	Very high
Black-throated Diver	Limited data; no flights recorded	Limited data; absent from areas where marine activity regularly takes place; no flights recorded	Highest response rate at 200-300m; swim or dive responses very likely; very unlikely to fly in response to disturbance	Very high
Slavonian Grebe	Limited data	Evasive flights often of greater distance/time than other species	Highest overall response rate; high likelihood of response at 200-300m	Very high
Red-breasted Merganser	Limited data; restricted to near shore so not suited to this method	Evidence of flight responses taking place at some distance from disturbance; sensitive to shorebound activity	Second highest flight rate at 200-300m; appeared sensitive to ferry noise	Very high
Long-tailed Duck	Reduced abundance following marine activity; increased likelihood of flight following marine activity	Evasive flights frequently recorded; significant reductions in flock size following disturbance; frequent flights recorded in absence of marine activity	Flight response frequent, but response rate much lower in 200-300m band; flight responses more likely in rougher seas	High
Great Northern Diver	Reduced abundance following marine activity	Never recorded taking flight following marine activity (or in absence of marine activity)	Very unlikely to fly in response to ferries; swim and dive responses likely; often swims out of path of ferry at some distance	High
Common Eider	Reduced abundance following marine activity; increased likelihood of flight following marine activity	Evasive flights frequently recorded; no significant effect on flock size	Low response rates to ferry traffic; flight responses more likely in rougher seas	Medium
European Shag	Reduced abundance following marine activity within a sector; increased likelihood of flight following marine activity	Limited data	Low response rates to ferry traffic; flight responses more likely in rougher seas	Medium
Black Guillemot	No effect of marine activity on abundance within a sector	Limited data	Least likely species to respond to ferry traffic; flight responses more likely in rougher seas	Low
Common Goldeneye	Limited data	No data	Limited data	Limited data
Velvet Scoter	Limited data; increased likelihood of flight following marine activity	Limited data	Limited data	Limited data

Methodological Insights and Recommendations for Further Work

Gathering robust data on the effect of marine disturbance on waterbirds is challenging. Whichever methodological approach is followed there are likely to be significant practical challenges in data gathering, and limitations on the conclusions which can be drawn. As such it is critical that methodologies should be trialled and refined in field conditions to ensure they are feasible prior to data collection commencing. We present the following insights gathered during this project as a potentially valuable source of information for those planning similar work.

The results from the ferry surveys and the results from Schwemmer et al. (2011) provide evidence that in rougher sea conditions disturbance effects are likely to be greater. However, when using shore-bound survey methods it becomes challenging to gain accurate counts in sea conditions from a sea state three upwards (assuming count areas extend to 1 km or greater). This means that during periods when birds may be most vulnerable to disturbance shore-bound surveys will either not be possible or the accuracy of the data gathered will be compromised.

Shore-bound surveys must be focused on areas of sea which are subject to regular marine activity, because if this is not the case, then little or no data on disturbance responses can be gathered (speculatively waiting for marine activity in areas of sea where activity rarely takes place is not a fruitful approach). However, it is probable that species (and individuals within species) that are most sensitive to disturbance will avoid areas of sea which are frequently disturbed by marine activity. Therefore, conclusions made on species' sensitivities based on data gathered in areas of sea subject to regular marine activity may not be transferable to relatively undisturbed areas. Experimental tests, discussed in Section 7.4.2, may be the only solution to this problem.

From the VP surveys we were able to detect a statistically significant effect of marine activity on target species for those species which were most abundant in regularly disturbed areas and therefore had the largest datasets available. However, the fact that these species were abundant in frequently disturbed areas may indicate that they were in fact less sensitive to disturbance. Therefore, it may be the case that those species for which we were able to detect significant effects on flight activity or changing abundance following disturbance using the VP survey methodology were actually *less sensitive* to disturbance than species for which we couldn't detect an effect.

Ferries follow regular routes so data gathering also took place in areas with regular marine activity, ferry surveys do have the benefit that relatively large datasets can be generated relatively quickly and cost-effectively (Larsen and Laubek 2005). It is also possible to gather data up to a sea state five because it is only necessary to detect birds up to 300 m from the boat (and only a sample is required). Schwemmer et al. (2011) found that the FID (flight initiation distance – the distance from the approaching boat at which birds took flight) varies significantly by species, and recorded instances of Common Scoters flushing at distances of up to 3.3 km. In this research, though we didn't systematically record FID, we didn't observe birds flushing at greater than approximately 1 km. While we are confident that few flight responses were missed, it is harder to judge whether swim and dive responses in advance of the ferry may have been missed. Great Northern Diver swim responses were regularly recorded and recorded up to 2 km ahead of the ferry, and on very calm days were recorded swimming out the path of the ferry at greater distances (up to approximately 4 km on occasion). However, the possibility that some distant responses were unrecorded is unlikely to affect the overall pattern of the data or lead to incorrect conclusions being drawn.

7.4.1 Suggested Alterations to Methodologies used During this Research

VP Surveys

The analysis of the VP survey data demonstrates that if the spatial scale of the analysis is inappropriate, then it may not be possible to accurately detect disturbance effects. We gathered data in sectors of four different sizes, and in the largest and smallest sectors we did not generate meaningful data on disturbance effects, as shown in Table 23. The size of the L1/R1 sectors was likely to be too small to detect disturbance effects, and too close to shore (where few disturbance effects took place at most VPs). The size of the L4/R4 sectors were likely to be too large to detect disturbance effects, with the size of the sector meaning that birds within the sector were less likely to interact with vessels, and when they were disturbed were less likely to leave the sector than birds within smaller sectors. There would also have been reduced count accuracy in the L4/R4 sectors due to the distance from the fieldworker. The only species for which including all sectors appeared to improve the modelling of change in abundance was Great Northern Diver. This will be because of the higher detectability of this species at distance, and because almost 80% of Great Northern Diver records were in the L4/R4 sectors, so including these sectors in the analysis increases the size of the dataset significantly.

There are clear trade-offs involved in data gathering methods: surveying a larger study area increases the amount of interactions between vessels and birds recorded, but requires more time be spent counting birds, which reduces the frequency with which birds can be counted. If the frequency with which counts are made does not correspond to the temporal pattern of responses to marine activity, then the impact of disturbance on birds may be missed or underestimated. We would recommend that recording should be limited to a distance of 1 km or less from the fieldworker to reduce counting time, and, therefore, enable increased frequency of counts – the VP surveys show that for most species, detecting an effect of marine activity on abundance of birds is easier when shorter time periods are analysed.

The behaviour, abundance and distribution of target species should be considered when designing VP surveys. For example, Velvet Scoters and Black-throated Divers are rarely recorded within 1 km of shore (per field obs), so shore-bound VP surveys may not be effective for these species.

Table 23: Comparisons of sectors used in VP survey analysis. Area relates to one individual sector (e.g. L4, rather than L4 and R4 combined). *Based on comparing the results of models which included only L2, R2, L3, R3, and models which included all sectors for Eider, Shag, Long-tailed Duck.

Sector	**Distance from fieldworker (m)**	**Area of sector (m^2)**	**Relative strength of disturbance as effects detected**
L4 / R4	1,000 - 2,000m	1,178,097	Weak*
L3 / R3	500 - 1,000m	294,524	Strong*
L2 / R2	250 - 500m	73,631	Strong*
L1 / R1	0 - 250m	24,544	Weak*

Focal Flock Watch Surveys

The propensity of some species to fly in response to marine activity can drop by as much as 50% from the 0-50 m to the 50-100 m distance band (Figure 21). However, when carrying out focal flock watches, the proximity of birds to the vessel could often not be accurately estimated. As such, the most significant variable determining response (distance to marine vessel) was not effectively recorded during flock watch surveys. This limitation will have reduced the effectiveness of the focal flock watch surveys in analysing behavioural responses.

The eleven different target species of this study have different flocking, feeding and evasive behaviours. Applying one methodology to assess disturbance impacts across all target species which in theory should allow comparison between the target species, may in fact limit the degree to which responses to disturbance can be recorded if behavioural responses vary significantly between species. The time periods within which behaviour was recorded (five minutes in this research) should also ideally be adapted for different species - there may be some species for which the behavioural consequences of disturbance occur over a longer or shorter time period, and thus are not picked up with five-minute recording periods. And indeed, the results from the VP surveys do suggest that the temporal scale of responses varies across the target species. Targeted survey methods informed by knowledge of individual species behavioural characteristics may be more effective in gathering meaningful data on behavioural responses to marine activity.

7.2.12 Recommendations for Future Research

The following recommendations for future research on waterbird sensitivity to marine activity are made:

A) Experimental Disturbance using Chartered Boats

The trial disturbances of target species using a chartered boat using a standardised approach protocol would be a time-efficient means of gathering data in areas not subject to regular marine activity. Depending on resources, it would also be possible to test the effect of the frequency and pattern of disturbance events. The significant advantage of chartering a vessel for experimental tests is that researchers would be able to select the areas for the experiments to be carried out, and would be able to make effective comparisons between responses in areas of sea subject to regular marine activity and areas of sea where marine activity is absent. This approach would also allow the gathering of systematic data on scarcer species which may avoid areas where regular marine activity is present.

B) Displacement Studies

An important research need is to gather evidence on the extent to which increased levels of marine activity can lead to long-term displacement effects. A multi-year study using a before-after-gradient (BAG) design (Mackenzie et al. 2013) in an area subject to significantly increased marine activity would address this need. It would also be possible, having carried out a long-term displacement study along these lines, to then refer back to this research and other research on short-term behavioural responses to examine the extent to which short-term behavioural responses are a reliable means of predicting sensitivity to displacement effects.

C) Tracking Studies

For future studies on the effects of marine activity on waterbirds, using tracking devices to monitor bird movements and activity during the wintering period may be an effective means of gathering data on interactions with marine activity. At a coarse scale, data on marine traffic are available (sometimes at a cost, depending on the type of data required) which could be analysed with data from tracking devices and/or accelerometers to infer behaviour, energetic costs and movements in relation to marine activity. A key priority for work on sensitivity to marine activity should be to gather data on the relative significance of habitat loss compared to the energetic costs of displacement; tracking studies may be the best means to assess this.

Spatial data on smaller vessels is often not available, which would limit the usefulness of this approach. In addition, issues related to long term attachment methods may affect the extent to which tracking studies are currently feasible.

D) Timing of Evasive Flights

An additional piece of data which wasn't a focus of this study but which may be a relatively simple means of gathering comparable data on the sensitivities of target species is the time/distance of evasive flights. This would provide some indication of i) the relative energetic cost of the disturbance event on the target species and ii) the distance the bird has to travel to find an equivalent area of habitat (see Section 7.5, where the importance of this is discussed). Whilst carrying out the focal flock watch surveys fieldworkers were able to gather a small dataset on the timing of evasive flights. We found that Slavonian Grebe evasive flights averaged 47 seconds (five flights), Red-breasted Merganser 28 seconds (6), Long-tailed Duck 20 seconds (11), Eider 18 seconds (7), and Red-throated Diver 12 seconds (3). These data correlate reasonably well with the sensitivities estimated during this project, except for Red-throated Divers, for which a higher result might have been expected (however there were only three timed evasive flights). Although the sample sizes are small, the variations found here between the target species may warrant further investigation.

E) Suggested Priority Species for Further Research

We recommend that Slavonian Grebe, Black-throated Diver and Velvet Scoter be priorities for further research. We assessed Slavonian Grebe and Black-throated Diver as highly sensitive species, however, we noted that these categorisations were based on smaller sample sizes. More data on these species would be useful to confirm these assessments. For Velvet Scoter, there was not enough data to draw any conclusions, however, there was some indication (from a very small dataset) that this species may be likely to take flight in response to marine activity.

Conclusions

This research has contributed to the body of available information on the target species. We have characterized the short term behavioural responses of wintering waterbirds to marine activity as follows: **very high** - Red-throated Diver, Black-throated Diver, Slavonian Grebe and Red-breasted Merganser; **high** - Long tailed Duck and Great Northern Diver; **medium** - Common Eider and European Shag; and **low** - Black Guillemot.

Our results are broadly comparable to previous assessments of sensitivity to disturbance and displacement effects (Furness et al. 2012; Furness et al. 2013). Where assessments of sensitivities differ, this may be because in previous assessments an absence of field data necessitated a reliance on expert opinion or was based on data gathered on similar species. Previous studies have also tended to focus more on flight responses, while here we considered all evasive responses. It's also worth noting that Red-breasted Merganser has not been included in previous reviews (Furness et al. 2012; Furness et al. 2013; Wade et al 2016); we would recommend they should be considered a relevant species when considering disturbance effects of marine activity on wintering waterbirds. For Great Northern Diver, Black-throated Diver and Slavonian Grebe, little information on sensitivity to disturbance was in the public domain prior to this work (WP1, Appendix 2), so the results of this research will fill important knowledge gaps for these species. Although all the fieldwork took place in Orkney, it is likely that the findings presented here are broadly applicable to the Western Isles in terms of the type and intensity of marine activity and coastal topography, (see WP2, Appendix 3). Because almost all the vessels which were recorded during this study were relatively small (<50 m length), we would advise against the conclusions made here being applied to the larger estuarine ports of mainland Britain for example, where the marine activity is likely to be characterized by much larger vessels.

For those very scarce target species (Common Goldeneye and Velvet Scoter) it was apparent that neither on-shore based surveys (which are reliant on marine disturbance events occurring) nor ferry surveys were an efficient method of gathering data. Trial disturbance of these species using a chartered boat may be the only way to gather data for these species. For Slavonian Grebe and Black-throated Diver for which our datasets were small, there are small but significant wintering populations around the Orkney Islands and the low number of records on the VP and ferry surveys may indicate that these species avoid busier areas.

Waterbirds are likely to be negatively affected by disturbance caused by frequent marine activity through elevated energetic costs. Flight is thought in most cases to be the most costly mode of locomotion among birds (Ellis 1984, Nudds and Bryant 2000), and will vary by species as a function of the relationship between body mass and wing area (Pennycuick 2008). The energetic costs of diving and swimming will also vary between species but measuring this is more challenging (Žydelis and Richman 2015). Gaining a better understanding of the relative energetic costs and the overall time spent carrying out evasive behaviour in response to marine activity will be an important next step towards an appreciation of the potential demographic impact of disturbance. Another long term consequence of disturbance arising from marine activity is displacement from key habitats.

For those species likely to fly in response to disturbance (Red-throated Diver, Long-tailed Duck) energetic costs may be a more significant consequence of disturbance (see Dierschke et al. 2017 for a discussion on Red-throated Diver disturbance). Those species for which the relative energetic costs of flight are high (Great Northern Diver, Black-throated Diver, Common Eider) may be relatively more sensitive to fast moving vessels, where flight may become the only means possible of avoiding collision. However, relying on flight response as a predictor of the importance of disturbance effects is also problematic: for example, Long-tailed Duck and Red-throated Diver are relatively frequent fliers in the absence of marine activity, so sensitivity may be over-estimated if it is measured solely by the likelihood of flight responses to marine activity. We also demonstrated here that Great Northern Divers, which very rarely fly in response to disturbance, do nevertheless experience short-term movements when subject to marine activity (Section 6.1.2, 6.1.3). In such instances where flight response was unlikely but the species did appear sensitive to marine activity (Great Northern Diver, Black-throated Diver), habitat loss may be a more significant mechanism.

While to date there has been limited work on the long-term effects of disturbance effects on seaducks, grebes and divers on wintering grounds, past work on waders has suggested that frequent disturbance can contribute to reduced survival (Burton et al. 2002, 2006; Burton and Armitage 2005, Davidson and Rothwell 1993). This may relate to time spent avoiding disturbance (Urfi et al. 1996, Stillman & Goss-Custard 2002) or to displacement from preferred foraging areas making it harder to meet their daily energy requirements (Burton et al. 2006). We would also advise caution when interpreting short term behavioural responses of wintering waterbirds to marine activity; birds which appear not to be responding to disturbance may be remaining at a site regardless of negative impacts of disturbance, due to a lack of suitable alternative habitat nearby (Gill et al 2001). This suggests that in order to better understand the consequences of disturbance, we also need to understand the relative importance and availability of areas of habitat within an individual's wintering range.

8 Acknowledgements

We are grateful to Andrew Upton, Jim Williams and Stuart Williams for carrying out fieldwork in often challenging conditions, providing valuable advice on wintering waterbirds around Orkney, and for advising on the methodologies used during this project. We are grateful to Orkney Ferries for allowing us access to the bridge area on ferries to carry out surveys and to Mark Wilson for providing valuable advice on statistical methods. This work was carried out on behalf of Marine Scotland and overseen by a steering group including Lucy Law, Jared Wilson (Marine Scotland), Helen Rowell, Tim Frayling (Natural England), Emma Phillip, George Lees (Scottish Natural Heritage), Matty Murphy (Natural Resources Wales), Alex Sansom (Royal Society for the Protection of Birds), Ross McGregor (Hi-def) and Peter Coldwell (Comhairle nan Eilean Siar). We also thank Alex Robbins (Scottish Natural Heritage) for useful discussions over the course of this project. The work was funded by the Scottish Government's Contract Research Fund.

9 References

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. *Proc. 2nd Inter. Symposium on Information Theory*, Budapest, 267-281.

Appleby, R. H., Madge, S. C. Mullarney, K. 1986. Identification of divers in immature and winter plumages, *British Birds*, 79, 365-391.

Burton, N.H. and Armitage, M.J. 2005. Differences in the diurnal and nocturnal use of intertidal feeding grounds by Redshank Tringa totanus. *Bird Study*, 52(2), 120-128.

Burton, N.H., Rehfisch, M.M. and Clark, N.A. 2002. Impacts of disturbance from construction work on the densities and feeding behavior of waterbirds using the intertidal mudflats of Cardiff Bay, UK. *Environmental Management*, 30(6), 865-871.

Burton, N.H., Rehfisch, M.M., Clark, N.A. and Dodd, S.G. 2006. Impacts of sudden winter habitat loss on the body condition and survival of redshank Tringa totanus. *Journal of Applied Ecology*, 43(3), 464-473.

Camphuysen, K. J., Fox, A. D., Leopold, M. F., and Petersen, I. K., 2004. Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the UK: a comparison of ship and aerial sampling methods for marine birds and their applicability to offshore wind farm assessments. NIOZ report to COWRIE, Texel.

Davidson, N.C., and Rothwell, P.I. 1993. Human activity to waterfowl on estuaries: conservation and coastal management implications of current knowledge. *Wader Study Group Bulletin*, 68, 97–106.

Dierschke, V., Furness, R.W., Gray, C.E., Petersen, I.K., Schmutz, J., Zydelis, R. and Daunt, F. 2017. Possible Behavioural, Energetic and Demographic Effects of Displacement of Red-throated Divers, JNCC Report 605, ISSN 0963-8901

Dorfman, R. 1938. A note on the delta-method for finding variance formulae. *The Biometric Bulletin*, 1, 129-137

Ellis, H. I. 1984. Energetics of free-ranging seabirds. Pages 203-234 in G. C. Whittow and H. Rahn, Seabird energetics. Plenum, New York, USA

Fournier, D.A., Skaug H.J., Ancheta J., Ianelli J., Magnusson A., Maunder M., Nielsen A. & Sibert J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optimization Methods and Software*, 27, 233-249.

Fowler, G. S. 1999. Behavioral and hormonal responses of Magellanic penguins *Spheniscus magellanicus* to tourism and nest site visitation. *Biological Conservation* 90(2), 143-149.

Fox, J. 2003. Effect Displays in R for Generalised Linear Models. *Journal of Statistical Software*, 8:15.

Furness, R. W., Wade, H. M., Robbins, A. M. C., and Masden, E.A. 2012. Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. *ICES Journal of Marine Science*, 69(8), 1466–1479

Furness, R.W., Wade, H.M. & Masden, E.A. 2013. Assessing vulnerability of marine bird populations to offshore wind farms. *Journal of Environmental Management*, 119, 56–66

Gardener, M. 2017. Statistics for Ecologists Using R and Excel: Data Collection, Exploration, Analysis and Presentation. Exeter: Pelagic Publishing

Gill, J. A., Norris, K. and Sutherland, W. J. 2001. The effects of disturbance on habitat use by Black-tailed Godwits *Limosa limosa*. *Journal of Applied Ecology.* 38: 846–856

Grecian, W. J., Inger, R., Attrill, M. J., Bearhop, S., Godley, B. J., Witt, M. J. and Votier, S. C. 2010. Potential impacts of wave-powered marine renewable installations on marine birds. *Ibis* 152, 683-697.

Hau, M., Ricklefs, R. E., Wikelski, M., Lee, K. A., Brawn, J. D. 2010. Corticosterone, testosterone and life-history strategies of birds. *Proceedings of the Royal Society of Biology*. 277, 3203-3212.

Larsen, J.K. and Laubek, B. 2005. Disturbance effects of high-speed ferries on wintering sea ducks. *Wildfowl*, 55, 99–116.

Mackenzie, M. L., Scott-Hayward, L. A. S., Oedekoven, C. S., Skov, H., Humphreys, E. and Rexstad, E. 2013. Statistical Modelling of Seabird and Cetacean data: Guidance Document. University of St. Andrews contract for Marine Scotland, SB9 (CR/2012/05).

McCullagh, P. and Neider, J. 1989. Generalized Linear Models, 2nd Ed. Chapman and Hall, London.

Mendel, B., N., Sonntag, J., Wahl, P., Schwemmer, H., Dries, N., Guse, N., Müller, S. and Garthe, S. 2008. Profiles of seabirds and waterbirds of the German North and Baltic Seas. Distribution, ecology and sensitivities to human activities within the marine environment. Naturschutz und Biologische Vielfalt 61, Bundesamt für Naturschutz, Bonn – Bad Godesberg.

Müllner, A., Linsenmair, K. E., and Wikelski, M. 2004. Exposure to ecotourism reduces survival and affects stress response in hoatzin chicks (Opisthocomus hoazin). *Biological Conservation*, 118(4), 549-558.

Nudds, R. L. and Bryant, D. M. 2000. The energetic cost of short flights in birds. *Journal of Experimental Biology*. 203, 1561-1572.

Pennycuick, C. J. 2008. Modelling the flying bird. Elsevier, Burlington, MA.

Powell, L.A. 2007. Approximating variance of demographic parameters using the delta method: a reference for avian biologists. *The Condor*, *109*(4), 949-954.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Robbins, A. M. C. 2017. Seabird Ecology in High-Energy Environments: Approaches to Assessing Impacts of Marine Renewables. PhD Dissertation, University of Glasgow.

Ross, K., Liley, D., Clarke, R., Austin, G., Burton, N., Stillman, R., Petersen, C., Panter, C., Cruickshanks, K. & Saunders, R. 2015. Habituation in wintering waterbirds. Unpublished report for Natural England (available on request).

Scherer, R. 2016. Sample Size Calculation for Various t-Tests and Wilcoxon-Test. R package version 0.2-4. https://CRAN.R-project.org/package=samplesize.

Schwemmer, P., Mendel, B., Sonntag, N., Dierschke V. and Garthe, S. 2011. Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. *Ecological Applications* 21:1851–1860.

Scottish Government. 2016. Pilot Pentland Firth and Orkney Waters Marine Spatial Plan, The Scottish Government, Edinburgh.

Soldatini C., Albores-Barajas Y. V., Tagliavia M., Massa B., Fusani L., Canoine V. 2015. Effects of human disturbance on cave-nesting seabirds: the case of the storm petrel. *Conservation Physiology*. 3(1)

SNH. 2016a. North Orkney proposed Special Protected Area (pSPA). Advice to Support Management. SNH report.

SNH. 2016b. Scapa Flow proposed Special Protected Area (pSPA). Advice to Support Management. SNH report.

Stillman, R. A. and Goss-Custard, J. D. 2002. Seasonal changes in the response of oystercatchers *Haematopus ostralegus* to human disturbance. *Journal of Avian Biology*, 33, 358–365.

Szumilas, M., 2010. Explaining odds ratios. *Journal of the Canadian Academy of Child and Adolescent Psychiatry*, *19*(3), p227.

Urfi, A.J., Goss-Custard, J. D. and Le V dit Durell, S. E. A. 1996. The ability of oystercatchers *Haematopus ostralegus* to compensate for lost feeding time: Field studies on individually marked birds. *Journal of Applied Ecology*, 33, 873–883.

Wade, H. M., Masden, E. A., Jackson, A. C, and Furness, R. W . 2016. Incorporating data uncertainity when estimating potential vulnerability of Scottish seabirds to marine renewable energy developments. *Marine Policy*, 70, 108-113.

Žydelis, R. and S. E. Richman. 2015. Foraging behavior, ecology, and energetics of sea ducks. 241–265 in J.-P. L. Savard,D. V. Derksen, D. Esler, and J. M. Eadie (editors). Ecology and conservation of North American sea ducks. Studies in AvianBiology (no. 46), CRC Press, Boca Raton, FL