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# Exploring Moulting Common Eider (*Somateria mollissima*) Escape Responses towards Ship Traffic.

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Biology

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## SUMMARY

**1.** The construction of bottom dwelling offshore wind farms in shallow waters is expected to interfere with seabird feeding and moulting habitats. This study focus on how the disturbance from ship traffic associated with construction and maintenance of offshore wind farms influence moulting common eiders. Such studies might help forming guidelines to minimize potential conflicts between seabirds and the establishment of bottom dwelling offshore wind farms.

**2.** The study was conducted in coastal areas near the island of Smøla in Møre og Romsdal, Norway, during the moulting period. To simulate the expected increase in ship traffic, flocks of common eiders were approached by boat, while escape responses was observed.

**3.** Compared to previous studies, there was no difference in the observed flock-to-boat distances regarding initiation of escape responses. The mean flock-to-boat distance for initiating (alert, swimming, diving, flapping/short sprint or flying) an escape responses was  $330 \pm 146$  meters (range 100 - 700, n=47), whereas the mean flock-to-boat distance when initiating an energy demanding response (diving, flapping/short sprint or flying) was  $178 \pm 103$  meters (range 30 - 400, n=47).

**4.** The variance in escape distance was influenced by wind speed and pre-disturbance habitat availability, as both factors caused shorter escape distances for the eider flocks. After 16.5 min 91.8 % of the flocks had returned to the pre-disturbance behaviour. The study did, however, not succeed in addressing important factors for explaining the variance in the time a flock needed to regain pre-disturbance behaviour.

**5. *Synthesis and applications*** The results from this study might be used to establish buffer zones towards ship traffic in the vicinity of foraging habitats for moulting common eiders. It is suggested that such buffer zones can be defined by applying the maximum bird-to-boat distances from which the escape responses was induced, with 400 m and 700 m as the least and most conservative, respectively. Applying such buffer zones might be an important step to reduce disturbance of moulting common eiders from ship traffic related to establishment and maintenance of bottom dwelling offshore wind farms, and to make production of green energy greener.

## SAMMENDRAG

- 1.** Utbygging av bunnfaste offshore vindkraftanlegg på grunne områder langs norskekysten er forventet å forårsake forstyrrelse for sjøfugl og deres myteområder. Dette studiet fokuserer på forstyrrelsen fra skipstrafikk tilknyttet konstruksjon – og vedlikeholdsfaser for et offshore vindkraftanlegg, og hvordan dette påvirker sjøfugl. For å minimere potensielle konflikter mellom offshore vindkraft og sjøfugl, er slike studier nødvendige, da det kan tydeliggjøre hvilke tiltak som må iverksettes for å unngå konflikter.
- 2.** Studiet ble utført i skjærgården rundt Smøla i Møre og Romsdal, Norge. For å simulere den forventede økningen i skipstrafikk i forbindelse med offshore vindkraft, ble mytende ærfuglflokker eksperimentelt forstyrret av tilnærmende båter, mens de forskjellige fluktresponsene ble registrert.
- 3.** Dette studiet viser at avstandene hvor fluktresponsen blir initiert er forholdsvis like i sammenligning med andre studier. Når man tar alle fluktresponsene (årvåken, svømming, dykking, flaksing/løping og flyvning) i betraktning var gjennomsnittlig initieringsavstand  $178 \pm 103$  meter (range 30 - 400, n=47). Om man tar de mest energikrevende responsene (dykking, flaksing/løping og flyvning) var gjennomsnittsavstanden  $178 \pm 103$  meter (range 30 - 400, n=47).
- 4.** Fluktavstandene til de forskjellige flokkene ble påvirket av vindstyrke og habitatkvalitet. Med økende vindstyrke og habitatkvalitet avtok fluktavstandene. Etter 16.5 min hadde 91.8 % av de observerte flokkene gjenvunnet atferdstyper registrert før starten av båttilnærmingen, men når variasjonen rundt dette tidsforbruket skulle analyseres, ble det ikke funnet noen faktorer som påvirket dette.
- 5. Forvaltningsmessige implikasjoner** Resultatene i dette studiet kan bidra til forvaltning av viktige områder for ærfugl langs norskekysten. For å forhindre at skipstrafikk fører til økt forstyrrelse i nærheten av slike områder, kan en opprettelse av buffersoner basert på den maksimale avstanden (700 meter) som utløste fluktresponsen være et godt forvaltningstiltak. Dette kan redusere den forventede forstyrrelsen fra skipstrafikk, tilknyttet konstruksjon - og vedlikeholdsfaser for et offshore vindkraftanlegg, på ærfugl flokker, og dermed gjøre grønn energi grønnere.

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## Introduction

Emission of carbon dioxide and other greenhouse gases due to fossil fuels are expected to result in long term alteration of future climate (NRC 2010). It is predicted that both natural ecosystems and anthropogenic systems such as agriculture and freshwater resources will experience changes due to global warming (IPCC 2013). Consequently, in order to reduce the emission of greenhouse gases it is urgently needed to increase the production of energy based on renewable energy sources, such as hydroelectric- and wind power. Many European countries have therefore planned to establish offshore wind farms, which are considered the most extensive offshore developments due to large geographical scale of the areas needed (Garthe & Huppopp 2004). Renewable energy from wind farms is considered clean and environmentally friendly compared to fossil energy. However, if the effects of habitat seizure and increased wildlife disturbance are considered, energy production from wind farms can cause large negative effects for local breeding bird communities, as well as migrating species (Guillemette & Larsen 2002; Drewitt & Langston 2006). One of the reasons for this is that offshore, bottom dwelling, wind farms often are established in shallow areas with depths of 5 - 30m, which often are important foraging, moulting and staging areas for waterbirds such as e.g. cormorants, ducks, geese and swans (Hockin *et al.* 1992).

Many studies have assessed possible conflicts between bird populations and onshore- (Larsen & Madsen 2000; Barrios & Rodriguez 2004; Drewitt & Langston 2006), and offshore wind farms (Guillemette & Larsen 2002; Garthe & Huppopp 2004; Desholm & Kahlert 2005; Larsen & Guillemette 2007). Less attention has been allocated to studies of the

disturbance created by supply and maintenance ships associated with the establishment and maintenance of offshore wind farms. Generally, disturbance might have negative effects on waterbirds through loss of foraging time, increased energy use, and reduced foraging efficiency (Merkel, Mosbech & Riget 2009). Consequently, these factors might reduce survival rates and/or reproductive success which consequently may result in a decline in population size (Carney & Sydeman 1999). Furthermore, disturbance might also cause displacement and abandonment of suitable areas. For instance, Hockin *et al.* (1992) demonstrated that ducks, geese and cormorants were displaced due to anthropogenic disturbance and in some cases suitable areas were abandoned completely. Furthermore, Kaiser *et al.* (2006) found that the Common Scoter (*Melanitta nigra*) showed strong avoidance to areas with intense shipping activity, even though the area contained high amounts of prey biomass. These studies suggest that if the number of suitable habitats is already low, the outcome of such habitat avoidance (due to disturbance) might be severe for local populations. However, the response to disturbance may depend on the availability of alternative foraging areas, as this might reduce the negative impacts of being disturbed (Gill, Norris & Sutherland 2001).

The temporal use of areas allocated to offshore wind farms by seabirds might also influence potential negative impacts of the associated disturbance from ship traffic. For instance, Common eiders (*Somateria mollissima*) (hereby referred to as eider) are regarded as especially vulnerable to disturbance during their moulting period due to their enhanced energy demands for growing new feathers and limited flying capabilities (King 1980; Guillemette *et al.* 2007). Many sea bird lose body mass during moulting, the greylag geese (*Anser anser*) as the most extreme, with an estimated 27% loss of its body mass during this period (Laursen, Kahlert

& Frikke 2005). However, for moulting eiders Guillemette *et al.* (2007) demonstrated that their daily metabolic rate increased by 9 %, but due to the energy savings caused by the absence of flights (6 %), the total energy budget was only slightly increased. Furthermore, during the moulting period seabirds often move to remote areas with, generally, lower disturbance and lower predation risk (Frimer 1993; Flint *et al.* 2000; Noer *et al.* 2000).

During the moulting period birds from larger areas normally gather in large flocks in suitable areas. The size of these flocks are positively linked to the escape distances from the source of the disturbance (“Selfish herd” hypothesis, Hamilton 1971; Elgar 1989; Reluga & Viscido 2005; Beauchamp 2007). On the other hand, species might habituate to disturbances (man-made or other) by reducing escape responses as a result of repeated stimulation (Whittaker & Knight 1998; Rankin *et al.* 2009; Schwemmer *et al.* 2011). Moving anthropogenic sources will, in most cases, be treated as a predator, unless the species has habituated to the source (Frid & Dill 2002). For instance, Burger and Gochfeld (1991) reported that the escape initiation distance for migratory bird species in India were longer for resident species, suggesting that the resident species were habituated due to the protective behaviour of the Hindu, whereas the migratory bird species with possible negative experiences to humans elsewhere, were more suspicious.

In Norway plans for developing bottom dwelling offshore wind farms are now evolving. One of the species that are assumed to be affected by this development is the eider, a benthic feeding, diving duck commonly distributed along the Norwegian mainland coast (Lorentsen 2009). There is a strong overlap between preferred moulting areas for eiders and preferred sites for bottom dwelling offshore wind farms along the Norwegian coast (S.-H.



Lorentsen pers comm.). Thus, there is a strong need to understand and quantify to what extent disturbance from ship traffic during construction and maintenance of these installations affects the behaviour of eiders in the moulting period.

The aim of the present study was to explore how the expected disturbance from ship traffic during construction and maintenance of offshore wind farms may influence the behaviour of moulting eiders. Flocks of moulting eiders were approached by boat to simulate the disturbances they may experience during construction and maintenance of bottom dwelling offshore wind farms. During the approaches the changes in escape response was continuously quantified together with the distance between the boat and the targeted flock. Information about these distances can be useful in order to develop guidelines on buffer zones for ship traffic. Next, the study aimed to identify important factors explaining the variance in escape distances of the eider flocks. As explanative variables habitat availability, flock size, tide, wind speed and time of day were included. Finally, the factors influencing the time it took for a disturbed flock to regain pre-disturbance behaviour was analysed.

## Method

### STUDY SPECIES

The eider is the most abundant marine diving ducks along the Norwegian coast. The breeding population is estimated to approximately 190.000 breeding pairs, whereas the wintering population is estimated to 500.000 individuals, constituting one fourth of Europe's total population of eiders during winter (Barrett *et al.* 2006; Lorentsen 2009). The eider is commonly found in shallow areas with kelp beds and sand/rock bottom throughout the year (Bustnes & Lønne 1997). It feeds on benthic prey such as mussels, nematodes and crustaceans (Player 1971; Bustnes 1998; Guillemette 1998) at depths between 10 and 20 meters, but might dive down to 40 m (Bustnes & Lønne 1997; Larsen & Guillemette 2000).

Full grown feathers are lifeless structures and therefore need to be replenished when they become worn (Guillemette *et al.* 2007). This is known as moulting and eiders lose all their wing feathers and, thus, their flight capabilities for approximately 25 to 30 days (late July to August for central Norway) (Dopfner, Quillfeldt & Bauer 2009). The regrowth of new feathers is energetically costly and the moulting period is therefore considered as a particularly vulnerable period (King 1980).

## STUDY SITE

The study was conducted during 6 - 24 August 2013 in shallow coastal areas near the islands Grip (63°13.20N, 7°36.16E), and Smøla (63°25.00N, 7°48.95E) in Møre og Romsdal county, and Frøya (63°45.47N, 8°17.34E) in Sør-Trøndelag county. These areas have large areas of shallow waters and high numbers of remote, small islands which, due to the tide and current systems along the coast, creates particularly suitable foraging habitats for the eider.

## EXPERIMENTAL DESIGN AND DATA COLLECTION

Based on an aerial count of moulting eiders in 2012, a list of possible locations was used to locate eider flocks for the study. An 11.8 meter (39 feet) long tourist/fishing boat was used to approach the flocks during the study period. In addition, another, similar sized boat was used for four days to enhance the effectiveness of the sampling. Throughout the experiment the positions of the boat(s) (latitude and longitude), the bearing to the flock (degrees) and flock-to-boat distance (meters) were recorded. Boat position was retrieved from hand held GPS and the boat's own navigation systems. Bearing of the flocks was obtained using a hand held compass as they were approached. Flock-to-boat distance was determined based on the boat's navigation system, and the observer's judgment of distance. Based on these recordings, it was possible to calculate the flock positions throughout the disturbance approaches, and thereby the flocks' escape distances from their initial site. The water depths below the flocks' positions were collected from navigational maps.

Before the experimental disturbance of the flock it was observed for 10 minutes to register baseline behaviour, which were categorized in three groups: Foraging, swimming

(transport between areas), and social behaviour/resting (pre-disturbance behaviours). The number of individuals per flock was counted in order to analyse whether initial flock size influenced the escape response. In addition, re-counts were done both when initiating, and throughout the disturbance approach, until the observers settled for a more precise number.

When the disturbance approach was initiated, and during the approach, the boat held a straight course towards the flock at a speed of 6 knots (11.1 km/h). The observer continuously reported changes in escape response, compass bearings and flock-to-boat distances to the person responsible for taking notes.

In the post-disturbance phase the boat was always as far as possible from the flock in order not to influence their behaviour. This distance was dependent on visibility due to weather and/or island topography, and average distance was  $585 \pm 216$  m (range 150 - 1000). From this position it was possible to observe the behaviour of the eiders as they were likely to swim towards an island to resume one of the three pre-disturbance behaviours. In this phase the timespan from the end of the disturbance approach until a flock returned to one of the three pre-disturbance behaviours was registered. The number of individuals the flock consisted of compared to the initial flock size was also registered.

The escape responses were initially divided into 6 categories, representing a scale from no response to flying: (1) Undisturbed behaviour/no response; (2) alert behaviour - attention towards boat and flock clumping; (3) swimming away from the boat; (4) escape diving which differs from forage diving; (5) wing flapping behaviour - short sprints across the sea surface; (6) flying, since some of the eiders had not shed their wing feathers yet. The categories wing flapping and flying were later pooled, due to small sample sizes.

To calculate the available foraging habitat for the flocks the pre-and post-disturbance positions were analysed using ArcGIS v.10.1 (ESRI 2013). The foraging habitats was defined as a the available benthic area with depths equal to or less than 20 meters (measured at lowest astronomical tide (LAT)) (Kartverket 2013), within a 150 meters radius from the geographical position of the flock. This radius (150 m) was judged as appropriate based on the area covered by a flock during foraging, which often covered a large area. When the entire benthic area was  $\leq 20$  meters within the 150 meter radius the foraging habitat was set to 100 %. In order to avoid small changes in this variable, percentage was divided by 10, so an increase by 1 unit represents an increase by 10 % available habitat in the analyses.

To calculate escape distances, all the registered flock positions was uploaded to ArcGIS (ESRI 2013). Here, the initial pre-disturbance position was located (position A). Next, the position furthest from the initial position was found (position B). The distance between position A and B was found and defined as the escape distance.

The data on tide and weather was collected from databases online (Kartverket 2013; Meteorologisk Institutt 2013a). Tide was categorized into 4 levels, with level 1 representing low tide  $\pm 1$  hour and level 4 representing high tide  $\pm 1$  hour. Time was recorded at all disturbances, flocks disturbed 08.00 – 09.00 was given the time value 1 (the earliest disturbance approach that was carried out), 09.00 – 10.00 was given the time value 2, and so on. Studies have shown higher foraging rate during low tide, but it has also been shown that dusk and dawn are favoured periods for foraging (Player 1971; Minot 1980; Systad & Bustnes 2001). Wind speed was coded according to the Beaufort scale (Meteorologisk Institutt 2013b). Disturbance

approaches were not performed when wind speed exceeded approximately 10.7 m/s (level 5 on Beaufort scale), as this wind speed along with waves made it difficult to do observations.

A total of 47 flocks were disturbed during the field period and the average flock size was  $51.8 \pm 50.9$  individuals (range 7 - 300). Four of the flocks did not initiate diving, flapping or flying (hereby referred to as EDE), as escape swimming was their final response, but were still used in the analysis. When analysing the time until pre-disturbance behaviour reoccurs, two of the flocks were omitted due to missing values in return time. The missing values rose when flocks went missing before the disturbance approach was finished.

The timespan between two separate disturbance approaches on flocks in a nearby area was minimum five days, and were treated as independent events. Kelp harvesting ships and smaller fishing boats interfered with eider flocks as both fishing grounds and kelp harvesting takes place in the same areas. Based on this traffic, five days between each disturbance approach was considered to be sufficient to treat them as independent flocks, since the probability of being disturbed by other boats within that period was high.

## STATISTICAL ANALYSIS

In order to analyse how the eiders behaviour changed when approached by a boat, a generalized linear model was fitted to describe the number of individuals distributed among the six escape responses as flock-to-boat distance decreased. Because the escape responses were scored as mutually exclusive, the number of birds displaying each response was assumed to follow a multinomial distribution. This assumption was met by applying a multinomial Poisson transformation which treat the data as if the counts in each of the escape responses for each flock follow a Poisson distribution (Baker 1994). This was done by fitting a generalized linear model (GLM) with the following linear predictor:

$$\eta_{ij} = \beta_{obs} + \beta_j + \alpha_j x_i, \quad [\text{eqn. 1}]$$

where  $\eta_{ij}$  is the estimated number individuals displaying a given response (j) for a given observation (i).  $\beta_{obs}$  is the estimated number of birds for a given observational event (bird count),  $\beta_j$  is the estimated mean number of birds for a given response and  $\alpha_j$  is the slope of the regression of number of birds displaying the focal behaviour (j) on bird to boat distance  $x_i$ . The parameter  $\beta_{obs}$  is necessary for the multinomial Poisson transformation to work properly, by controlling for the differences in flock size at each observational event. As an example, three observations on flock 1 with flock-to-boat distances 300, 150 and 50 meters were given the values 1-3, whereas the same observations on flock identity 2 were given the values 4-6. Quasi-Poisson distribution was used to account for over-dispersion, which corrects count data where the variance-mean ratio is  $>1$  (Ver Hoef & Boveng 2007). Preferably, the dependent observations done on the same flocks should have been accounted for, but this was not possible

when the sample size was this low ( $n = 47$ ). Although the parameter estimates have artificially low standard errors and high degree of significance, the estimates themselves can be used to describe how the changes in escape responses.

The predicted values from [eqn. 1] can be used to compute the probabilities of how the different escape responses change in relation to one another at different flock-to-boat distances. The probability of a given escape response was scaled by the sum of all escape responses to obtain a probability distribution that sums to 1:

$$p_{ij} = \frac{e^{\beta_j + \alpha_j x_i}}{\sum_{j=1}^n e^{\beta_j + \alpha_j x_i}} \quad [\text{eqn. 2}]$$

Next, the aim was to identify the factors which influenced the observed variance in both escape distances as a consequence of boat disturbance by applying a linear model (LM).

Finally, the factors influencing the variance regarding the time a flock needed to regain pre-disturbance behaviour after a disturbance approach was analysed by applying the cox proportional hazard regression (hereby cox regression). This was performed using the survival package (Therneau 2014). Even though the methods were developed for the analysis of survival, the approach is general and can easily be applied to other purposes as the analysis investigates what factors influence the time until a specific event occurs. Time is defined as the (survival) time from the start of a follow-up. In this case, the time spans from the end of a disturbance approach until an event occurs. Whether a flock regained pre-disturbance behaviour or not is the event in the present study. If a flock failed to regain this behaviour, it was referred to as right-censored (Walters 2001; Kleinbaum & Klein 2005). A flock was censored when 50 % or less of the subgroup that was pursued failed to regain pre-disturbance behaviour



(86 % of the flocks split at least once). Of the 47 flocks, eight flocks failed to achieve this and were thereby censored.

For the linear model and cox regression the following explanatory variables were included in the analyses: foraging habitat in the pre-disturbance flock positions, flock size, tide, wind speed and time of day. The squared effect of tide and time of day was included, in order to account for the non-linear effects. In order to evaluate the problem of multi-collinearity the variables were assessed for possible correlations by Pearson's correlation test, but no correlations of crucial magnitude were found (highest correlation was  $r_p = 0.31$ ,  $p < 0.05$ ,  $n = 47$ , between tidal level and wind speed). Both of the analyses were tested with a number of candidate models, and the structure and composition of variables in the models were based on biological sound considerations, and evaluated by AICc (see below). First, each of the explanatory variables was run in separate analyses. Next, since habitat availability was a variable of interest, this was included together with each of the other variables. Next, flock size was included as a main factor and also in interaction with each of the other variables. Finally, the foraging habitat was included together with the interaction between flock size and one of the other variables (Appendix A, Table A1 for the complete list of candidate models). In order to avoid over-parameterization, the models did not include more than 5 explanatory variables, considering the total sample size included in the study ( $n = 4x$  flocks). The cox regression had two extra variables that were included among the candidate models: escape distance and post-disturbance foraging habitat (see Appendix A, Table A2 for the complete list of candidate models). Apart from this, the model structures were similar for the two last analyses.

To select the most favourable model the Akaike Information Criterion (AIC) with correction for small sample size (AICc) were used (Burnham & Anderson 2002). AIC is an estimate of the distance between the candidate models and the mechanism that generated the observed data. The AIC values are only comparable among the candidate models, and if  $\Delta AICc$  between two models was  $< 2$ , the models should receive equal support. Akaike weights,  $w_i$ , were applied to provide an estimate of how good a model are compared to all the other candidate models considered. In addition, evidence ratios were calculated to further examine the strength of one model in favour of another, based on the Akaike weights ( $w_1/w_2$ ) (Burnham & Anderson 2002).

All statistical analyses and geographical calculations were performed using the software R v.3.0.2 (R Development Core Team 2013) and ArcGIS v.10.1 (ESRI 2013), respectively.

## Results

### ESCAPE RESPONSE

The proportion of undisturbed individuals declined rapidly as flock-to-boat distance started to decrease (Figure 1, Table 1). Alert response was the initial observed escape response, followed by escape swimming. As alert response started to decline, escape swimming continued to increase while escape diving started to develop. For even shorter flock-to-boat distances, escape diving became the most dominant escape response. When flock-to-boat distance was at its shortest, 74.7 % of the flocks had initiated diving, while 23.1 % continued escape swimming at this distance.

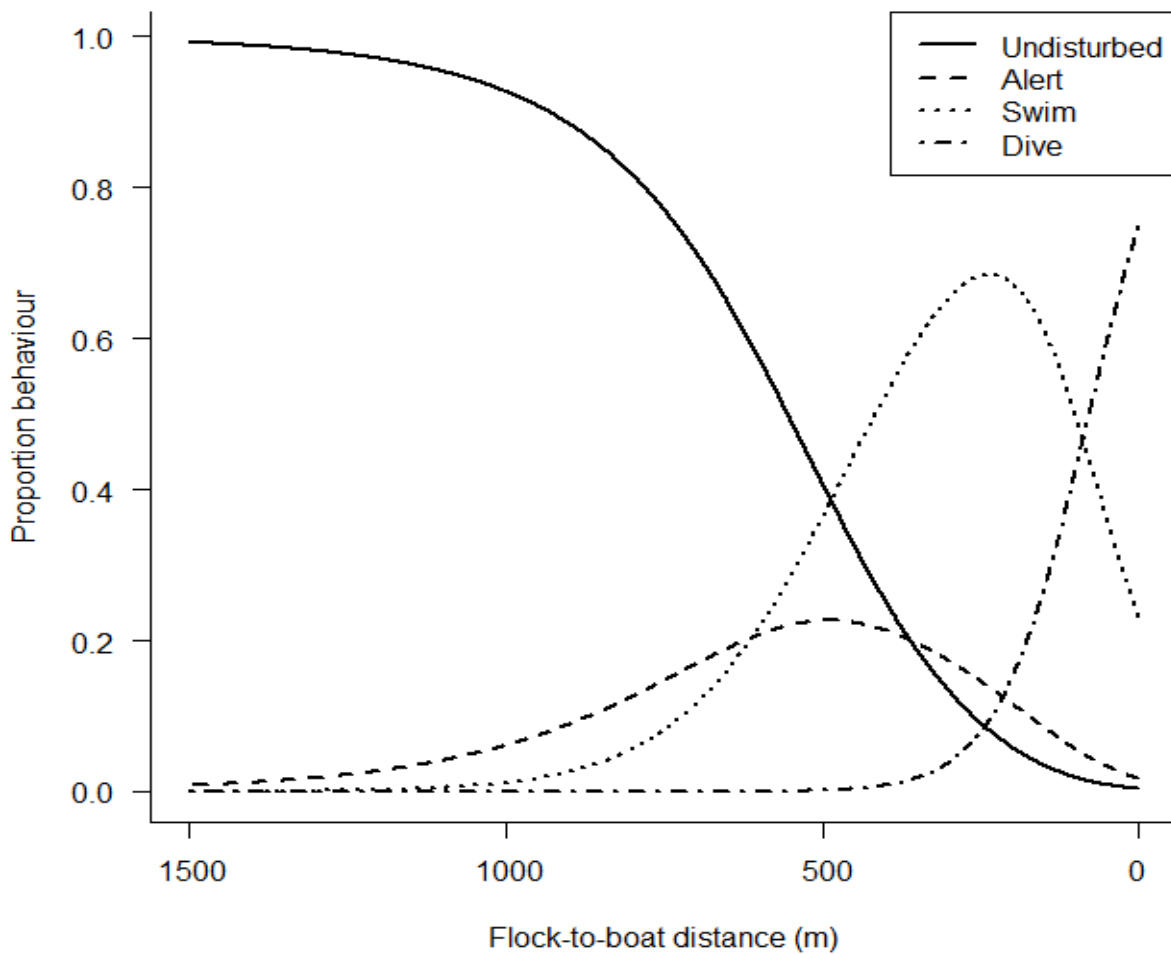


Figure 1: The proportional relationship between the escape responses as flock-to-boat distances decrease, among eider flocks that were approached by boat off the coast of Sør-Trøndelag - and Møre og Romsdal counties during August 2013. The result is based on a multinomial Poisson transformation (equation 1, Parameter estimates in Appendix B) and an equation which creates a probability ratio for the behavioural categories (see eqn 2). Flapping and flying response constituted < 5 % of the dataset and due to this excluded from the figure (and eqn. 2). Proportions of the different behavioural categories sums to 1. n = 47.

Table 1: Describing at what distances the different escape responses were most frequently observed, and their respective ranges. The data was sampled by approaching flocks of eider by boat off the coast of Sør-Trøndelag county and Møre og Romsdal county during August 2013. Data on the excluded variables flapping and flying are included. The table is based on a multinomial Poisson transformation (equation 1) and an equation which sums the behavioural categories to 1 (equation 2) (See Appendix B for parameter estimates). n = 47.

Response	Most frequently observed (m)	Min (m)	Max (m)
Undisturbed	1500	700	1500
Alert	488	150	600
Swimming	236	0	700
Diving	0	5	400
Flapping	134	40	300
Flying	185	30	400

The average flock-to-boat distances from which initial escape response was initiated (omitting undisturbed behaviour) was  $330 \pm 146$  m (range 100 - 700). The mean flock-to-boat distance when initiating EDE response was  $178 \pm 103$  m (range 30 - 400).

## ESCAPE DISTANCE

The highest ranked model regarding escape distance included the variables wind speed and foraging habitat (Table 2). One other model had a  $\Delta AICc < 2$ , which included wind speed as the only explanatory variable. AICc weight and evidence ratio clearly favours the two highest ranked models, but the top model was undoubtedly the best. The mean escape distance for the flocks' was  $775 \pm 300$  m (range 283 - 1462).

Table 2: The five highest ranked models, according to AICc, explaining the variation in escape distance for flocks of eider off the coast of Sør-Trøndelag county and Møre og Romsdal county during August 2013. An x indicates an interaction, and always includes the main effect. All models include intercept. Appendix A, table A1 includes all candidate models.  $n = 47$ .

Rank	Model parameters	K	$\Delta AICc$	AICc Weights	ER
1	W + PRH	3	0.00	0.30	1.00
2	W	2	0.91	0.19	1.58
3	PRH	2	2.32	0.09	3.33
4	PRH + NN x T	5	3.51	0.05	6.00
5	PRH x NN	3	3.74	0.04	7.50

*K* number of parameters,  $\Delta AICc$  AICc difference from the highest ranked model, *Weight* Akaike weight for each model, *ER* Evidence ratio for each model compared to the top model. The explanatory variables included: *W* wind speed, *PRH* pre-disturbance habitat availability, *T* time of day, *NN* flock size.

The highest ranked model indicated that the escape distances were shorter in average when they were disturbed in an area with high habitat availability. Also, the negative relationship between wind speed and the variance in escape distance indicates that the eiders had shorter escape distances with increased wind speed.

Table 3: The top ranked model's (based on AICc) variable estimates, explaining the variation in escape distance for experimental disturbed flocks of eider off the coast of Sør-Trøndelag county and Møre og Romsdal county during August 2013. n = 47.

Variable	Estimate $\pm$ SE	95 % Confidence interval	
Intercept	1146.58 $\pm$ 130.97	882.63	1410.53
Wind speed	-77.14 $\pm$ 35.79	-149.27	-5.01
Pre disturbance habitat availability	-26.13 $\pm$ 14.58	-55.51	3.24

## REGAIN PRE-DISTURBANCE BEHAVIOUR

The highest ranked model included time of day as the only explanatory variable (Table 4). Four models had a  $\Delta AICc < 2$ , and by comparing the evidence ratio to the three other models, the top model was undoubtedly the best. Still, it does not have convincingly support as the AICc weights are distributed among several of the candidate models (Appendix B2). Also, the  $R^2$  value indicated that 6.3 % of the variance in escape distance is explained by the top model. The top ranked model included the variable time of day, and propose that if a flock was disturbed one hour later, it would decrease the time until pre-disturbance behaviour reoccurred by 10.5 %. After 16.5 min 91.8 % of the flocks had returned to the pre-disturbance behaviour (Figure 2). The average time a flock used to regain pre-disturbance behaviour was  $6.5 \pm 3.5$  min (range 0.5 - 16.5).

Table 4: The top five models explaining the variation in time until pre-disturbance behaviour reoccur, among eider flocks that were approached by boat off the coast of Sør-Trøndelag county and Møre og Romsdal county during August 2013. An x indicates an interaction, and always includes the main effect. Appendix A, table A2 includes all candidate models.  $n = 45$ .

Rank	Model parameters	K	$\Delta AICc$	AICc Weights	ER
1	T	1	0.00	0.16	1.00
2	D	1	1.13	0.09	1.89
3	T + T <sup>2</sup>	2	1.35	0.08	2.13
4	TL	1	1.58	0.07	2.43
5	NN x POH	3	2.01	0.06	2.83

*K* number of parameters,  $\Delta AICc$  AICc difference from the highest ranked model. *Weight* Akaike weight for each model, *ER* Evidence ratio for each model compared to the top model, *T* time of day, *D* escape distance, *TL* tidal level, *NN* flock size, *POH* post-disturbance habitat availability.



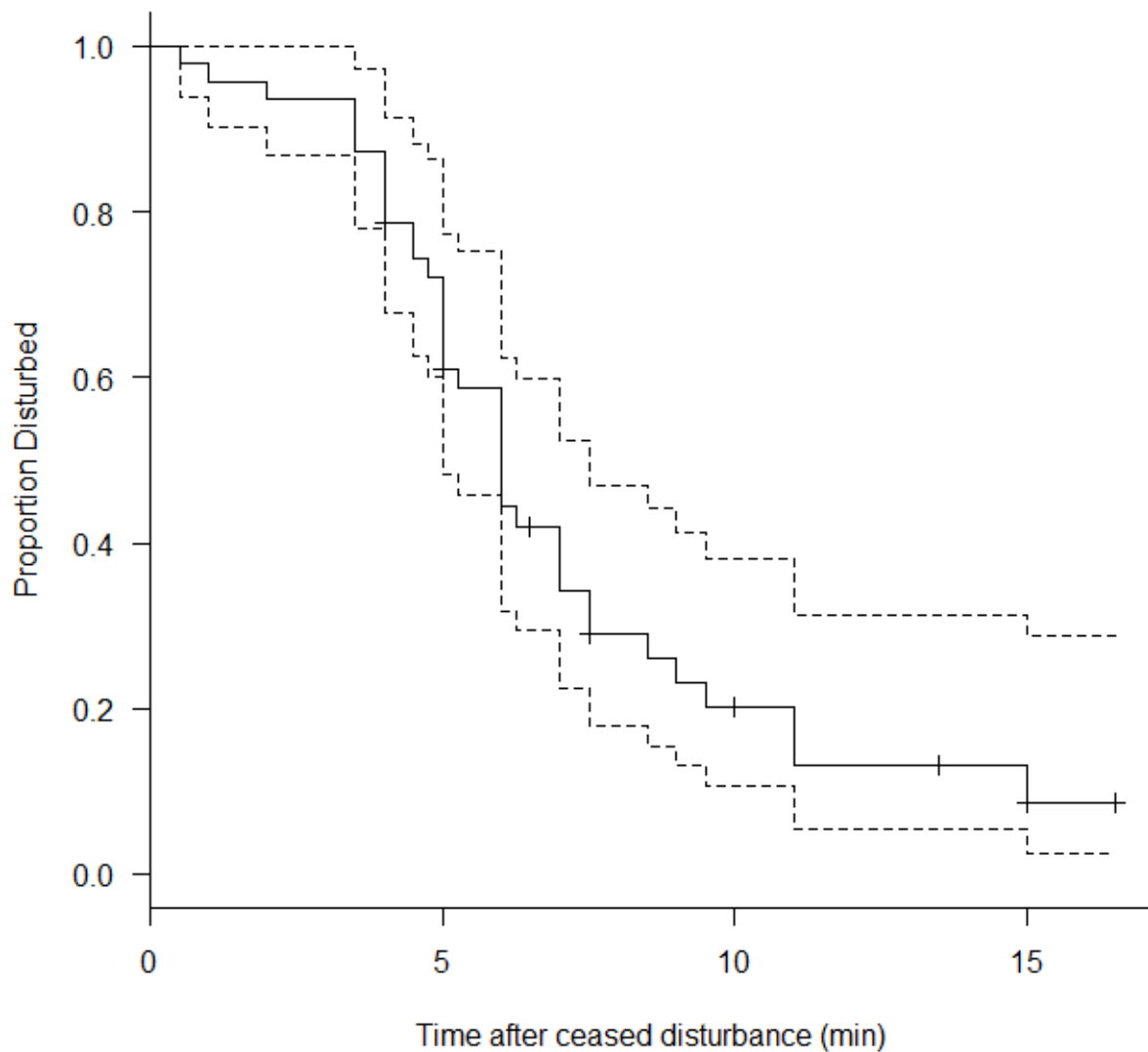


Figure 2: Time until flocks of eider regained pre-disturbance behaviour after being disturbed by a boat in a study performed off the coast of Sør-Trøndelag - and Møre og Romsdal county during August 2013. The vertical drops in the solid line represent a different flock, with a different time consume for regaining pre-disturbance behaviour. The broken lines represent a 95 % confidence slope for the survival function. See text for further details. n = 45.

## Discussion

By experimentally approaching flocks of eider by boat this study quantified the successive effect of disturbance on the behavior of flocks of eiders along the coast of mid Norway. The study demonstrated that escape distances were influenced by the availability of feeding areas as well as wind strength. The proportional behavior of eider flocks changed when approaching flocks by boat. Undisturbed behavior changed to more stressed alert behavior, followed by swimming and finally diving and or flapping behavior at very close distances (Fig. 1). The current study provides important quantitative knowledge about the flock-to-boat effects on the behavior of eiders that can be used to give concrete advices about restrictions and buffer-zones related to the disturbance created by supply and maintenance ships associated with offshore wind farms. The most conservative option would be to establish buffer zones based on the maximum flock-to-boat distances from which the initial escape response was observed (700 meter). A less conservative approach is to use the maximum flock-to-boat distance from which EDE was observed (400 meters).

In the current study the eiders initiated EDE when the flock-to-boat distance was  $178 \pm 103$  meters. The study by Schwemmer *et al.* (2011) the eiders initiated EDE at 208 meters, and when regarding the standard deviation (only given graphically) the two studies overlap. The study by Schwemmer *et al.* (2011) was, however, performed during the non-moulting period and the most frequently observed escape response was flying. This suggests that the observed flock-to-boat distance from which EDE was initiated might be preferable as the eiders tries to limit their energy usage. From the eiders perspective, an approaching boat can be evaluated as a predator (Frid & Dill 2002), and by showing the predator it has been detected at an early stage (by clumping and/or swimming away) can cause the predator to re-evaluate its chance of success and give up early in an attack (Caro 1995). In addition, animals are expected to maximize fitness by overestimating rather than underestimating risk (Frid & Dill 2002). This can contribute to reductions in allostatic load associated with moulting, which in turn can result in a shorter moulting period (Borras *et al.* 2004). Such mechanisms are also in accordance with a study by Dopfner, Quillfeldt and Bauer (2009), which stated that the increased energy demands during moulting should be met by reducing the energy usage, by increased nutrition intake or by

metabolize of stored energy. Ydenberg and Dill (1986) stated that if the foraging habitat is of low quality the initiation of escape responses might increase as the benefits of staying are less likely to outweigh the risk of staying.

Differences in disturbance intensity may result in habituation which modifies the behaviour (Ross, Lien & Furness 2001; Richman 2013). The current study could not detect this, whereas the study by Schwemmer *et al.* (2011) found indications of habituation. More intense disturbance, habitat heterogeneity, local genetic differentiation among populations may explain differences between studies. Seltsmann *et al.* (2012) suggested that habituation among older individuals could be more common, as they are more experienced than their younger conspecifics. Compared to other seabirds the shorter EDE distance for eiders might be explained by their heavier wing load (Laursen, Kahlert & Frikke 2005).

The present study indicate that the pre-disturbance habitat availability influence the escape distance negatively, which can imply that the eiders regard the disturbance as tolerable and will thereby attempt to return to the same foraging habitat. Depending on prey biomass and predation risk, the shorter escape distance can be an indication of return (Frid & Dill 2002). Borrás *et al.* (2004) reported that moulting individuals of the Citril Finch (*Serinus citrinella*) that resided in high quality habitats in the Pyrenees (Spain) gained higher body condition, and had shorter moulting period compared to individuals that lived in low quality habitats. Laursen and Frikke (2008) showed that eiders returned to good foraging habitats when disturbance (hunting) was removed. The area was regarded as high quality based on high quantities of prey biomass, the willingness to return and the increased body condition. Furthermore, the consequences by moulting in a poor quality habitat can influence flying performance and/or sexual character, as the regrown feathers are developed suboptimal (Gordo 2007). Accordingly, the observed negative relationship between escape distances and pre-disturbance habitat quality may indicate that eider flocks prefer to stay close to high quality habitats as this is an important factor when moulting. However, the response to disturbance may also be influenced by whether there were alternative foraging areas in nearby areas, and this effect may conceal the estimated effect of disturbance on the escape distance (Gill, Norris & Sutherland 2001). If considering leaving for the alternative foraging habitat, the trade-off between the migrating

distance, prey biomass and predation risk must be evaluated (Frid & Dill 2002). If staying in an area with disturbance, the eiders might experience increased energetic costs due to anti-predator behaviour together with reduced foraging effectiveness (Gill, Norris & Sutherland 2001). Consequently, a high philopatry to undisturbed areas for moulting and breeding has been documented for several duck species (Hohman *et al.* 1992; Frimer 1993; Bollinger & Derksen 1996; Flint *et al.* 2000; Phillips & Powell 2006).

As Table 3 shows, as wind speed increased, escape distance decreased. This may indicate that higher waves might influence the eider's probability to detect the source of disturbance. This corresponds with the findings by Laursen, Kahlert and Frikke (2005) that demonstrated delayed escape with increasing winds and poorer visibility for seabird species. Schwemmer *et al.* (2011) also proposed that higher waves make it more difficult for the birds to spot an approaching boat. After periods with strong wind (>5 Beaufort scale), flocks of eider were observed heading from the major island and towards smaller islands further offshore (pers. obs). This is in accordance with Johnson and Richardson (1981) who suggested that eiders seek shelter among bigger island during strong winds.

Flock size did not influence the escape distance in the present study. Large flocks have been proposed to decrease the per capita probability of being killed by a predator, by detecting the predator at longer distances (Elgar 1989; Reluga & Viscido 2005; Beauchamp 2007). This has been demonstrated in a number of other studies (Madsen 1985; Fox & Madsen 1997; Dumont *et al.* 2012). Among other, Laursen, Kahlert and Frikke (2005) found a positive connection between flock size and escape distance, when evaluating ten different species of waterbirds. On the other hand, a review reported that many studies showed the opposite or no effect at all (Ydenberg & Dill 1986). Tidal level had no effect on escape distances in the present study. With a difference between low and high tide of 266cm, Player (1971) argued that low tide foraging becomes more important were the differences are larger. Anyhow, foraging is more often observed during low tide in marine diving ducks (Systad & Bustnes 2001; Laursen, Kahlert & Frikke 2005).

The present study showed that the time until a flock regained pre-disturbance behaviour was rather low, as approximately 90 % of the flocks had regained this behaviour after

16.5 minutes. Significant explanatory factors could not be identified, suggesting that the present study failed to address important explanatory factors in the candidate models (Appendix A, Table B2). The study by Schwemmer *et al.* (2011), registered a 100 % return rate of individuals to the disturbed sites 61 - 120 minutes after the disturbance approach. The current study differs from Schwemmer *et al.* (2011), as it was performed during the moulting period, along with lower thresholds for a flock to regain pre-disturbed behaviour. Kaiser *et al.* (2006) studied the return rates for moulting greylag geese which used  $19.49 \pm 9.45$  minutes before returning to the foraging habitat. The time span is more comparable to the current study, as the limitations in flying capabilities causes relatively short escape distances. On the other hand, this study also differs due to the disturbance of individuals, not flocks, and land based foraging habitat (Kaiser *et al.* 2006).

Although the design of the present study addresses important questions, there are many aspects on the effect of disturbance that are not addressed, for instance the effect of repeated and intense disturbances. A study by Merkel, Mosbech and Riget (2009) showed that the effect of fast moving open boats disturbed the feeding activity of eiders in Southwest Greenland to such extent that the eiders reduced their feeding activity with about 60 %. In addition the study showed that feeding activity was scheduled to periods when feeding conditions were less profitable (mid-day, high tide). The switch to nocturnal foraging due to boating activities was also registered at a migratory site for diving ducks in the Mississippi River, Colorado, USA (Korschgen, George & Green 1985). It has also been shown that local topography in connection with disturbance can cause changes in foraging habits. Merkel and Mosbech (2008) showed that the foraging regime between the open, flat landscape further off the coast had different foraging regimes, compared to areas closer to the mainland with cliffs. Closer to the mainland the eiders fed by night, and it was proposed that the topography made it more difficult to spot predators. Furthermore, the study by Borrás *et al.* (2004) showed that the preferable foraging sites was reoccupied when disturbance was removed.

This study has demonstrated that eiders are vulnerable to ship traffic. Authorities should therefore mitigate offshore wind farm-related shipping activity. This should be done in order to create predictable movement by the associated ships, and to avoid areas which are of

great importance for seabirds, as for instance shallow areas for marine diving ducks. Since the availability of eider foraging habitats was found to decrease the escape distance, it is important to minimize disturbance in such areas by applying buffer zones. The maximum distance for the initiation of escape response (alert, swimming, diving, flapping/short sprint and flying) found in this study (700 meters) could be a guideline when establishing buffer zones around important moulting areas for eiders. A less conservative buffer zone can be established based on the maximum EDE (diving, flapping/short sprint and flying) distance (400 meters). Schwemmer *et al.* (2011) found indications of habituation among eiders regularly feeding near shipping lanes, compared to eiders exposed to ship traffic irregularly. On the other hand, Laursen and Frikke (2008) reported that eiders were displaced from favoured areas due to human activity. Since this project could not detect any habituation, the flock-to-boat distances found in this study could serve as the best option for buffer distance. This is supported by Laursen, Kahlert and Frikke (2005) who proposed that escape distances, which is comparable to EDE distance in the current study, should determine buffer zones. Using the results from the current study, a buffer zone of 400 meters would then be implied.

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## Appendix A

**Table A1.** List of candidate models when analysing which variables influenced the observed variance in escape distances. The project was carried out off the coast of Sør-Trøndelag county and Møre og Romsdal county during August 2013, by experimentally disturbing flocks of eider by boat. All models include intercept. n=47.

Model parameters	K	AICc	$\Delta AICc$	AICc Weights
PRH + W	3	669.4	0.00	0.30
W	2	670.32	0.91	0.19
PRH	2	671.72	2.32	0.09
PRH + T x NN	5	672.91	3.51	0.05
PRH + NN	3	673.15	3.74	0.04
PRH + T	3	673.62	4.22	0.03
PRH + W x NN	5	673.91	4.50	0.03
W x NN	4	674.01	4.61	0.03
PRH + TL	3	674.11	4.71	0.03
NN	2	674.79	5.38	0.02
T	2	675.00	5.60	0.02
PRH x NN	4	675.11	5.71	0.02
TL	2	675.26	5.85	0.01
PRH + T <sup>2</sup> + T x NN	6	675.42	6.02	0.01
PRH + TL x NN	5	675.63	6.23	0.01
PRH + TL + TL <sup>2</sup>	4	675.88	6.48	0.01
PRH + T + T <sup>2</sup>	4	676.10	6.70	0.01
TL + TL <sup>2</sup>	3	676.40	7.00	<0.01
T x NN	4	676.56	7.16	<0.01
PRH + TL <sup>2</sup> + TL x NN	6	676.59	7.19	<0.01
T + T <sup>2</sup>	3	677.39	7.99	<0.01
TL x NN	4	677.69	8.29	<0.01
TL <sup>2</sup> + TL x NN	5	677.92	8.51	<0.01
T <sup>2</sup> + T x NN	5	679.20	9.79	<0.01

*K* number of parameters,  $\Delta AICc$  AICc difference from the highest ranked model, *Weight* Akaike weight for each model. The explanatory variables included: *PRH* pre-disturbance habitat availability, *W* wind speed, *T* time of day, *NN* flock size, *TL* tidal level.

**Table A2.** List of candidate models when analysing which variables influenced the observed variance in time until pre-disturbance behaviour was regained. This was done off the coast of Sør-Trøndelag county and Møre og Romsdal county during August 2013, by experimentally disturbing flocks of eider by boat. n=45.

Model parameters	K	AICc	$\Delta$ AICc	AICc Weights
T	1	225.29	0.00	0.17
D	1	226.42	1.13	0.09
T + T <sup>2</sup>	2	226.64	1.35	0.08
TL	1	226.87	1.58	0.07
NN x POH	3	227.31	2.02	0.06
T + PRH	2	227.46	2.17	0.05
POH	1	227.94	2.65	0.04
W	1	228.07	2.78	0.04
PRH	1	228.07	2.78	0.04
NN	1	228.19	2.90	0.04
NN x D	3	228.54	3.25	0.03
D + PRH	2	228.60	3.31	0.03
T + T <sup>2</sup> + PRH	3	228.76	3.47	0.03
TL + TL <sup>2</sup>	2	228.98	3.69	0.03
TL + PRH	2	229.06	3.77	0.03
NN x T	3	229.43	4.14	0.02
NN x POH + PRH	4	229.71	4.41	0.02
POH + PRH	2	229.95	4.66	0.02
W + PRH	2	230.18	4.89	0.01
NN + PRH	2	230.22	4.93	0.01
NN x TL	3	230.70	5.40	0.01
NN x D + PRH	4	230.95	5.66	<0.01
NN x T <sup>2</sup> + T	4	231.10	5.81	<0.01
TL + TL <sup>2</sup> + PRH	3	231.28	5.99	<0.01

*K* number of parameters,  $\Delta$ AICc AICc difference from the highest ranked model, *Weight* Akaike weight for each model. The explanatory variables included: *T* time of day, *D* escape distance, *TL* tidal level, *POH* post-disturbance habitat availability, *NN* flock size, *PRH* pre-disturbance habitat availability, *W* wind speed.

## Appendix B

Table B1. The estimated parameters when parameter estimates from the multinomial Poisson transformed model. Data was sampled by experimentally disturbing flocks of eider off the coast of Sør-Trøndelag county and Møre og Romsdal county during August 2013. n=47.

Variable	Intercept $\pm$ SE	Slope $\pm$ SE
Undisturbed	-2.65 $\pm$ 1.44	0.012 $\pm$ 0.002
Alert	1.54 $\pm$ 0.50	0.008 $\pm$ 0.002
Swimming	4.14 $\pm$ 0.48	0.004 $\pm$ 0.002
Diving	5.32 $\pm$ 0.55	-0.009 $\pm$ 0.003
Flapping/flying	2.60 $\pm$ 0.66	dd

*dd* data deficient.