ENERGISTYRELSEN

LONGTERM RESPONSE OF OFFSHORE WIND FARMS ON WINTERING BIRDS

SPATIAL DISTRIBUTION OF LONG-TAILED DUCKS (*CLANGULA HYEMALIS*) AT THE KRIEGERS FLAK OFFSHORE WIND FARM 2022-2023

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CONTENTS

1 INTRODUCTION

This report presents data from vessel-based surveys conducted during the winter period 2022/23 at the Kriegers Flak Offshore Wind Farm.
The scope of the project is to estimate the abundance and density of wintering Long-tailed Ducks (*Clangula Hyemalis*) in the Kriegers Flak area, as well as to describe their spatial distribution.
The overall purpose is to assess the effect of the existing operational wind farm on the abundance and densities Long-tailed Ducks in the area. The surveys were conducted approximately one year after the commissioning of the wind farm offering the opportunity to investigate potential post construction affects, of an operational wind farm on wintering Long-tailed Ducks.

Post construction surveys of operational wind farms are relatively rare, especially in Denmark, and the data presented in this report can provide valuable information to be applied in future Environmental Impact Assessments (EIA) of offshore wind farms. In particular this concerns the ecological and behavioural responses of Long-tailed Ducks to potential displacement or attraction effects from offshore wind farms in operation. There is a need to gain further insights into the impacts of offshore wind farms on this species, especially given the apparent state of the Long-tailed Duck population in the Baltic Sea, which appears to have suffered a significant and long-term decline according to the IUCN, warranting a downlisting in 2012 - from Least Concern (LC) to Vulnerable (VU) (BirdLife International, 2023).

This study and applied methods are largely inspired by the Nysted/Rødsand II report by the Danish Centre for Environment and Energy (DCE) (Petersen et al. 2018). Kriegers Flak is fairly similar to other sand banks in the Baltic Sea and this study as well as the study from Nysted/Rødsand II wind farm by DCE, serve as case studies for future projects.

1.1 KRIEGERS FLAK

The Kriegers Flak Offshore Wind Farm is situated approximately 15-40 km east of the Danish island Møn, in the southern region of the Baltic Sea and has a production capacity of around 600 MW. The wind farm is comprised by 72 wind turbines located on the shallow sandbank known as Kriegers Flak near the offshore boundaries of the exclusive economic zones (EEZ) of Sweden, Germany, and Denmark, covering an area of 132 km^2. The construction began in May 2018 and the wind farm was fully operational in September 2021 (information from Vattenfall 2021). The Kriegers Flak Offshore Wind Farm is a crucial component of the Danish Energy 21 action plan and aligns with the national planning of the energy transition outlined in 2014 by the Danish Energy Agency. The designated project area for the Kriegers Flak Offshore Wind Farm is located in the central part of the Arkona Basin. This area is characterized by a relatively high biomass of blue mussels, which supports a wintering population of Long-tailed Ducks, the only common species in the area, while Red-throated/Black-throated Divers *Gavia stellata/arctica* and Black Guillemots *Cepphus grylle* are less common. The water depths within the boundary of Kriegers Flak OWF varies from 16 to 30 meters, deepening towards the periphery and edges of the bank (Skov et al., 2015). Based on the national midwinter counts it has previously been shown that 65 % of the resting Long-tailed Ducks were found at similar water depths between 14 and 24 meters (Petersen et al., 2006).

1.2 LONG-TAILED DUCK: BIOLOGY, ABUNDANCE AND DISTRIBUTION

The Long-tailed Duck (*Clangula hyemalis*) has a circumpolar distribution range and migrates between Arctic breeding grounds and temperate wintering areas. They mainly breed in freshwater habitats located in the Arctic tundra or in areas that provide similar conditions – e.g. the alpine areas of the Norwegian west coast. During the breeding season Long-tailed Ducks forage on a variety of organisms including insect larvae, fish spawn, crustaceans, and molluscs. During the non-breeding season, Long-tailed Ducks are gregarious, and often seen in flocks at temperate marine coastal areas and offshore banks, where they mainly feed on bivalves supplemented by polychaeta worms, echinoderms, and fish spawn (Stempniewicz, 1995).

The Long-tailed Ducks that winter in the investigation area are part of the Fennoscandian-West Siberian population division (Birdlife International, 2023). They start arriving from the breeding grounds in October and are most numerous during winter (January-February). The last birds are seen in April before migrating back towards the breeding grounds. Presence of Long-tailed Ducks in the investigation area during summer can be considered extremely rare.

Long-tailed Ducks belonging to the Fennoscandian-West Siberian population winter in the central and Southern part of the Baltic Sea (Skov et al., 2011). A relatively large part of the Fennoscandian birds are believed to winter in the Atlantic Ocean off the Norwegian coast, whereas the wintering population in the Baltic Sea is assumed to be comprised mostly by West Siberian birds, which is confirmed by tracks of gps-tagged individuals commuting between breeding and wintering grounds (Quillfeldt et al., 2022).

From the coordinated Baltic survey conducted between 2007 and 2009 a total wintering population in the Baltic Sea of 1.5 million Long-tailed Ducks were estimated (Quillfeldt et al., 2011). This estimate suggests a 65% population decline since the census period 1988-1993, where 4.3 million Long-tailed Ducks were estimated to winter in the Baltic Sea. Despite this immense decline in population size there has been no obvious change in the species' winter distribution patterns within the Baltic Sea (Skov et al., 2011, Birdlife International, 2023). The areas of the Baltic Sea hosting the highest numbers of Long-tailed Ducks are the Pomeranian Bay, the Gulf of Riga, and the Midsjö banks south of Gotland which are all located well outside the investigation area.

However, a considerable number of Long-tailed Ducks have also been observed at Kriegers Flak inside the investigation area. Maximum densities of 100 birds/km^2 were predicted in Period 1 (1987-1993) compared to densities of 10 birds/km^2 in Period 2 (2004-2009) (Skov et al., 2015). Other studies have recorded up to 10,000 birds or 3-10 birds/km^2 during winter and spring at Kriegers Flak which is below 1% of the total number of Long-tailed Ducks wintering in the Baltic Sea (Skov et al., 2011, Durinck et al., 1994).

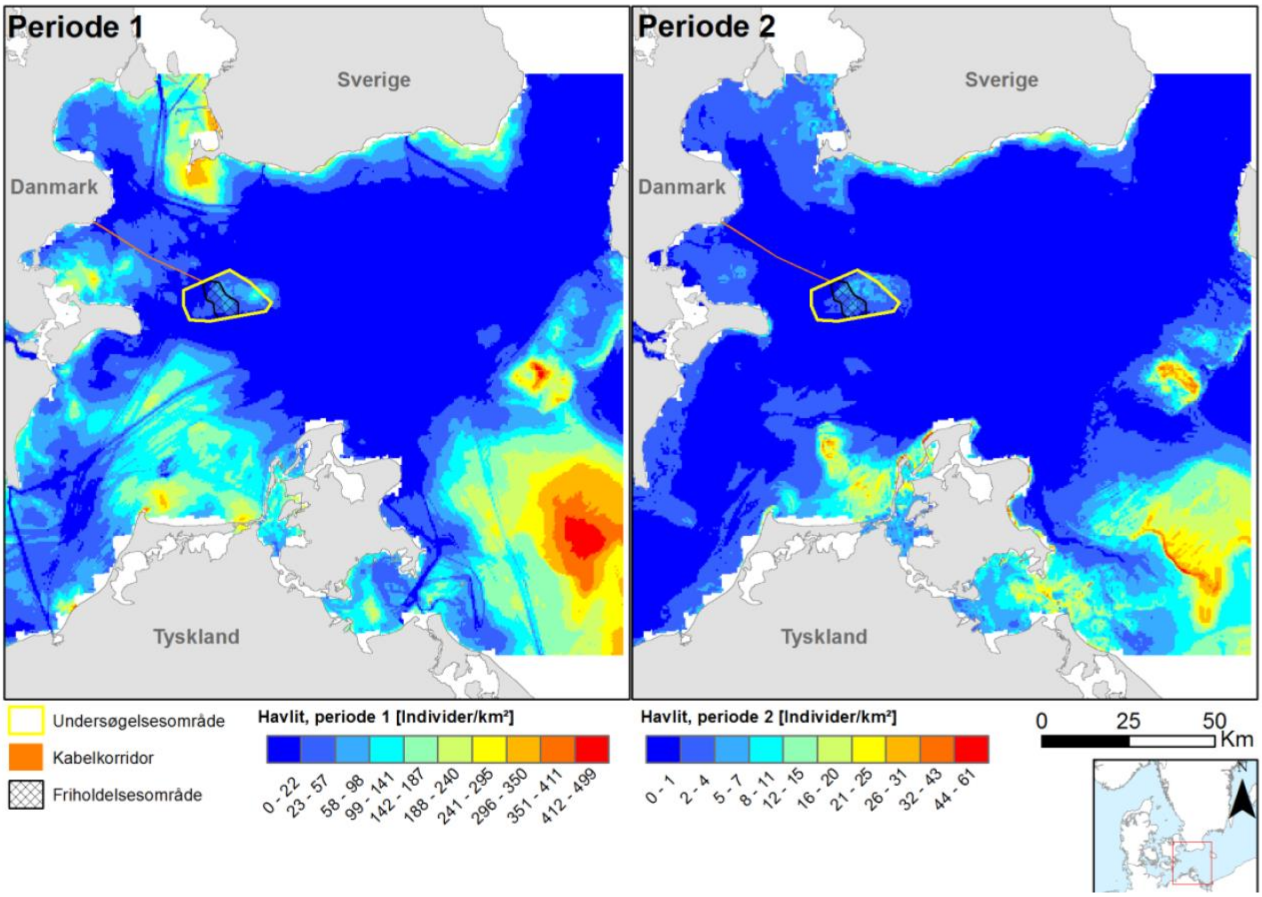

Figure 1 – Estimated densities of wintering Long-tailed Ducks (individuals per km2) for two different periods (Period 1: 1987-1993; period 2: 2004-2009) (Source: Skov et al., 2015)

CONSERVATION STATUS

Of all sea duck species, the Long-tailed Duck is the most abundant. Despite their occurrence at relatively large numbers, their populations have declined in the last decades due to many anthropogenic factors, especially oil pollution (Skov et al., 2011; Nilsson, 2016; Nilsson & Haas, 2016).

Specifically, the wintering population of Long-tailed Ducks, in the Baltic Sea, has undergone an apparent population decline from over 4 million individuals in the survey period 1992-1993 to just under 1.5 million individuals in the survey period 2007-2009 (Skov et al., 2011). This apparent population decline justifies an IUCN Red Listing category of Vulnerable (VU). The justification is based on the IUCN Red List criteria A4bce:

*"*An observed, estimated, inferred, projected or suspected population size reduction of ≥30% over any 10 year or three generation period, whichever is longer (up to a maximum of 100 years in the future), where the time period must include both the past and the future, AND where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on (and specifying) any of (a) to (e) under A1*"* (IUCN, 2012, pp. 20-21):

The downlisting from Least Concern (LC) to Vulnerable (VU) was done in 2012 after the findings of Skov et al. (2011). When the IUCN Red List criteria A4 is used, it is an expression of the environmental precautionary principle. This principle emphasizes caution when extensive scientific knowledge is lacking on a particular matter. In this case it is lacking scientific knowledge on the Long-tailed Ducks' population size and whereabouts outside the Baltic Sea, combined with the apparent decline in population size within the Baltic Sea. BirdLife International (2023) report the global population to number between 3.2 to 3.75 million individuals - hence 40% to 47% of the global population winter within the Baltic Sea.

IUCN is a non-governmental organization (NGO), and their Red List categories have no direct legal implications.

Legally the Long-tailed Ducks are protected within Western Palearctic under the Bern- and Bonn convention. The Bern convention was signed in 1979 and is the legal foundation for the European Birds Directive. The Bonn convention, also known as the Convention on Migratory Species (CMS), was also signed in 1979, and is the legal foundation for the treaty Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA).

The Long-tailed Duck is listed in Appendix II-B of the European Birds Directive (European Union, 2010), and has been recommended as A1b by AEWA, which has led to a total hunting ban on Long-tailed Ducks in Denmark.

In general, all sea duck species are sensitive and respond towards ship traffic by either flying away or diving. About 80% of Common Scoters, Velvet Scoters and Long-tailed Ducks reacted by flying away as a response to approaching ship traffic. Similarly, flush distances of sea ducks have been found to be large compared to other seabirds as shown in the study by Fliessbach et al. (2019), with Common Scoters expressing the largest mean flush distances (1600m) of all evaluated species. This avoidance behaviour towards ship traffic can cause a displacement, of sea ducks - limiting their available foraging habitat an increasing their energy expenditure caused by the flush reaction. During the operational phase of an OWF, ship traffic is likely to increase due to regular service visits, which could elevate the impact of disturbance on sea ducks. Long-tailed Ducks are likely to be affected by offshore wind farms and there is evidence suggesting that they tend to avoid them to a varying degree, according to the review by Dierschke et al. (2016).

In the following section, the methods used for estimating the distribution and abundance of Long-tailed Ducks is presented.

2 METHODOLOGY

The survey was conducted in alignment with the methods used in the environmental assessment of the Kriegers Flak area, where the offshore wind farm exists today.

The methods used in this survey are comparable to the methods used in Webb & Durinck (1992), which are also implemented in the German standard for vessel-based transect surveys (StUK4) in relation to off-shore wind farms projects (BSH, 2021). This also applies for the methods used by DCE (Danish Centre for Environment and Energy) in relation to vessel-based surveys of marine mammals and birds (Johansen et al., 2015).

Alignment of methods ensures collection of comparable and high-quality data creating a good basis for interpretation and comparison with previous findings. At the same time, a similar survey methodology ensures compliance with the relevant safety regulations resulting in a safe working environment.

The raw data was distance corrected, which is an internationally acknowledged and widely used method in ecological monitoring and surveys (Buckland et al., 2005). It is particularly useful for species that are difficult to observe on the sea surface or for species that are widely distributed in a given area, like the Long-tailed Duck in the Baltic Sea. The main principles behind in distance sampling are to quantify any distance-related bias in the observations (relative to the observer) and perform an appropriate correction for this bias in order to improve accuracy of the estimated bird densities within a given area.

The normal procedure for distance sampling consists of four overall steps:

> *1. Survey design:* the survey is planned as either a point or line-transect sampling – depending on the location, species, and survey objectives. It is also during the survey design, that the survey area is defined. In this survey we applied line-transect sampling. Line-transects are straight lines drawn across the survey area, along which the survey is conducted while observers record the distance to each detected individual or flock.
>
> *2. Data collection:* Trained observers census along the pre-determined line transects recording relevant information – e.g., angle of detection (to calculate perpendicular distance), species, flock size, time of observation and weather conditions.
>
> *3. Detection function & analysis:* an integral part of distance sampling is the detection function, which predicts the probability of detecting an individual or flock at a given distance from the observer. The most used detection functions are the half-normal and hazard-rate functions. The choice of detection function is most often selected based on the collected data using the Akaike information criterion (AIC). When a model set of detection function candidates have been fitted and the best candidate selected by means of AIC a statistical analysis is performed to estimate species-specific abundance and/or density within the survey area.
>
> *4. Abundance and/or density estimation:* using the selected detection function as an integrated part of the Distance-sampling method, it is possible to extrapolate from the observed data to estimate the abundance and density of Long-tailed Ducks within the entire survey area. This is achieved by

integrating the detection function over the entire range of distances while accounting for survey effort – e.g., length of the surveyed line-transects. The abundance is an estimate of the total number of individuals within the survey area, while the density is the number of individuals per unit of area (often individuals per square kilometer).

SETTING OF THE VESSEL-BASED SURVEY

The transects were covered by the survey vessel M/S Skoven during the winter 2022/2023. Surveys always began at dawn and ended around dusk with continuous monitoring along the transect lines.

In total, four separate surveys were conducted on the following dates: 21/12/2022, 07/01/2023, 08/02/2023 and 28/02/2023.

Transect lines were approximately three kilometers apart and their mutual distance and overall layout were governed by the presence of the wind turbines in the surveyed area. Surveys always started in the south-eastern corner of the survey area. A total of five line-transects were covered per survey with a starting direction from east to west and conducted at a vessel speed of around 10 knots per hour.

Two observers were stationed on top of the vessel bridge, inside a wooden construction made for the purpose of vessel-based surveys, facing either starboard or portside, so that both directions were covered continuously. Due to the general weather conditions, sea state and encounter rate of Long-tailed Ducks, the line-transect width was set to 500m, north and south of the survey vessel. As part of the equipment, a “Range stick” was made, following page 27 in Johansen et al., 2015, adjusted to the observer height on the vessels bridge (7.6m), for a more accurate estimate of the distance of the sightings.

The position and direction of the vessel were logged by a handheld GPS (Garmin, GPSMAP® 66s) and were set up to record the position every minute, with date and time (precision seconds, time zone UTC) latitude and longitude (decimal degrees, datum: WGS84) recorded. In addition, the GPS installed on the vessel also recorded positions in case of failure to record by the handheld GPS.

The survey area and the transect lines are shown in figure 2:

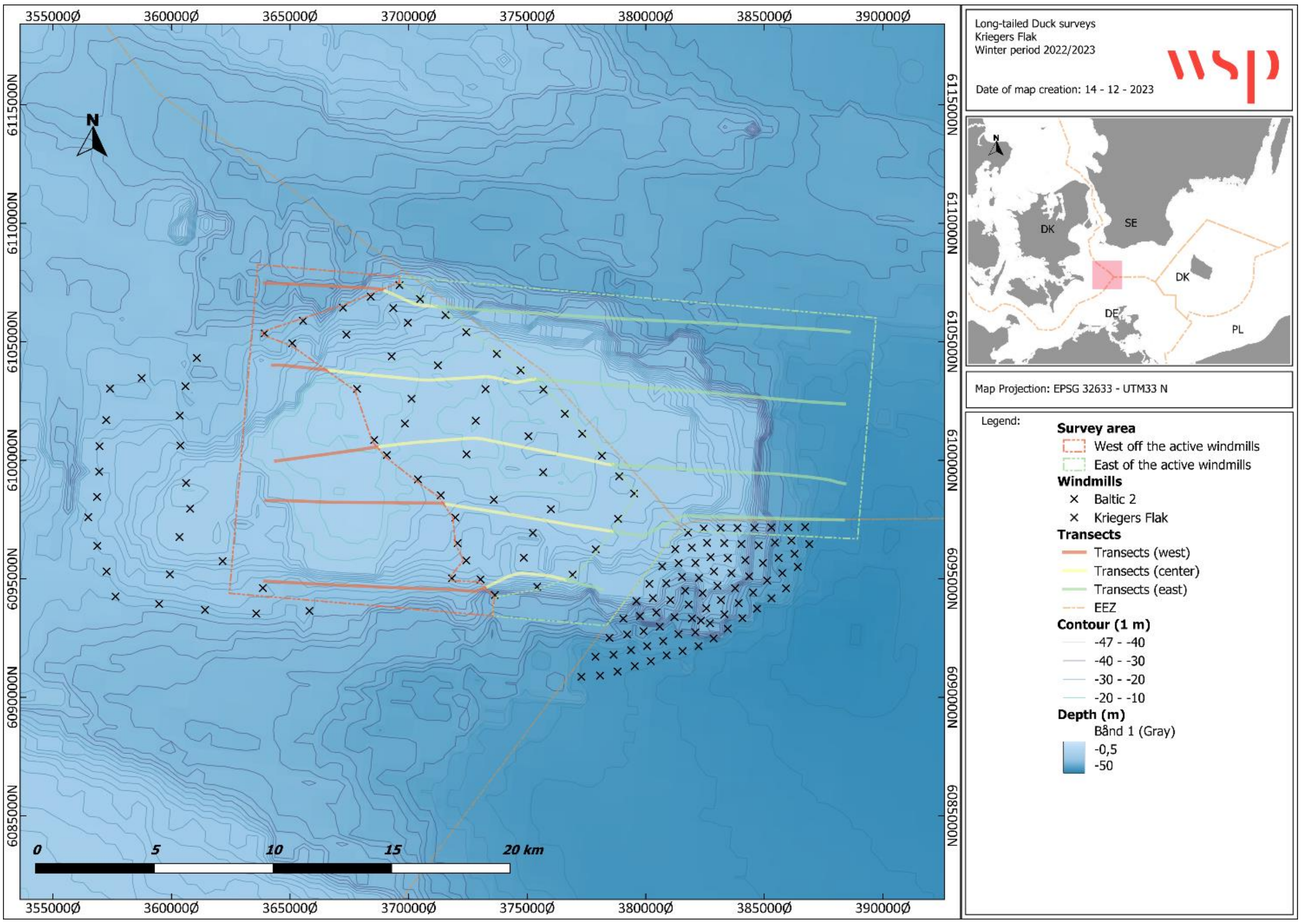

Figure 2 - Overview of the survey area divided into three sub-areas (west: A1, center: A2 and east: A3) and the line transects covered within these sub-areas. The two wind farms within the survey area, Kriegers Flak and Baltic II, are displayed as black and grey squares, respectively. Bathymetry is displayed with depth shading and contour lines represented in meters (m).

RECORDING OF SIGHTINGS BY THE OBSERVERS

The bird species of highest priority in this survey was the Long-tailed Duck and hence, only Long-tailed Ducks were recorded during periods of high activity. In cases of moderate to low activity, other marine bird species and mammals were also recorded (see supplementary field sheets).

The observations were made by naked eye or by using a pair of binoculars (Kite Forrester 8x42).

Flocks of resting birds were recorded, including swimming and diving individuals and birds flushed due to the approaching vessel. In cases of mixed flocks of different species or activity on both starboard and portside separate data entries were recorded.

Due to the speed of the survey vessel along the transects (10 knots per hour), and a 1-minute interval between time logs the recorded positions of the sightings of birds are associated with a combination of spatial and temporal uncertainty. This results in a maximum uncertainty of approximately 309 m. for the collected records of a given timestamp.

The recordings were noted on a field sheet (see supplementary), including information such as: date, time, species, flock size, distance, behavior and comments.

DATA INTERPRETATION AND ANALYSIS

The collected field sheets from the surveys were digitalized, sorted, and combined.

Timestamps from the handheld GPS were exported to QGIS (QGIS, 2023) and the matching information of the observed sightings were added in order to map and visualize the spatial distribution of the recorded flocks of Long-tailed Ducks inside the survey area.

Furthermore, to be able to extrapolate the information of the observed sightings to the total survey area, and to correct for distance-bias i.e. to account for the decreasing likelihood of spotting flocks of birds with increasing distance to the observer(s) (Thomas et al., 2010). The data was processed through the program R (version 4.3.1), using the packages Distance (version 1.0.7) and mrds (version 2.2.9). Both half-normal and hazard-rate functions were fitted to the data, with three different types of adjustment (cos, poly & herm), yielding a total of six candidate functions. All six detection functions were visually inspected and evaluated by means of AIC model selection. The visual inspection has the purpose of ensuring that the different adjustments do not skew the function in any inappropriate way. Using the build-in function in the mrds package in R, all candidate functions were ranked according to their AIC (see table 1), with the 'best' model having the lowest AIC value.

Table 1: Candidate models fitted to the data and ranked after their mutual difference in Akaike Information Criterion (Δ AIC), with the 'best' model ranked on top having the lowest AIC value (360.31). Note that the type of adjustment had no effect on the three Hazard-rate models.

Model	AIC	Δ AIC
Half-normal detection function with cosines adjustment	360.31	0.00
Half-normal detection function with simple polynomial adjustment	362.16	1.85
Half-normal detection function with hermite polynomial adjustment	363.74	3.34
Hazard-rate detection function with cosines adjustment	365.13	4.82
Hazard-rate detection function with simple polynomial adjustment	365.13	4.82
Hazard-rate detection function with hermite polynomial adjustment	365.13	4.82

Based on AIC model selection the half-normal detection function with cosine adjustment was selected to estimate abundance and density. These estimates were first quantified for the four different survey dates and the total survey area and in a second step they were further stratified into three units of area (west, center and east).

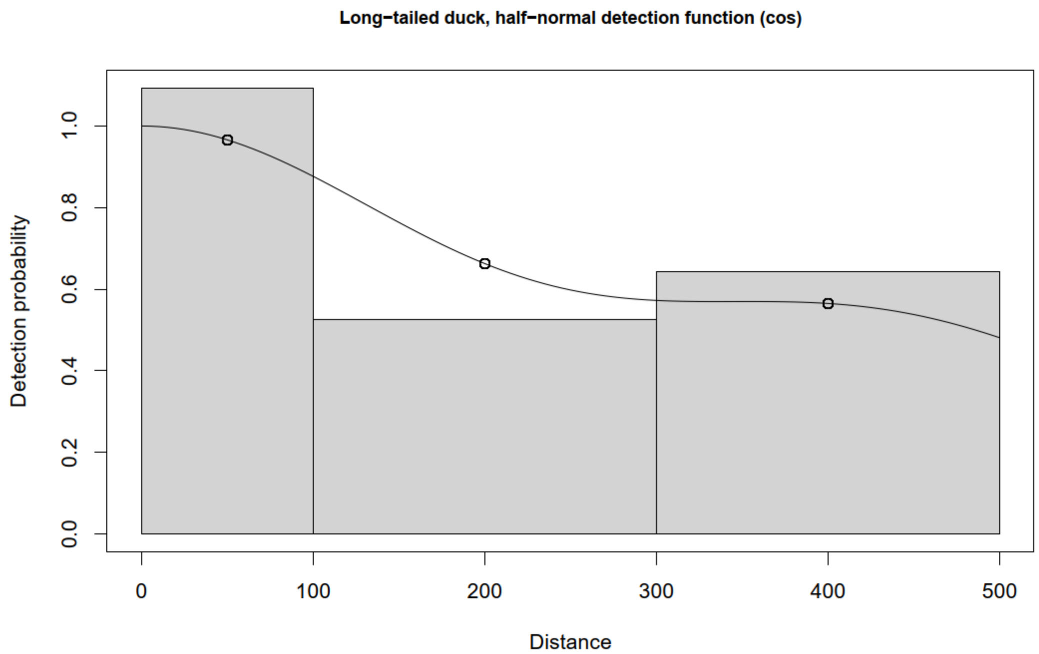

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Figure 3 – Visualization of the selected detection probability function. Note that for practical reasons in the field, the data is organized in three unbalanced histogram bins. The histogram bins represent the distance bands applied in the field.

3 RESULTS

The collected data was used to create maps of the Long-tailed Duck observations inside the survey area. Moreover, extrapolation of the transect observations by means of Distance-sampling was used to estimate total numbers of Long-tailed Ducks in the area at the time of the four surveys conducted during winter in 2022/2023.

SPATIAL DISTRIBUTION OF WINTERING LONG-TAILED DUCK OBSERVATIONS

Recorded observations of wintering Long-tailed Ducks, based on line transect surveys are displayed in figures 4 – 7:

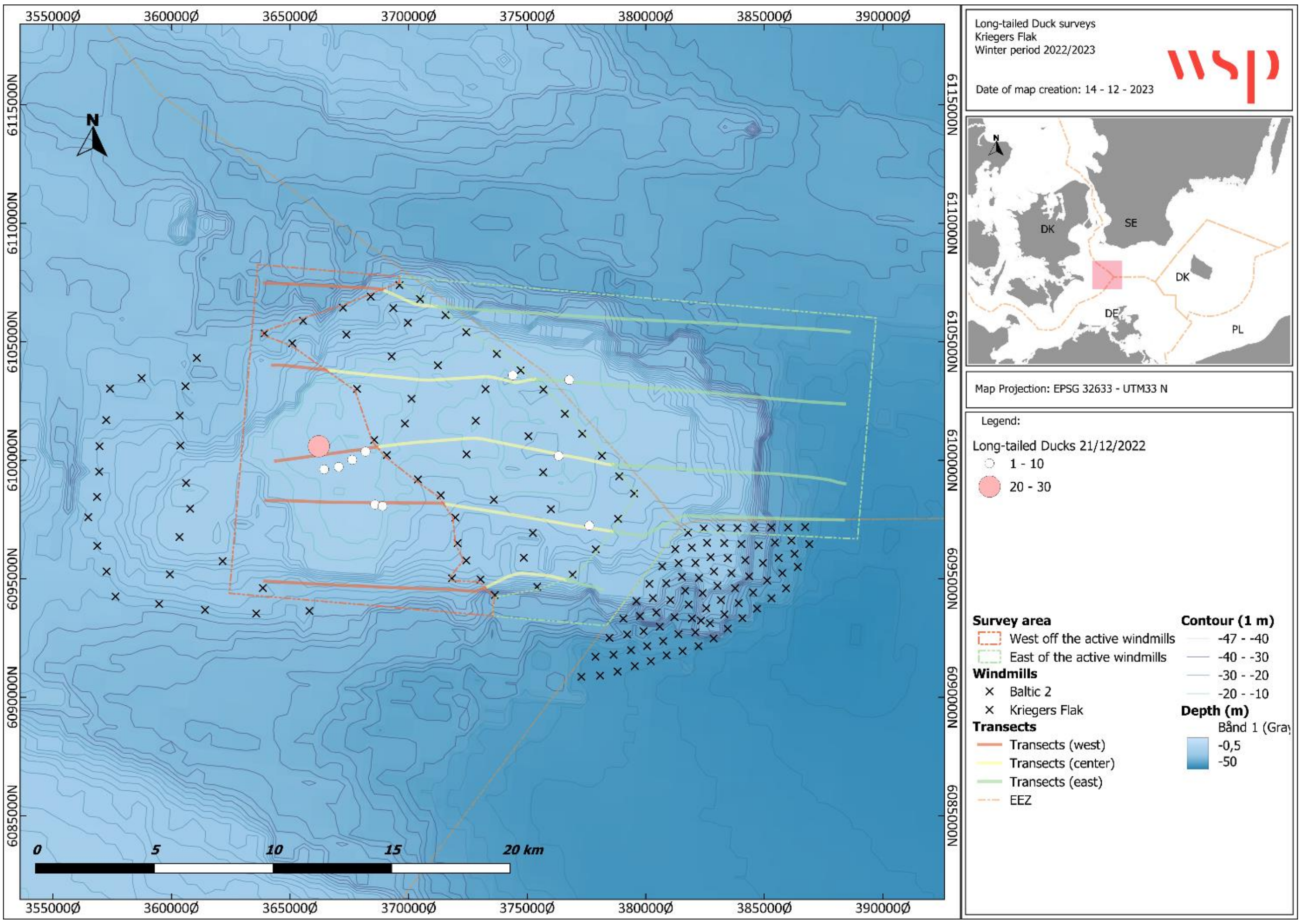

Figure 4 – Distribution of recorded flocks of Long-tailed ducks on the 21-12-2022 survey.

First survey was carried out on the 21st of December 2022 from 08:27 – 15:22 (UTC – 1). The wind was from the southwest with an approximate speed of 5 m/s and air temperature around 7 degrees Celsius. The survey consisted of five transects, with a starting point at the south-eastern corner of the survey area. During the survey, a total of 11 flocks of Long-tailed Ducks were observed, with a maximum flock size of 29 individuals, and a total abundance of 74 birds. Seven of these flocks consisting of 64 individuals in total were found in the area in-between the two parts of Kriegers Flak wind farm (A1). Three of the flocks, consisting of 5 birds in total, were found in-between the wind turbines, in the eastern part of Kriegers Flak wind farm (A2). One flock, consisting of 5 birds, was discovered outside to the east of the wind farm (A3).

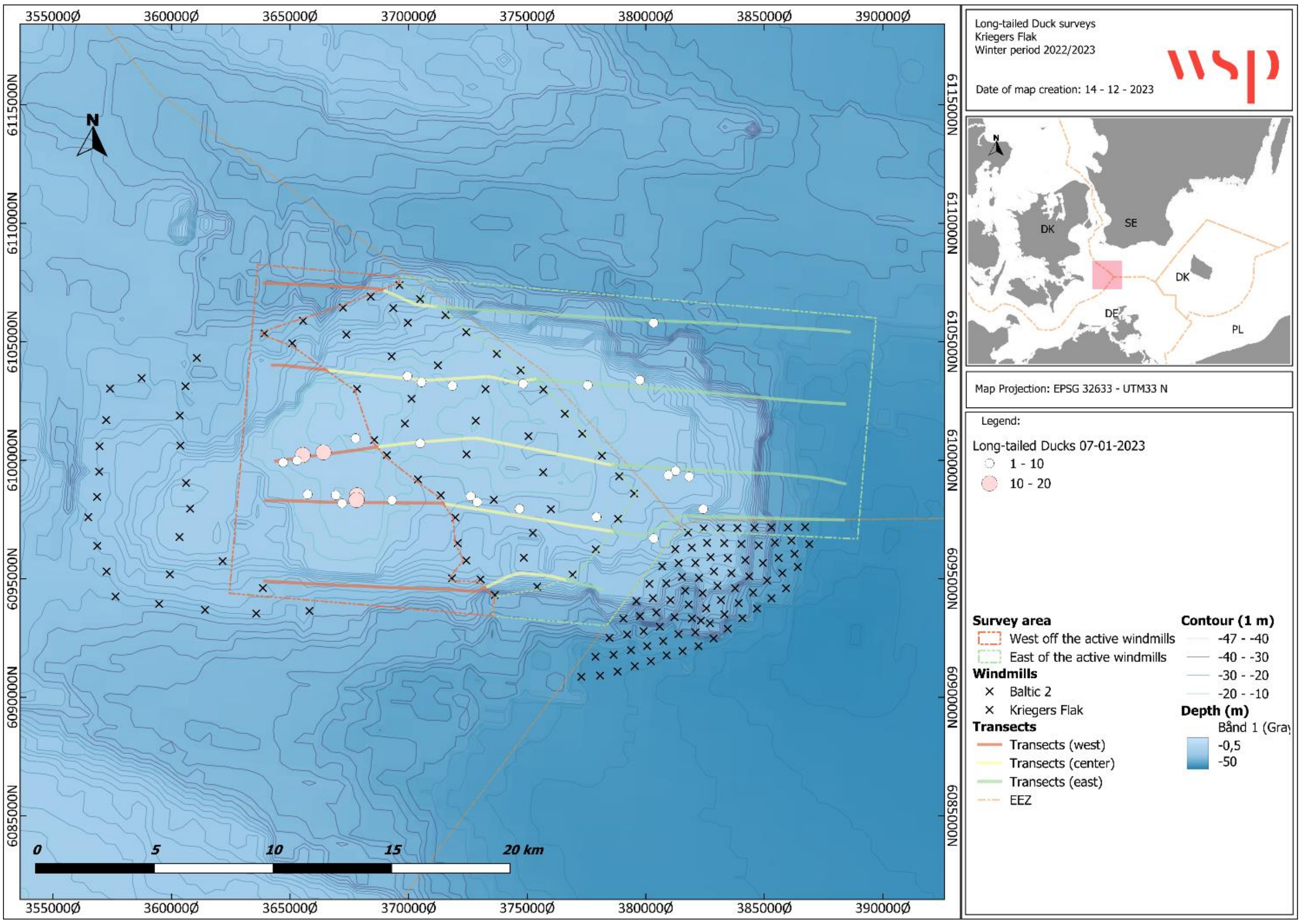

Figure 5 – Distribution of recorded flocks of Long-tailed ducks on the 07-01-2023 survey.

Second survey was carried out on the 7th of January 2023 from 08:12 – 15:28 (UTC – 1). The wind was from south, with an approximate speed of 5 m/s and air temperature around 5 degrees Celsius. The survey consisted of five transects, with the first transect starting at the south-eastern part of the survey area, heading west, following the transect route displayed on figure 2. During the survey, a total of 28 flocks of Long-tailed Ducks were observed, with a maximum flock sizes of 19 individuals, and a total abundance of 143 birds. Of these, eleven flocks consisting of 78 birds in total were found in the area in-between the two parts of the Kriegers Flak wind farm (A1). Nine of the flocks, consisting of 39 birds, were found in-between the wind turbines in the eastern part of the Kriegers Flak wind farm (A2). Eight flocks consisting of 26 birds were discovered outside to the east of the wind farm area (A3).

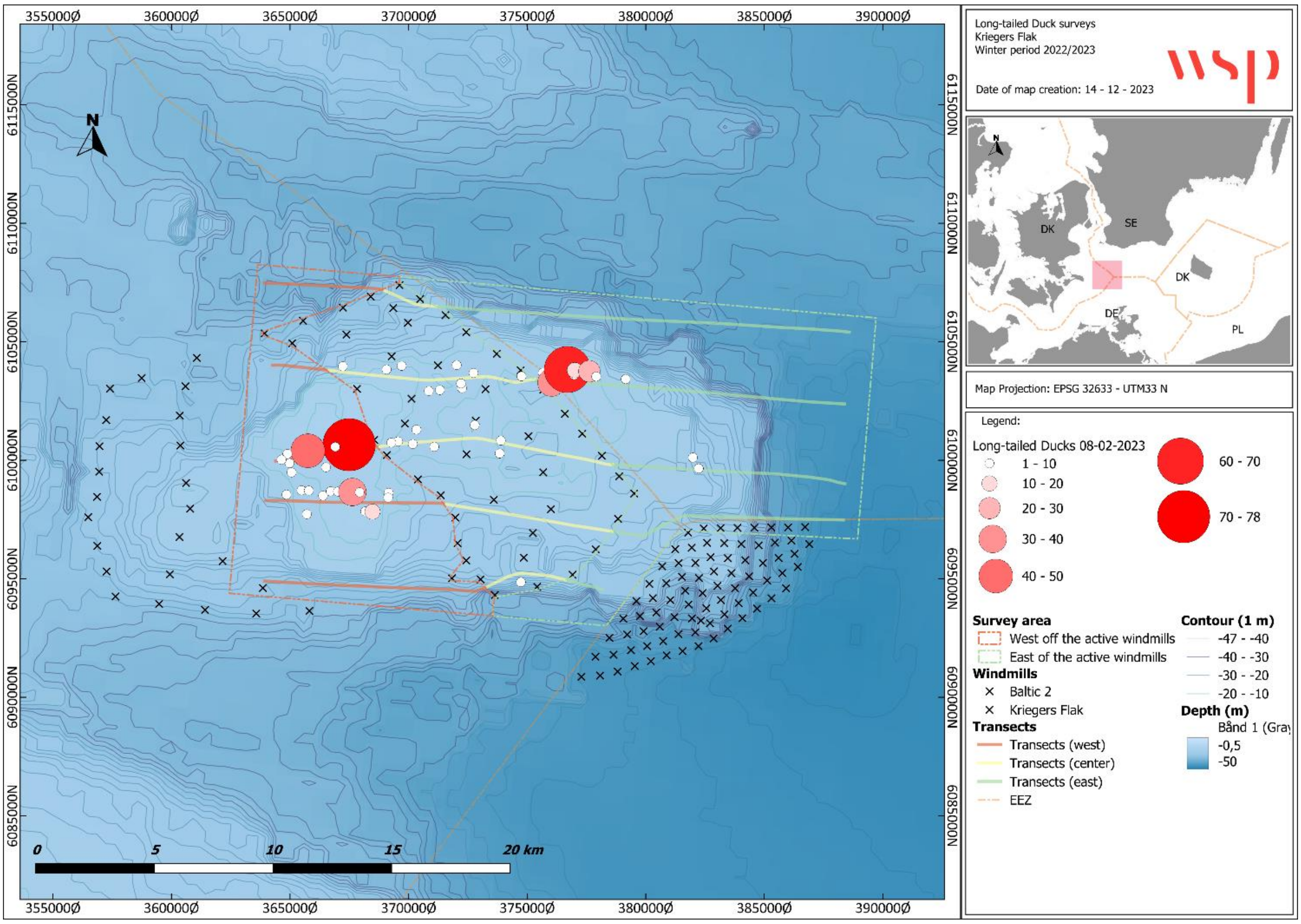

Figure 6 – Distribution of recorded flocks of Long-tailed ducks on the 08-02-2023 survey.

Third survey was carried out on the 8th of February 2023 from 07:46 – 15:02 (UTC – 1). The wind was from southwest, with an approximate speed of 7 -10 m/s and air temperature around 6 degrees Celsius. The survey consisted of five transects, with the first transect starting at the south-eastern part of the survey area, heading west, following the transect route displayed on figure 2. During the survey a total of 53 flocks of Long-tailed Ducks were observed, with a maximum flock size of 78 individuals, and a total abundance of 454 birds. Of these, 23 flocks consisting of 224 birds in total were found in the area in-between the two parts of the Kriegers Flak wind farm (A1). Nineteen flocks consisting of 47 birds were found in-between the wind turbines in the eastern part of the Kriegers Flak wind farm array (A2). Moreover, eleven flocks consisting of 183 birds were observed outside to the east of the wind farm (A3).

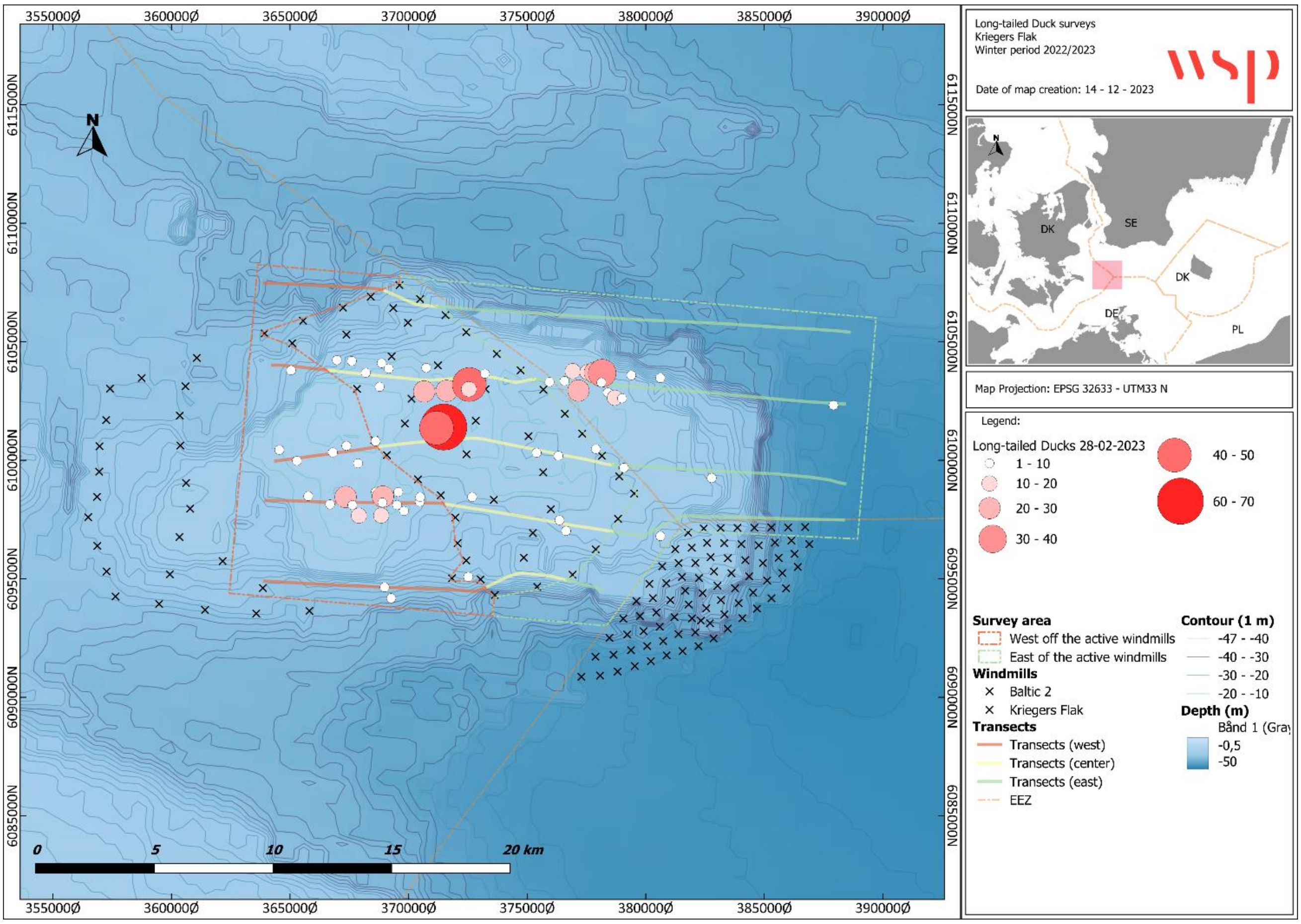

Figure 7 – Distribution of recorded flocks of Long-tailed ducks on the 28-02-2023 survey.

Fourth survey was carried out on the 28th of February 2023 from 07:20 – 14:43 (UTC – 1). The wind was from southwest with an approximate speed of 2.5 – 3.5 m/s and air temperature between 6-8 degrees Celsius. The survey consisted of five transects, with the first transect starting at the south-eastern part of the survey area, heading west, following the transect route displayed on figure 2. During the survey, a total of 62 flocks of Long-tailed Ducks were observed with a maximum flock size of 65 individuals and a total abundance of 577 birds. Of these, 22 flocks consisting of 138 birds in total, were found in the area in-between the two parts of the Kriegers Flak wind farm, whereas 23 flocks of 267 birds in total were found in-between the wind turbines, in the eastern part of the Kriegers Flak wind farm. Moreover, 17 flocks, consisting of 172 birds, were discovered outside to the east of the wind farm area.

ANALYSIS OF COMBINED LONG-TAILED DUCK OBSERVATIONS

To address the influence of the active wind turbines on the spatial distribution of Long-tailed Duck observations, the survey-area was divided into three parts: west of the active wind turbines (A1), in-between the active wind turbines (A2) and east of the active wind turbines (A3). A summed overview of the spatial distribution of the observations and the location of the wind farm is displayed in figure 7.

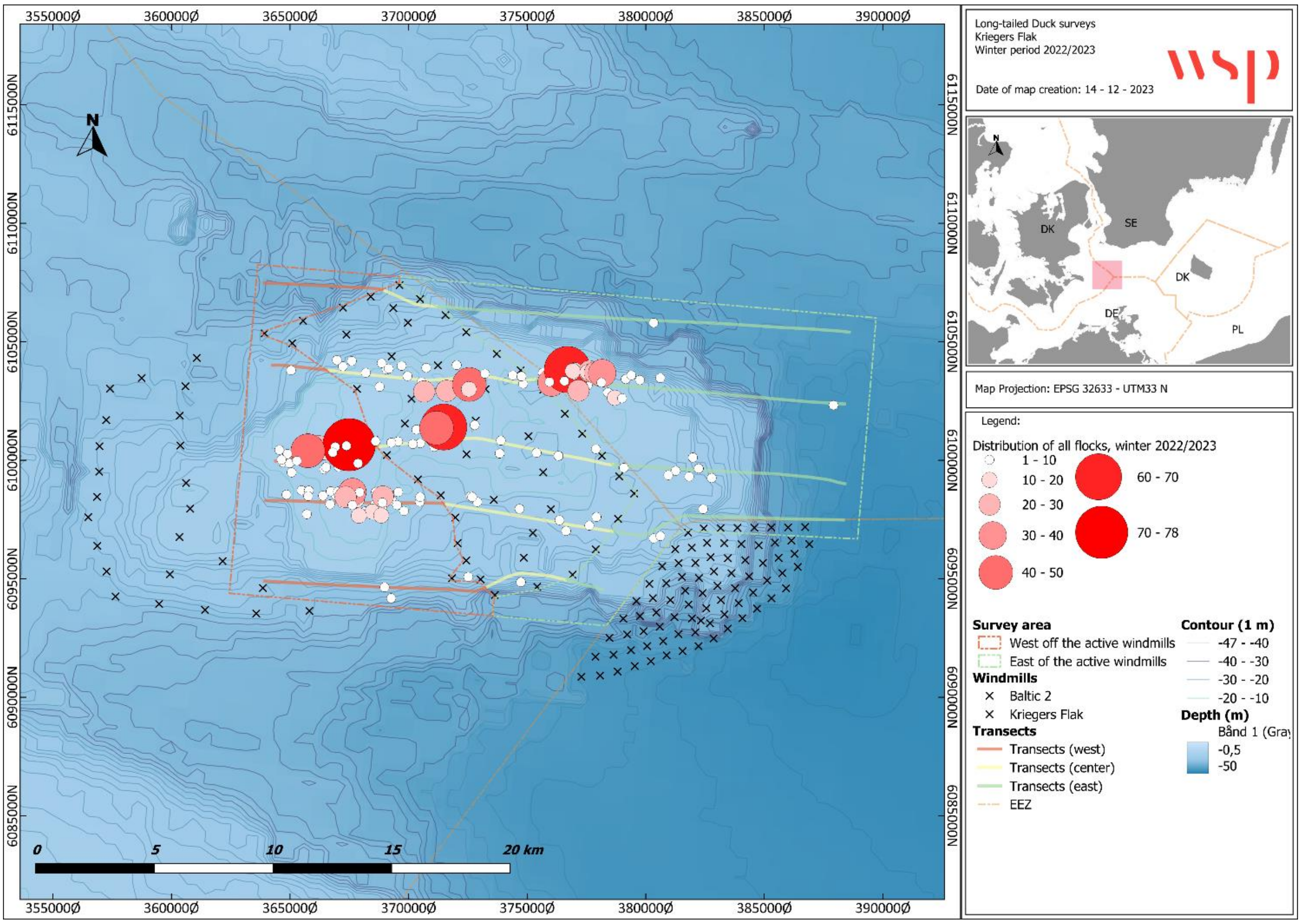

Figure 8 – Distribution of all recorded flocks of Long-tailed ducks on the four surveys during winter 2022/2023.

By summing the four independent surveys together, a total number of 154 flocks of Long-tailed Ducks consisting of 1,248 birds were observed over the 2022/2023 survey period. Of these, 63 flocks were observed west of the wind farm, 54 flocks in-between the active wind turbines and 37 flocks east of the wind farm, corresponding to 41 percent, 35 percent, and 24 percent, respectively, of the total number of recorded flocks.

The abundance of individuals within these three spatial zones were 504 birds west of the wind farm, 358 birds in-between the active wind turbines and 386 birds east of the wind farm, corresponding to 40 percent, 28 percent, and 30 percent, respectively, of the total number of Long-tailed Ducks observed during the line transects.

ABUNDANCE AND DENSITY ESTIMATION (DISTANCE SAMPLING)

Our analysis revealed a notable temporal trend in Long-tailed Duck density, with a gradual increase from December to February (Figure 9).

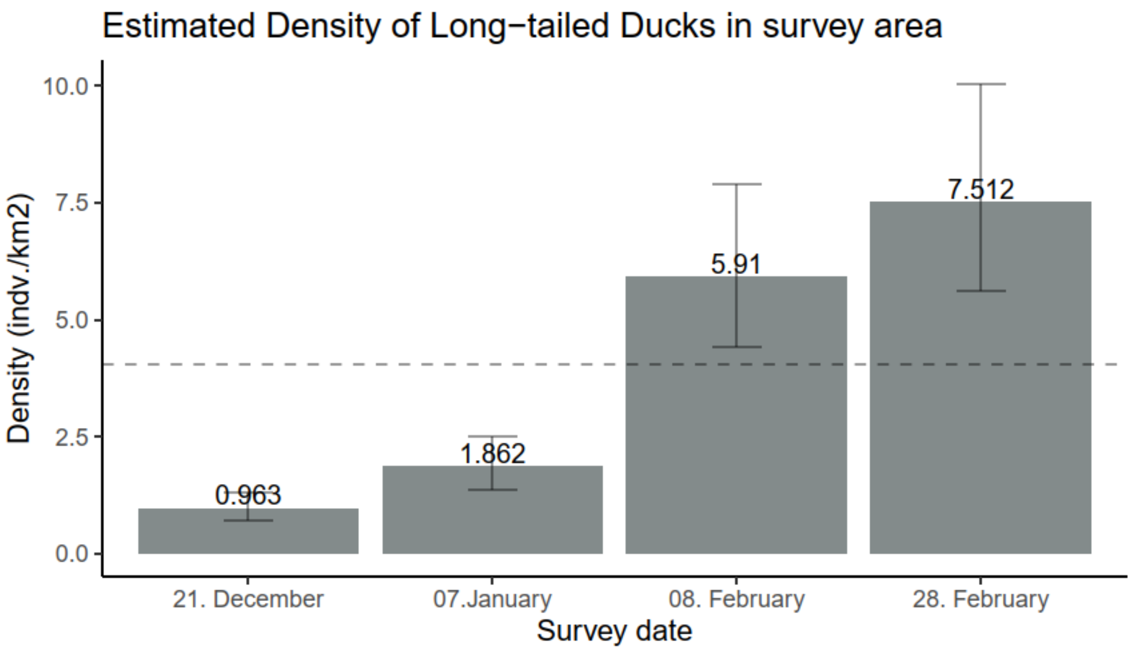

Figure 9 – Estimated density of Long-tailed Ducks in the combined survey area. Error bars are 95%-confidence intervals, and the dotted line is the average density across all four surveys. See appendix, table 1, for tabular version of the data.3

The western survey area (A1) showed a discernible preference, as evidenced on three distinct observation dates: December 21, January 7, and February 8 (figure 10). Significantly higher numbers of Long-tailed Ducks were observed in this area during these dates, suggesting greater attractiveness or resource availability for the species during the winter months and/or potential avoidance of wind turbines in the central survey area (A2).

Spatial disparity of Long-tailed Duck densities were evident across different survey areas and dates. Notably, the center area (A2) exhibited the highest density on February 28, with 12.2 individuals per square kilometer (Figure 10). Conversely, the eastern area (A3) recorded the lowest density on December 21, with a mere 0.14 individuals per square kilometer. The eastern survey area (A3) was generally less attractive for the ducks, however, on the 8th of February the abundance of Long-tailed Ducks was higher than in the other two areas (A1, A2), especially I^{n} the center area (A2). These inter-area variations and shifts in bird abundance could be driven by parallel shifts in resource availability occuring inside the study area.

The average and maximum density of wintering Long-tailed Ducks were estimated at approximately 4 and 12 individuals per square kilometer, respectively.

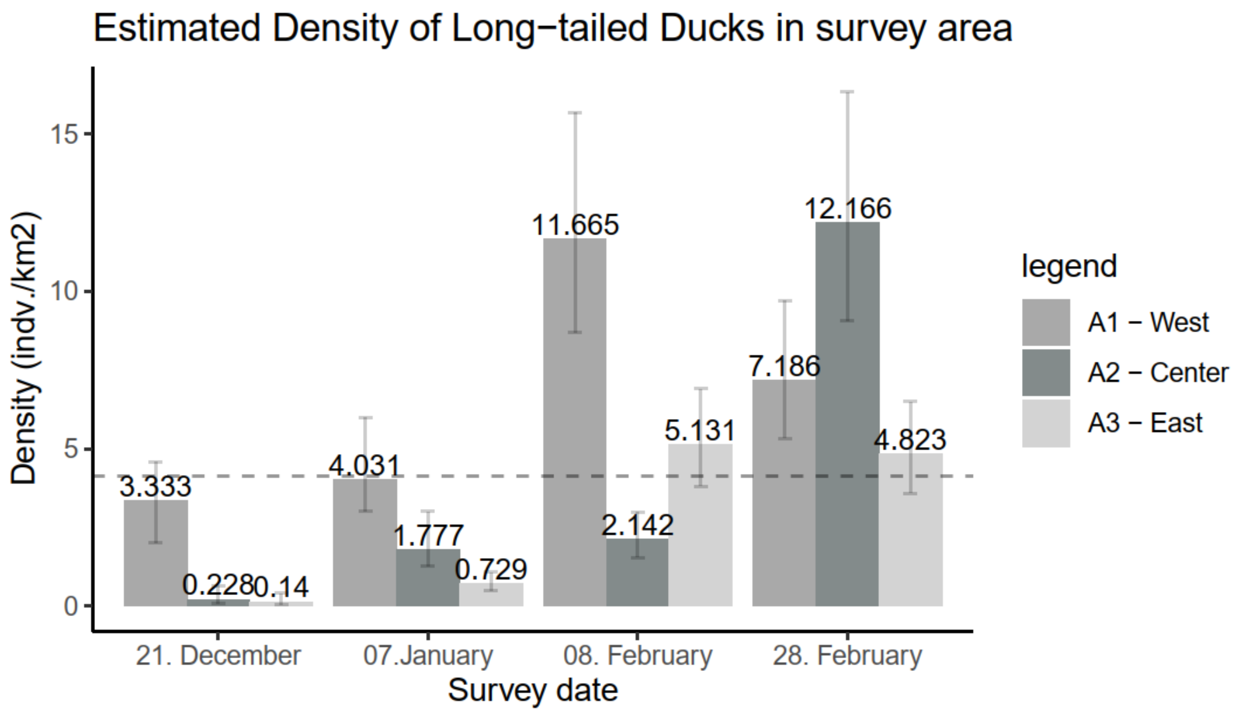

Figure 10 Estimated density of Long-tailed Ducks in the stratified survey area. Error bars indicate 95%-confidence intervals and the dotted line is the average density of all three stratified survey areas over the four survey dates. See appendix, table 2, for tabular version of the data.4

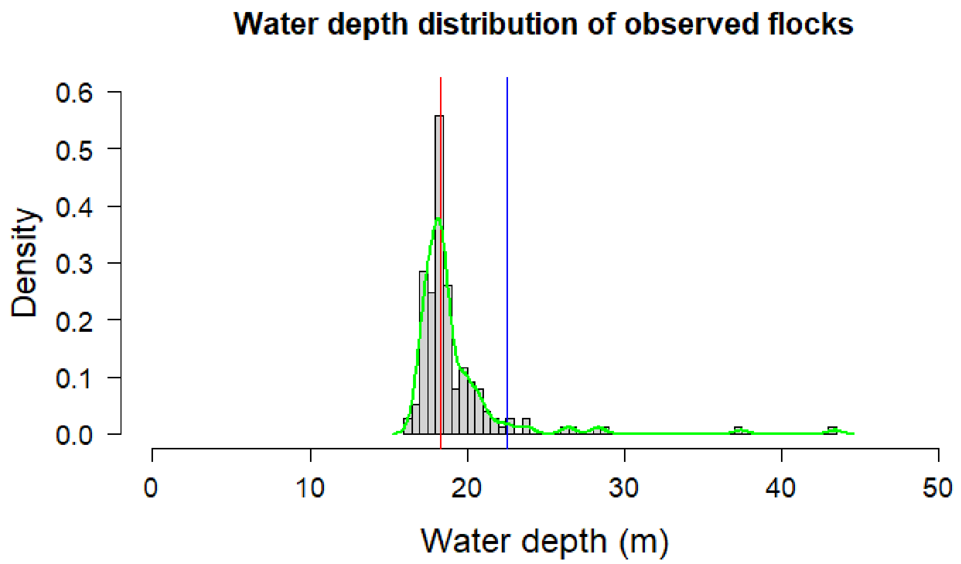

Figure 11 – Water depth 16istribution of Long-tailed Duck observations during the 2022/2023 surveys. The red vertical line indicates the median water depth at which Long-tailed Ducks were observed and the green curve is the probability density line of the distribution. The blue vertical line indicates the median water depth in the survey area.

4 DISCUSSION

The observed increase in Long-tailed Duck density from December to February may be influenced by various factors, including food availability, weather conditions, and migration patterns. Additionally, the pronounced preference for the western survey area suggests specific habitat characteristics that are particularly favorable to Long-tailed Ducks during the winter months, such as shallow waters ideal for foraging. The presence of the offshore wind farm in the center area (A2) could also be affecting the distribution patterns of the species. Because this specific area had not previously been investigated using the same methods employed in this survey, we compared our findings with data from similar ship-based surveys from nearby locations, as well as aerial surveys from the Kriegers Flak area. In addition, we considered midwinter-counts of Long-tailed Ducks presented in the Environmental Impact Assessment report by Skov et al. 2015 to provide context for our results. The estimated, maximum density of Long-tailed Ducks during the survey period from December 2022 to February 2023, was found to be in line with but slightly higher than the estimates presented in the baseline and EIA reports (12 birds/km compared to 10 birds/km^2).

The high density of Long-tailed Ducks in the western part (A1) of the study area gives rise to several hypotheses regarding this spatial distribution. One plausible explanation is the presence of shallower waters in the western region, providing favorable foraging conditions for the ducks during their resting periods. Water depth is also proposed by Skov et al. as one of the main drivers of distribution. Likewise, the low densities observed in the eastern area (A3) could be attributed to the fact that water depth ranges from 30-50 meters in most of the area, well above the species' preferred range of water depths.

It is essential to consider potential cumulative effects (Fox & Petersen, 2019) of wind farm developments on Long-tailed Duck populations, even though the impact of an individual wind farm may appear minimal. The combined effect of multiple wind farms could have more substantial consequences on the distribution and abundance of Long-tailed Ducks in the area. Fox & Petersen (2019) found a decrease in densities within the wind farm and an increase in densities outside occuring simultaneously suggesting a habitat displacement effect as a result of the presence of the wind farm. This finding emphasizes the need to consider cumulative effects when multiple wind farm developments are planned in a given area. Preservation of suitable wintering habitat is key for the conservation of Long-tailed Ducks in the Baltic Sea area, and hence, the cumulative impacts resulting from an increasing number of offshore wind farm projects in the area should be thoroughly investigated and addressed in the planning of future offshore wind farm developments.

5 CONCLUSION

In conclusion, the post-construction monitoring of distribution patterns of Long-tailed Ducks provide valuable insights into the dynamics of resting birds during the operation phase of the Kriegers Flak wind farm. The findings show an expected increase in density over the three winter months, highlighting the significance of the area west of the wind farm as preferred habitat due to favorable foraging conditions. Understanding wind turbines' impact on waterfowl ecology is crucial for conservation efforts and for designing a green future with minimum impact on wintering and migrating populations of seaducks. Based on total numbers, estimated densities and the spatial distribution of the Long-Tailed Duck observations found in this study, there seems to be no clear and consistent sign of habitat displacement caused by the Kriegers Flak Offshore Wind Farm. Even though the Western area (A1) had the highest numbers of Long-tailed Ducks overall, it is worth noting that the greatest count on any of the four surveys was recorded inside the wind farm array (A2). However, the results must be interpreted with caution as there is no baseline data available for the specific area, which could have provided a base for comparison and opportunity to consider the effect of the wind farm in isolation. Nonetheless, the spatial distribution patterns of Long-tailed Ducks found in this study do not indicate any clear effects of habitat displacement due to the turbine array of the Kriegers Flak wind farm. This may, however, be influenced by the quite large mutual spacing of individual turbines in the array.

Further investigations into distribution patterns of sea ducks within and around offshore wind farms of varying layouts are recommended in order to minimize the potential impact of habitat displacement in important wintering areas such as the southern Baltic Sea.

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7 APPENDIX

Table 1 - Estimated abundance and density of Long-tailed Ducks with associated lower- (Lcl) and upper confidence level (Ucl). Estimates are separated over survey dates.

Label	Area	Estimated abundance	Lcl	Ucl	Estimated Density	Lcl	Ucl
21. December	Survey area	312	228	427	1.0	0,7	1.3
07. January	Survey area	601	447	815	1.9	1.4	2.5
08. February	Survey area	1,915	1430	2,564	5.9	4.4	7.9
28. February	Survey area	2,434	1819	3,256	7.5	5.6	10.0

Table 2 - Estimated abundance and density of Long-tailed Ducks with associated lower- (Lcl) and upper confidence level (Ucl). Estimates are separated over survey dates and stratified survey area.

Label	Area	Estimated abundance	Lcl	Ucl	Estimated Density	Lcl	Ucl
21. December	West	290	211	398	3.3	2.0	4.6
21. December	Center	21	7	61	0.2	0.1	0.7
21. December	East	20	7	61	0.1	0.0	0.4
07.January	West	353	259	482	4.0	3.0	6.0
07.January	Center	165	117	233	1.8	1.3	3.0
07.January	East	105	71	155	0.7	0.5	1.1
08. February	West	1,015	755	1,363	11.7	8.7	15.7
08. February	Center	199	143	278	2.1	1.5	2.3
08. February	East	739	548	996	5.1	3.8	6.9
28. February	West	625	463	844	7.2	5.3	9.7
28. February	Center	1,131	843	1,519	12.2	9.1	16.3
28. February	East	694	515	936	4.8	3.6	6.5