Photo-ID Analysis of Harbour Porpoises in the Eastern Scheldt: Insights, Patterns, and Conservation

Figure 1: Stichting Rugvin. (2023). Photo ID with Harbour Porpoises. https://rugvin.nl/english/photo-id-with-harbour-porpoises/

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Abstract

The "Photo-ID Analysis of Harbour Porpoises in the Eastern Scheldt" thesis project with Stichting Rugvin represents a comprehensive and long-term investigation into the individual harbour porpoises residing there. The project initially began ad hoc in 2010 and has evolved into a structured and dedicated research endeavour, spanning from 2015 to 2023. The study involves the systematic documentation of 92 recognized harbour porpoises, including both long-standing and recently identified individuals. This project hinges on the extensive collection of photographs and associated GPS data, resulting in a large dataset.

The research seeks to understand the environmental factors, such as tidal status, bathymetry, and prey availability that impact the distribution and behaviour of porpoises. The study utilised Photo-ID techniques to track individual porpoises, allowing for the analysis of their movement patterns and social dynamics using their unique markings. GIS mapping provides additional clarity on the spatial preferences of these marine mammals, specifically identifying important areas, the hotspots of high population density, within the Eastern Scheldt where they engage in activities such as foraging, socialising, travelling and mating.

The results suggest that harbour porpoises demonstrate a preference for deeper waters associated with a depth gradient in the Eastern Scheldt, specifically in areas near the harbours of Zierikzee and Kats, where this gradient causes turbulence in the water, likely influencing the harbour porpoises' habitat preferences. The research indicates that tidal conditions have minimal impact on harbour porpoise behaviour, but bathymetry is an important variable in determining their foraging locations and social interactions. However, further research is needed to determine if the social interactions convene in these locations out of coincidence due to food source and foraging. The areas near the harbours of Zierikzee and Kats indicates these areas are important to the harbour porpoises' survival within the Eastern Scheldt, underlining the necessity of targeted conservation strategies to protect these zones.

This study provides valuable information about the ecology of harbour porpoises in the Eastern Scheldt, offering essential data for the development of appropriate conservation strategies. Additionally, it addresses the current lack of information regarding the behaviour and habitat preferences of these marine mammals, providing a foundation for conducting similar research throughout this region.

Table of Contents

1. Introduction

The conservation and study of marine mammals have become increasingly important because of the growing impact of environmental changes and anthropogenic factors on marine ecosystems.[31] The harbour porpoise (*Phocoena phocoena*) is among these species due to its sensitivity to these changes.[31]

Photo-identification (Photo-ID) and Geographic Information Systems (GIS) mapping are valuable tools in marine mammal research.[9] They offer comprehensive analysis concerning the behaviour and habitat preferences of these mammals.[9] However, there is a lack of comprehensive research aimed at investigating the distribution patterns and social dynamics of harbour porpoises, particularly in estuarine habitats such as the Eastern Scheldt.

This study aims to address this gap by using Photo-ID and GIS mapping to investigate the spatial distribution, behaviour, and social interactions of harbour porpoises in the Eastern Scheldt. The main research question guiding this study is: "How do the photo-ID analysis and GIS mapping of harbour porpoises in the Eastern Scheldt provide insights into their behaviour, social interactions, and habitat preferences?"

In order to provide context for this question, the study will initially present background information regarding harbour porpoises and their utilisation of the Eastern Scheldt. Moreover, it will analyse the environmental factors that impact their distribution and behaviours, such as bathymetry and tidal status, and investigate the social dynamics within this population.

1.1 Harbour Porpoise

The harbour porpoise (*Phocoena phocoena*) is among the smallest cetaceans globally. The worldwide population of harbour porpoises is approximately 700,000 individuals, leading to its classification listed as a “species of Least Concern by the IUCN Red List”.[30] Approximately 350,000 individuals are present in the North Sea.[30,45] These mammals occupy the “temperate to sub-polar waters of the Northern Hemisphere and have been documented in at least 36 countries worldwide”.[18] They are predominantly found in waters shallower than 200 metres, typically in areas with an apparent continental shelf. Additionally, they are known to be present in estuaries, bays, and river mouths.[18,46]

The harbour porpoise population experienced a significant decrease in the North Sea during the 1950s and 1960s. The decline continued until the 1980s due to pollution from toxic chemicals found in the North Sea, the overfishing of prey fish, and accidental capture as bycatch.[18,31,41] Prior to the decline, a limited number of harbour porpoises were seen in the Eastern Scheldt estuary in the Zeeland province in the Netherlands.[39] Due to the significant decrease in the number of harbour porpoises found in the North Sea, there was a corresponding decline in the population of these marine mammals in the Eastern Scheldt.[18,31] Due to the flooding of the Zeeland province, a Storm surge barrier called 'Oosterscheldekering' was constructed during this time. The construction of this barrier may have had an impact on the presence of harbour porpoises in the area.[28,42,43] For decades, there were not many documented sightings of harbour porpoises in the Eastern Scheldt.[39] Regardless, the population of harbour porpoises experienced a significant increase during the 1990s and 2000s.[31]

The presence of the harbour porpoise in the Eastern Scheldt was previously thought to indicate that it is a suitable habitat with a well-functioning ecosystem.[34,39] This was due to the idea that top predators like harbour porpoises may only inhabit an area when the ecosystem is in balance.[34] However, this no longer appears to be the case, as the Eastern Scheldt does not suit a stable ecosystem due to the lack of available prey, inability to avoid predators, like the grey seal, and increased human-activity.[39] The demand for energy is high in these mammals due to their small size and the cold temperatures of the water they inhabit.[35] As a result, they are heavily reliant on their prey as they require the ability to consume roughly 10% of their body weight on a daily basis.[31,35] The research conducted on stranded adult harbour porpoises in the Eastern Scheldt indicates that their diet in this area mainly comprises of whiting, sand goby, and small sand eel.[18,32]

1.2 Research Questions

This thesis project employs photo-identification (Photo-ID) analysis and Geographic Information Systems (GIS) mapping to delve into the behaviour and habitat preferences of harbour porpoises in the Eastern Scheldt, providing critical insights for their conservation. By systematically tracking and analyzing individual harbour porpoises through unique markings and spatial distribution, the research seeks to uncover patterns of movement, social structure, and environmental preferences within this unique estuarine habitat.

The primary research question is:

- "How do the photo-ID analysis and GIS mapping of harbour porpoises in the Eastern Scheldt provide insights into their behaviour, social interactions, and habitat preferences?"

The subsequent questions are:

- "What is the distribution pattern of harbour porpoises in the Eastern Scheldt?"

- "Which environmental factors affect the spatial distribution and behaviours of harbour porpoises within the Eastern Scheldt?"

Through this multifaceted approach, the project aims to fill existing knowledge gaps and contribute valuable data to the scientific community, aiding in the development of targeted conservation strategies for these marine mammals.[10] The study will cover the period from 2020 to 2023 and will utilise photo-identification and GIS mapping techniques to investigate the behaviour, habitat preferences, and social dynamics of harbour porpoises in the Eastern Scheldt. This research includes the systematic documentation of approximately 92 recognised harbour porpoises, including both established and recently identified individuals. This project relies on an extensive database of photographs and their corresponding GPS data and location names, resulting in a significant dataset.

1.3 Study Aims

Harbour porpoises in the Netherlands are safeguarded by the Nature Protection Act and the Habitat Directive.[18,28] The legislation mandates the implementation of protective measures to safeguard both the habitat and the species occupying it.[28] In order to protect the harbour porpoise population in the Eastern Scheldt, it is necessary to understand how their foraging behaviour and spatial distribution are influenced by environmental influences. Cetaceans depend heavily on the environmental conditions and resources of their habitat.[29] Environmental factors considered in this study include tidal range and bathymetry, which are considered. Given the Harbour Porpoise's sensitivity to changes in their environment and anthropogenic pressures, studying the harbour porpoise offers insights into the Eastern Scheldt habitat. The Eastern Scheldt provides a unique setting for the study of these elusive mammals. This research proposal aims to utilise photo-identification (Photo-ID) analysis and Geographic Information Systems (GIS) mapping to gain a deeper understanding of the behaviour and preferred ecosystems of harbour porpoises in this specific environment.

1.4 Conservation Implications

The data derived from photo-ID analysis and GIS mapping are invaluable for conservation efforts[6] of these marine mammals.[9] Understanding the habitat preferences and behaviour patterns of harbour porpoises enable more effective management of their environment. Specifically, it aids in the designation of protected areas, the implementation of boat traffic regulations, and the development of conservation strategies tailored to the unique needs of the Eastern Scheldt population.[10,31] Additionally, this research contributes to a broader understanding of the ecological role of harbour porpoises in the estuarine ecosystem.

1.5 Benefit to the Scientific Community

This research will contribute to the scientific community by enhancing an understanding of harbour porpoise ecology in a unique semi-enclosed estuarine habitat.[47] It will offer valuable insights into the effects of environmental variables on marine mammal behaviour and habitat use, inform conservation strategies, and provide a model for similar studies in other regions.[4] The findings will be relevant not only to marine biologists and conservationists but also to policymakers, helping to guide effective management and protection measures for harbour porpoises and their habitats.

1.6 Limitations and Gaps in Knowledge

The research on harbour porpoises in the Eastern Scheldt faces several limitations. The challenges of individual identification, the need for extensive temporal and spatial coverage, and the inherent biases in sample collection can affect the comprehensiveness of the data.[48] Moreover, gaps in knowledge remain regarding the detailed behavioural aspects of harbour porpoises, the long-term environmental impacts on their populations,[6] the genetic diversity within the Eastern Scheldt population, and their comparative ecological roles.[49] Addressing these limitations and filling these gaps requires ongoing, multifaceted research efforts. It's important to mention that a few years back, the database experienced a problem resulting in the loss of hundreds of photographs. However, due to backups made by former volunteers, the bulk of these photos were recovered. Nevertheless, several images from 2019 to 2021 remain unaccounted for. Furthermore, the period from 2020 to 2021 was impacted by the COVID-19 pandemic, resulting in a decrease in the number of surveys that could be conducted during this period. Consequently, this research will primarily concentrate on data from the years 2020 to 2023.

2. Methods and Materials

The methodology of this research hinges on the systematic use of photo-ID analysis and GIS mapping. Photo-ID analysis involves the identification of individual porpoises based on distinctive markings or features captured in photographs.[12] This technique allows for the tracking of individual movements, social interactions, and behaviour patterns[9] over time. Each photo is catalogued with corresponding data, including the date, location (via GPS coordinates), and observed behaviour.[13] GIS mapping, on the other hand, is utilized to analyse and visualize the spatial distribution and movement patterns of these identified individuals within the Eastern Scheldt.[5]

Since 2009, Stichting Rugvin has been carrying out yearly counting and field surveys in the Eastern Scheldt. Throughout the field surveys, Stichting Rugvin records environmental influences such as precipitation, tide, wind, in addition to occurrence and behaviour data. As a result, their investigation has significance for comprehending the foraging patterns and spatial distribution of harbour porpoises in the Eastern Scheldt. The methodology for applying these surveys for this research project follows a systematic sequence, starting with pre-sailing preparations and ending with data analysis. Firstly, according to the Photo-ID protocol provided by Stichting Rugvin,[23] safety inspections are carried out, and responsibilities are allocated to the team through a WhatsApp group. The sailing route is thoughtfully planned, considering the prevailing weather patterns and tidal conditions. Prior to departure, newly recruited crew members are provided with instructions on boat operation instructions, and the initial survey datasheet is completed. Throughout the survey, the team observes porpoises, adhering to international protocols to avoid disturbance, and captures identification photos. These photos serve as documentation of individual porpoises, based on their distinct markings. After arriving back at the harbour, the team finalises the survey data and ensures that the boat is adequately maintained.[23]

After the survey, the accuracy of the datasheets is checked, and they are converted into a digital format. Photos are then chosen and uploaded to the NAS (Network Attached Storage). The data is systematically arranged and subsequently examined through the integration of photo-identification (Photo-ID), which are analysed during team volunteer meetings to identify individuals. The data analysis was done using R and Geographic Information Systems (GIS) mapping. Photo identification is used to monitor and record the movements, behaviours, and social interactions of individuals over time. Each photograph is systematically organised with corresponding data, including the date, location (determined through GPS or written location), and observed behaviour. GIS mapping is used to examine and depict the spatial distribution and movement patterns of the harbour porpoises in the Eastern Scheldt. This analysis involves establishing connections between these patterns and environmental factors such as water depth, tidal status, and prey availability.

The analysis employs software such as ArcGIS Pro and R for the purpose of data processing and visualisation. R is used for data cleaning and manipulation, while ArcGIS Pro is used to generate spatial distribution maps using Kernel Density analysis. This analysis identifies regions with significant aggregations of porpoise sightings, referred to as 'hot spots.' The research's methodology relies on well-established techniques such as Photo-ID and GIS. It also uses photographic and GPS data gathered by volunteers and previous researchers. This combination of resources supports the feasibility and effectiveness of the research.

The feasibility of this project was underpinned by the availability of extensive photographic and GPS data collected by volunteers and previous students at Stichting Rugvin. The project accessed an existing database of harbour porpoise sightings and photographs, supplemented by ongoing fieldwork, given weather conditions, to collect new data. Collaborations with volunteers and researchers of Stichting Rugvin ensured a steady flow of data and facilitated fieldwork logistics. The methodology's reliance on established techniques in wildlife research (Photo-ID and GIS) further supports the project's feasibility.

2.1 Study Area

The[7] Eastern Scheldt is a 350-square-kilometer tidal bay and National Park in the southwestern Netherlands. Between 1979 and 1986, the Storm Surge Barrier was constructed to connect the North Sea and the Eastern Scheldt. While sightings of harbour porpoises were uncommon along the Dutch coast, starting in the mid-1990s, their population in the southern North Sea increased. The Eastern Scheldt offers a rare chance for in-depth research on these small cetaceans, with an increase in sightings starting around the year 2000.
The conservation and study of marine mammals have become increasingly important as these species act as indicators of the health of our marine ecosystems. Among these, the harbour porpoise (*Phocoena phocoena*) holds a special place due to its sensitivity to environmental changes and anthropogenic pressures.[10] The Eastern Scheldt presents a unique setting for the study of these elusive creatures.

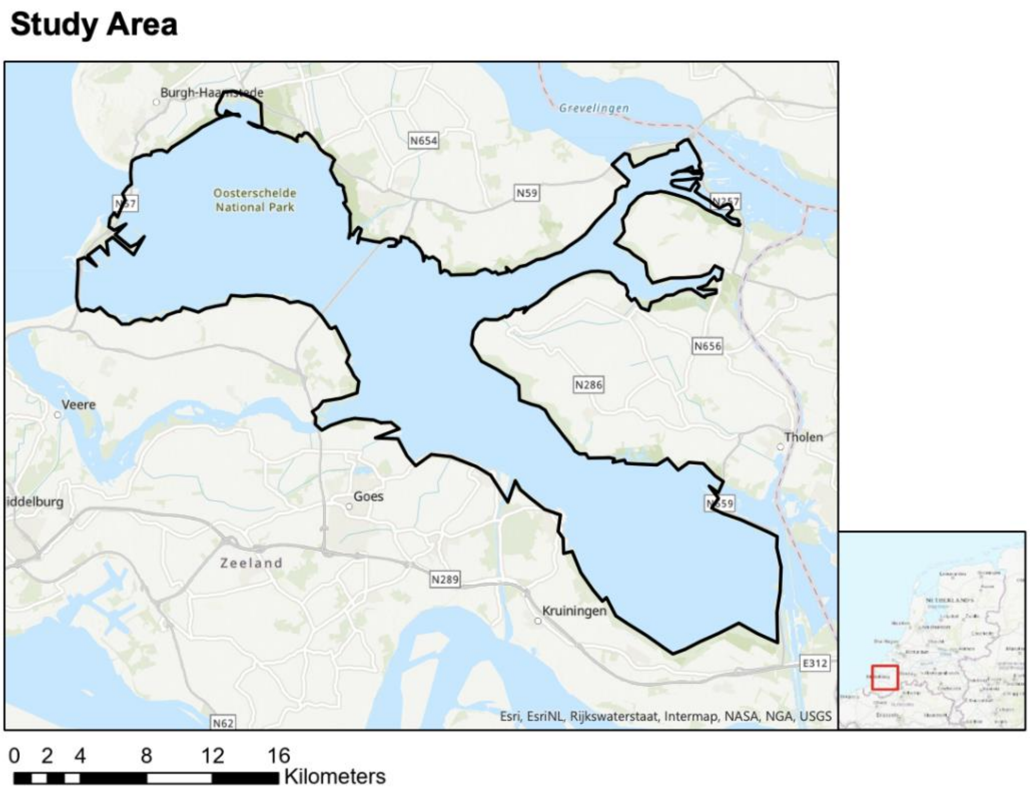

Figure 2: A topographical map of the Eastern Scheldt highlighting the study area with a black outline. (This map was created using ArcGIS Pro.)

2.2 Data Analysis

The data collected for this research was analysed using the software ArcGIS Pro 3.3 and R 4.3.1. In this study, ArcGIS Pro is used for data preparation, while data analysis is conducted using R. ArcGIS is a geospatial processing software application that enables the analysis of geographic data. R is a statistical computing environment and programming language that enables the modelling of species distribution and potential realised niches using various packages and techniques. The CSV file containing metadata provides the following for all sightings: survey number, date, number of encounters per date, time, GPS coordinates, tidal status, weather, behaviour towards the boat, how many individuals spotted together, and the behaviours of foraging or mating, group composition, and whether a calf was present (table A5 in the appendix depicts the metadata file). These were noted as they indicate interactions, abundance of individuals within high populated areas, foraging behaviours, and hot spot locations. Tidal status was noted as it was thought environmental changes may influence clarity of water column, and distribution when individuals seek rest, how much energy is expended while traveling or mating, and foraging techniques.[50-53]

2.3 Photo-Identification

The photos are stored in a Network Attached Storage (NAS) drive and have been systematically categorised since 2011 by Stichting Rugvin. The data used for this research includes conducted 74 field surveys from 2020-2023 to collect occurrence data of harbour porpoises in the Eastern Scheldt. Throughout these 74 surveys, a total of 226 observations occurred. These field surveys were conducted by multiple volunteers and members at Rugvin. They were carried out when weather conditions permitted, particularly when there were winds did not exceed Beaufort 5, without high waves, and preferably without precipitation. The route is determined based on the skipper's navigational expertise, rather than following a linear path. Throughout these field surveys, GPS coordinates, behavioural patterns, group size, and composition of groups were recorded. The data was subsequently collected and annotated in Excel, and later transformed into CSV format for application in ArcGIS Pro. GPS coordinates were included by using snapshots stored within folders that captured precise sightings of a date, as well as by extracting information from survey forms. Good Analytics, non-profit team of data professionals[27], extracted GPS data from photos captured by GPS-enabled cameras and provided this data in the form of an Excel sheet for 19 dates, in the form of Decimal Degrees. The GPS coordinates were converted from Degrees, Minutes, Seconds in other folders to Decimal Degrees, to ensure compatibility with ArcGIS Pro. Additionally, the photo-ID method utilises distinct characteristics such as pigmentation patterns, notches, fin shape, and scratches to identify individuals.

Figure 3: Shown is the individual L022R041. The photograph on the left was taken in 2015, and the photograph on the right was taken in 2018. Based on the dorsal fin shape and pigmentation pattern circled, it is determined this is the same individual. Primary features used to distinguish individual Harbour Porpoises: pigmentation patterns, scarring, shape of dorsal fin, and any other features that stand out.

Figure 4: Shown is the individual known as L045R038. This individual Harbour Porpoise has quite distinctive scarring on its back, likely due to a boat strike.

Date Observed	GPS Coordinates	Individuals Observed
13/05/2021	(Kats) 51.5679° N, 3.8860° E	**L018R015, L063R063**
13/05/2021	(Schelphoek) 51.6995° N, 3.8014° E	**L005R009, L012R004**

Figure 5: Shown is an indication to the initial data analysis showing spatial distribution of the individuals organized by date and GPS coordinates. Additionally, this shows where certain individuals were on a given date. This will later be used in GIS for a larger scope of spatial preferences of individuals. It is unclear if this can determine if individuals appear in this location with the other individuals or coincidence due to habitat preferences.

2.4 R

In this study, R utilised the "readxl" package in R to examine Excel files. The data cleaning process involved standardising the conversion of date formats, texts, and the removal of missing values that could potentially skew the results. The data manipulation, grouping, and interpretation of occurrences of each behaviour were performed using the "dplyr" package. The visualisations were generated using the 'ggplot2' package, which produced bar graphs to facilitate comprehension of the distribution of primary behaviours and temporal patterns. The dataset was cleaned by removing any NAN fields, or fields that were incomplete, in order to make the file readable by ArcGIS Pro and R.

2.5 ArcGIS Pro

In this study, the output extent was configured to match the CSV file of the cleaned dataset, which includes all the relevant data. As mentioned in the previous section, the data cleaning involved removing any empty or NAN cells, and was necessary to make the file more readable by R and ArcGIS Pro. This file represents the defined research area used in the study. The cell size was specified as 0.0001 decimal degrees, which is equivalent to 11.1 metres. Additionally, the coordinate system was then set to WGS_1984. The 'cell size' was adjusted to 0.0001 decimal degrees in order to maximise the precision of the spatial parameters. The WGS_1984 coordinate system was utilised due to its status as the worldwide standard. The majority of the datasets provided by Rugvin and Good Analytics were in the form of XLS Excel sheets.

The provided sheets were converted into CSV files to standardise the data and ensure compatibility with ArcGIS Pro. Once all the datasets were converted into vector data and met the necessary criteria for ArcGIS Pro, they could be further transformed into Kernel Density spatial distribution maps. The points were subsequently reclassified to represent a distribution that is more visually comprehensive. Ultimately, the data was then imported into ArcGIS Pro and used the coordinates that were visualised on the map. An analysis was conducted on the data to determine whether all data points fell within the Eastern Scheldt area, possessed a tidal status, showed foraging behaviour, and categorised social interactions. The incomplete cells within the metadata, and the data that were not within the Eastern Scheldt, were omitted from the analysis. The spatial distribution analysis was conducted to show the distribution and patterns of observations of harbour porpoises. The Kernal Density analysis tool was used to identify areas characterised by high concentrations of observations within 'hot spots,' or spatial clusters.

3. Results

This section provides a summary of the findings obtained from this research study. The text is separated into four different parts relating to distribution and behaviours: abundance, tidal statuses, foraging behaviours, and group/individual interactions. The data summary provides as insight to the data set that was used for this study. The distribution and density then show the results of the total abundance within the set boundary (as indicated in figure 5). The tidal status maps depict the densities within the Eastern Scheldt depending on the status of the tide when spotted. Foraging behaviours show the results of the type of foraging the harbour porpoises engaged in surface, surface/deep, and deep. And finally, the last results section indicates the group composition, if a calf was present, mating behaviours, or individual interactions.

3.1 Data Summary

The data used in this analysis were obtained from field surveys conducted in the years 2020, 2021, 2022, and 2023. A total of 226 interactions took place during these field surveys. Two distinct maps were obtained, one representing tidal status and the other representing bathymetry, which is the measurement of water depth in oceans, seas, or lakes.

3.2 Abundance

The map in figure 6 generated using the data on harbour porpoise sightings and the kernel density analysis tool in ArcGIS Pro. This Kernal density map displays the spatial distribution of harbour porpoises in the Eastern Scheldt, within the specified boundary area, along with the corresponding number of observed porpoises within this area. The red density zones indicate that a total of 35 to 50 harbour porpoises have been observed within a radius of 3.33 kilometres. Demonstrating that the harbour porpoises are mainly found in two specific areas within the central region of the Eastern Scheldt. Given the results of the R testing, the environmental conditions in areas where harbour porpoises are observed are considered favourable. The graph indicating total number of harbour porpoise sightings per year from 2020-2023.

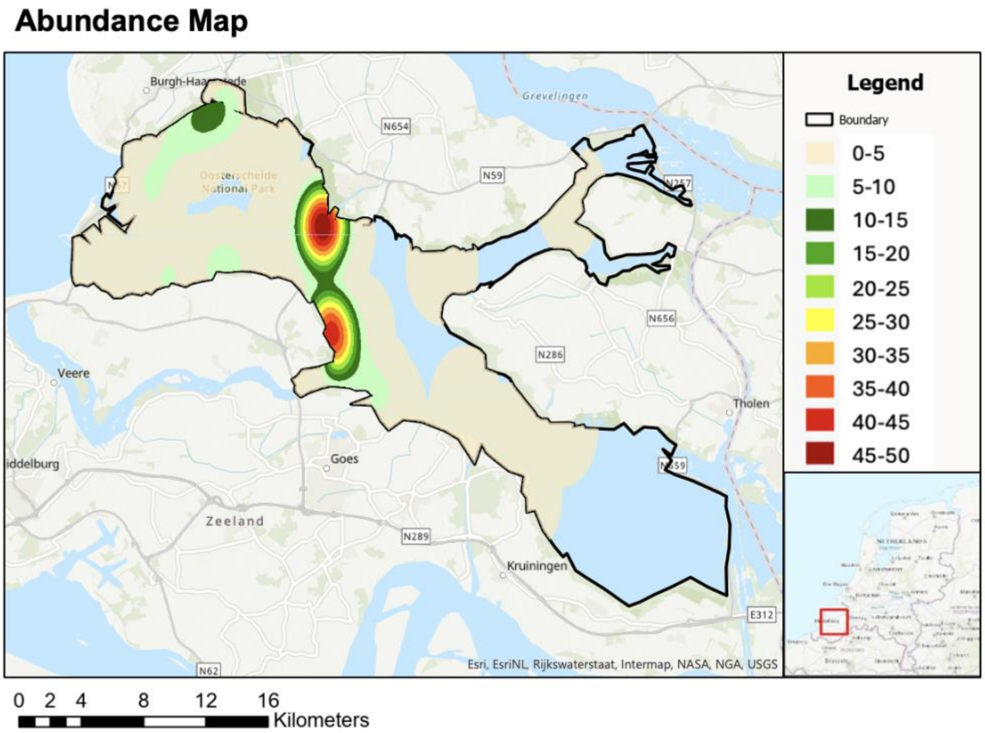

Figure 6: This map shows the spatial distribution and density of harbour porpoises within the Eastern Scheldt. The black line indicates the boundary area of research. The red zones indicate the highest point of abundance. This map was created using the Kernal Density analysis tool in ArcGIS Pro.

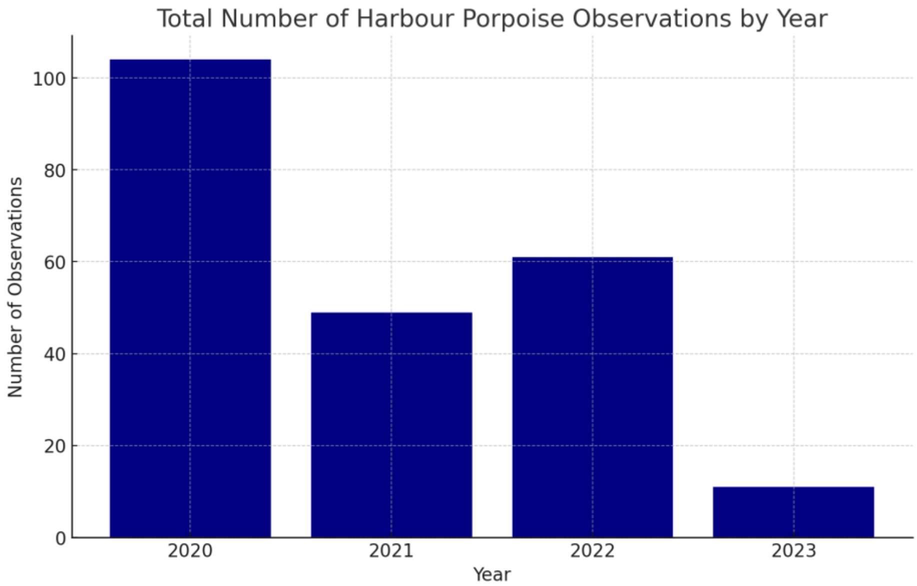

Figure 7: This graph was created using R. It depicts the total number of observations of harbour porpoises by year from 2020-2023. There were 104 observations in 2020, 49 observations in 2021, 61 observations in 2022, and 11 observations in 2023.These numbers are gathered from 74 surveys from 2020-2023.

3.3 Tidal Status

The tidal statuses displayed in Figure 8 indicate the presence of four different statuses. The kernel density analysis tool was used to analyse the spatial distribution and density of harbour porpoises across various tidal statuses. Each map displays a distinct tidal status. When comparing the maps, regardless of tidal conditions, the spatial distribution of harbour porpoises remains relatively consistent in the same areas. There is a noticeable disparity in the number of observations made during different tidal conditions. These values are approximately 10 during high and low tide, with a trend of 20 to 25 during rising and falling tides.

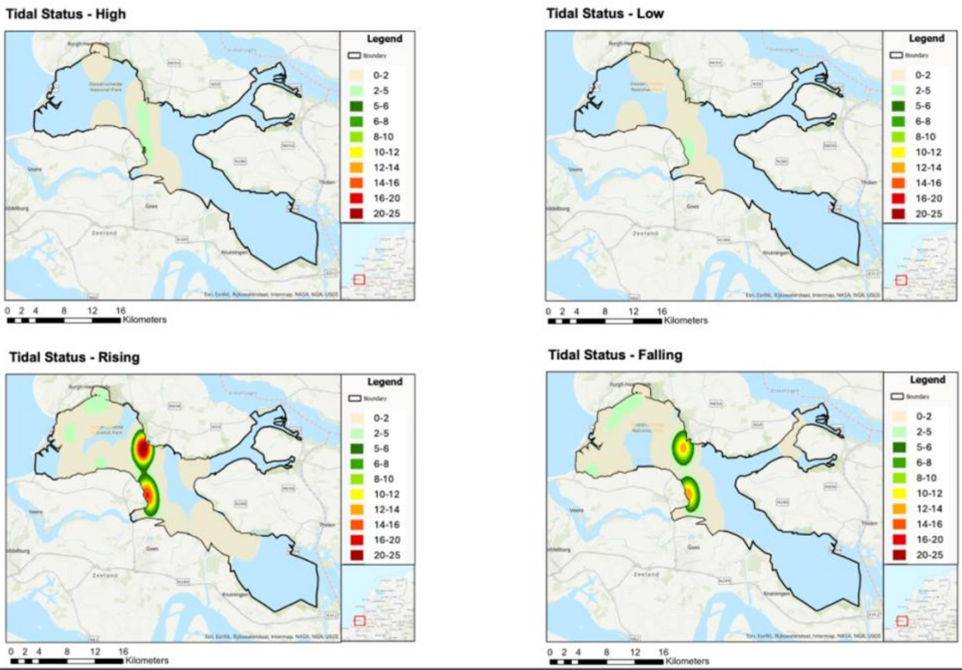

Figure 8: These density maps indicate the hot spots of each tidal status. The highest number of porpoise sightings during high and low tide were 10 individuals. While the highest number of observations during rising tide was 25 individuals, and 20 individuals observed during falling tide.

3.4 Foraging Behaviours

Figures 9, 10, and 11 were created using foraging classifications and the kernel density analysis tool. The metadata shows when an individual was sighted while foraging, which depicts the individuals that are foraging and does not include harbour porpoises that are travelling, or participating in other behaviours that do not include foraging. The maps indicate that surface foraging primarily takes place in a single location within the Eastern Scheldt. This location is in close proximity to the Kats harbour. The results of the Kernal Density maps (figures 9-11), when compared to bathymetry, show that deepwater foraging predominantly takes place in two locations, near the Zierikzee and Kats harbours.[35,39] Deep water foraging, in contrast to surface foraging, takes place extensively throughout the Eastern Scheldt but is primarily concentrated in two specific locations. Surface and deep-water foraging activities mainly occur in the vicinity of Zierikzee's harbour. Furthermore, it is apparent that there was a significantly higher occurrence of deep water foraging during the observations conducted by Stichting Rugvin.

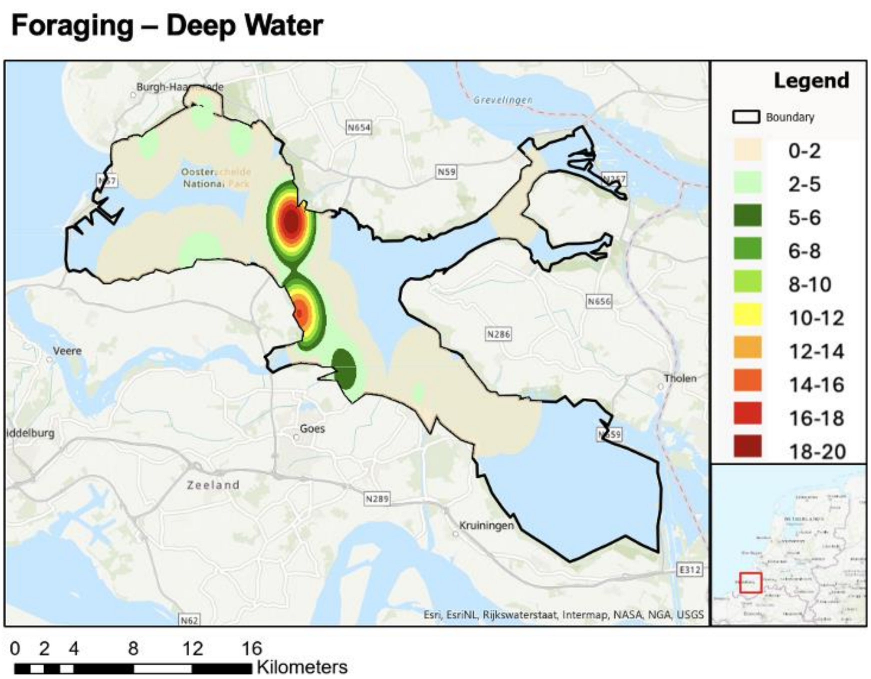

Figure 9: This density map indicates the spatial distribution of hot spots for foraging in deep water. This map was created using the Kernal Density analysis tool in ArcGIS Pro.

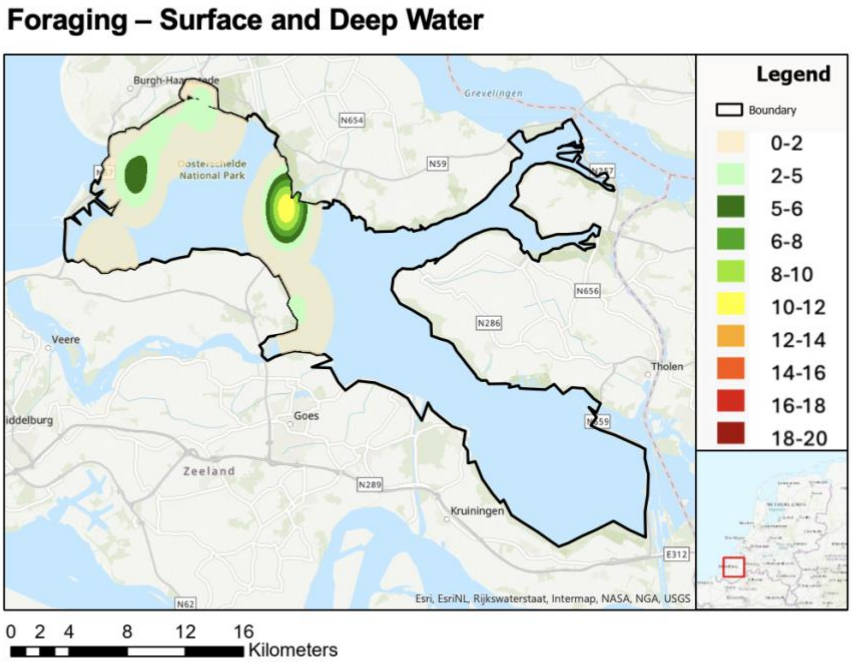

Figure 10: This density map indicates the spatial distribution of hot spots for foraging in deep and surface water. This map was created using the Kernal Density analysis tool in ArcGIS Pro.

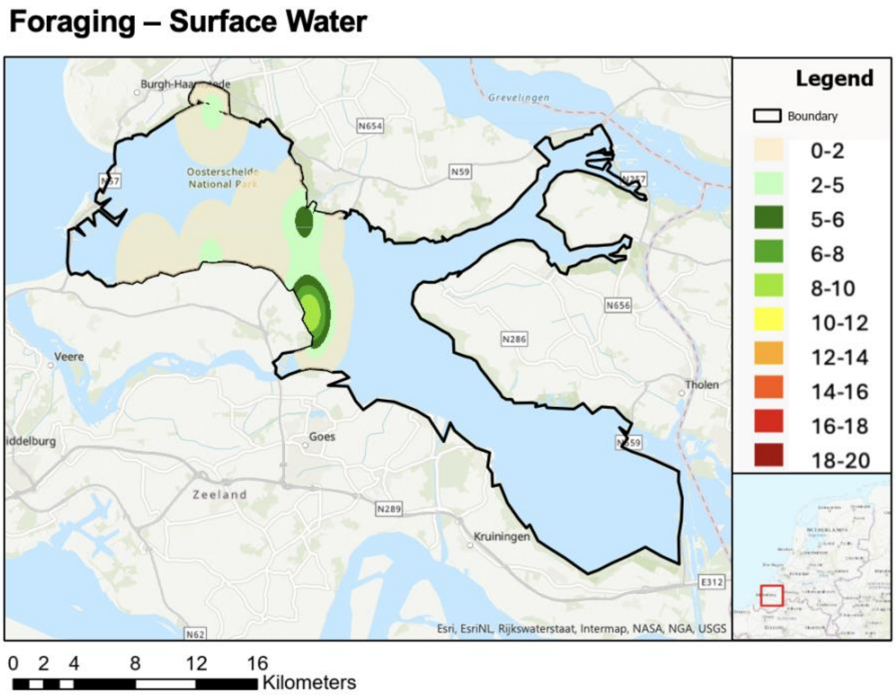

Figure 11: This density map indicates the spatial distribution of hot spots for foraging in surface water. This map was created using the Kernal Density analysis tool in ArcGIS Pro.

3.5 Group and Individual Interactions

The map was generated using the Kernal density tool, which utilises group composition and types. The map indicates that group composition primarily took place near the Kats harbour. This could be relevant to the previous maps on foraging if a significant number of individuals congregate in this area. Mating primarily takes place in two specific locations: near the Zierikzee harbour and the Kats harbour, as well as between Kats and the Roompot marina. The calves were primarily present near the harbour of Kats, as well as near the bridge of the

Eastern Scheldt. The final table shows the identified individuals seen together at the specified coordinates and given date.

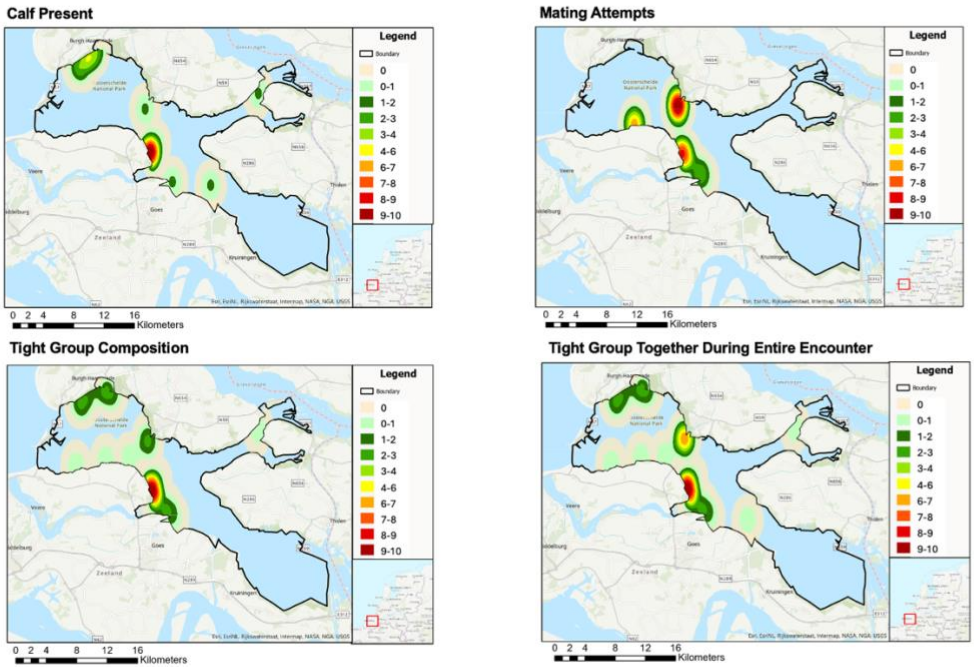

Figure 12: This density map indicates the spatial distribution of hot spots for group interactions regarding calves present, mating attempts, tight group composition, and maintaining a tight group during the entire encounter. The red density zones range

Porpoises_Seen_Together_Table

Date	Coordinates	Porpoises Seen Together
02-06-2020	(51.5726, 3.8958)	L028R023, L038032, L013R053
02-06-2022	(51.6463, 3.7476)	L015R001, L076R076, L012R004
04-04-2021	(51.674668, 3.752028)	L012R004, L079R079, L080R080
04-05-2022	(51.34251, 3.53523)	L013R053, L071R071
04-05-2022	(51.4015, 3.45239)	L074R074, L065R065
07-12-2020	(51.5713, 3.8915)	L067R066, L072R072, L084R084
09-05-2022	(51.6518, 3.9146)	L019R056, L043R037
10-04-2022	(51.6813, 3.755)	L015R001, L074R074
13-05-2021	(51.6865, 3.8054)	L018R015, L038R032
13-06-2021	(51.6334, 3.8857)	L032R016, L048R044, L085R085
15-04-2022	(51.6843, 3.747)	L015R001, L074R074, L012R004
16-04-2022	(51.651, 3.925)	L074R074, L007R010, L029R052
16-06-2022	(51.515, 3.405)	L014R011, L029R052, L062R062
18-06-2022	(51.515, 3.405)	L062R062, L083R083, L084R084
20-05-2020	(51.5449, 3.9336)	L043R037, L047R043
22-05-2022	(51.6542, 3.8958)	L054R049, L087R087
22-05-2022	(51.6833, 3.75)	L065R065, L075R075
22-07-2022	(51.63168, 3.889845)	L077R077, L037R031
29-11-2022	(51.645, 3.9146)	L019R056, L054R049, L043R037, L041R035, L013R053

Figure 13: This table indicates the individual identified harbour porpoises within the Eastern Scheldt according to date and coordinates. The table was made using R and converted to a CSV file.

4. Discussion

The map in figure 14 illustrates the underwater topography of the Eastern Scheldt.[44] The hypothesis of this study aimed to determine the distribution of harbour porpoises and investigate the potential impact of environmental factors on their foraging behaviour, social interactions, and spatial distribution within the Eastern Scheldt. The potential influencing factors identified were tidal status and bathymetry, which were used as environmental indicators. The following discussion subchapters will discuss the results in comparison with these environmental indicators, as depicted in the introduction. Initial findings from the photo-ID analysis have started to paint a complex picture of harbour porpoise life in the Eastern Scheldt. Seasonal patterns of habitat use have become evident, with certain areas favoured during specific times of the year, likely related to prey availability and breeding activities.[4,31]

These methodologies have also potentially highlighted[2] the importance of specific zones within the Eastern Scheldt for feeding, socializing, and possibly breeding[5,39]. Notably, monitoring behaviours have revealed that certain areas with environmental characteristics are consistently frequented by harbour porpoises,[2] suggesting these areas are critical to their survival and well-being in the estuary.[35]

Current gaps in knowledge regarding the harbour porpoises in the Eastern Scheldt include a detailed understanding of their behaviour patterns, habitat preferences, and social structures within this specific estuarine environment. This research aims to assist in filing these gaps by providing detailed insights into the spatial and social ecology of harbour porpoises in the Eastern Scheldt.

Rugvin primarily operates from the harbour of Kats. Therefore, the boats will pass through the zone in front of Kats twice during each survey, thereby increasing the likelihood of observing individuals. During the surveys, Rugvin regularly visits the buoy known as "studio porpoise". This buoy records underwater echolocation noises made by harbour porpoises and enables people to hear these calls.[7,18] This is situated opposite to the Zierikzee harbour. Essentially, this implies that there is a bias towards these two locations due to the higher occurrence of sightings.

It is important to mention that a few years ago, the database encountered an issue that led to the loss of many photographs. However, thanks to the backups created by previous volunteers, many of these photos were successfully retrieved. Despite this recovery, there are still a number of images from the years 2019 to 2021 that remain unaccounted for. Thus, further investigation is required to obtain a more comprehensive dataset. Additionally, 2023 did not provide appropriate conditions for taking the boat on surveys, therefore there is less data available for this year.

While analysing the abundance map, it becomes evident that there are two prominent areas of high concentration, located in front of the Zierikzee harbour and the Kats harbour. The areas in front of Zierikzee have a gradient of depth ranging from 25 to 52 meters, while the areas in front of the harbour of Kats have a depth ranging from 25 to 39 meters.[44] Therefore, these areas, characterised by a depth gradient, are considered relatively deep in the Eastern Scheldt.[26] This likely impacts the spatial distribution of harbour porpoises in the Eastern Scheldt. The results suggest that harbour porpoises demonstrate a preference for deeper waters in areas with a depth gradient in the Eastern Scheldt, particularly near the harbours of

Zierikzee and Kats, where the gradient influences turbulence in the water column, likely affecting their habitat preference.[26]

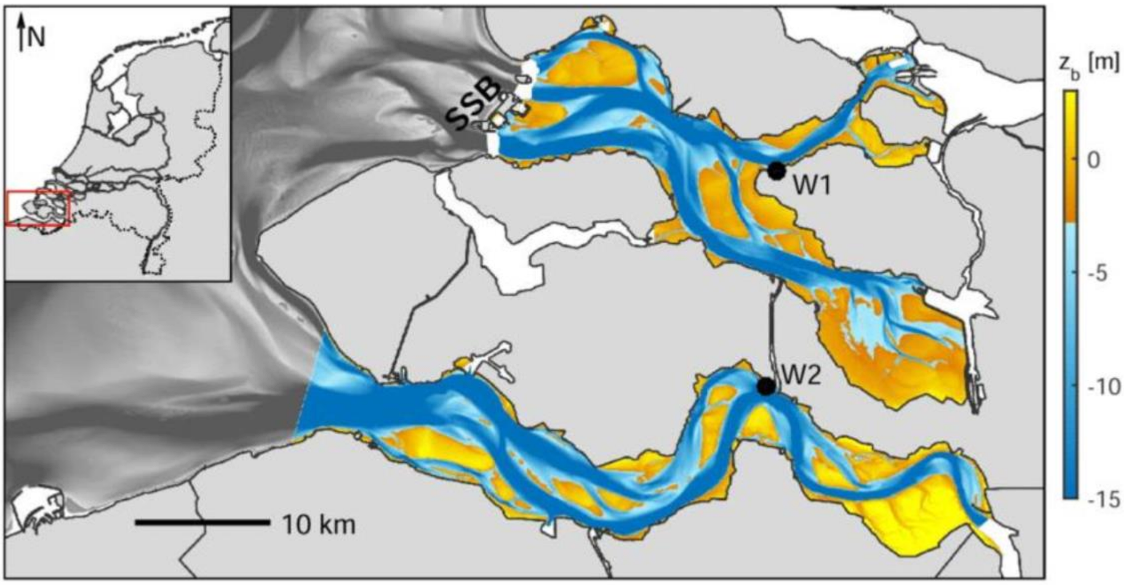

Figure 14: Current map showing the bathymetry of the Eastern Schedlt[33]

4.1 Tidal Status

The figures depicting the spatial distribution of harbour porpoises during various tidal statuses within the Eastern Scheldt showed a pattern that was consistently similar. Throughout all tidal cycles, the majority of sightings of harbour porpoises occurred in the central region of the Eastern Scheldt, as depicted in figures 9,10, and 11, where the porpoise population is concentrated, indicating an apparent preference for this particular area. The harbour porpoise density changed during the different tidal statuses. During high and low tides, the abundance of spotted harbour porpoises was significantly lower compared to the tides that were rising and falling. The observed trend may be attributed to the timing of the surveys. This may also be attributed to the relatively brief duration of high and low tide periods (approximately 30 minutes) compared to the longer duration of the rising and falling tide (approximately 6 hours). The presence of tides in the Eastern Scheldt does not significantly alter the behaviour of harbour porpoises, if at all.

4.2 Foraging

The foraging distribution of harbour porpoises shows a notable difference among the three individual figures. According to the observed sightings in this study, surface foraging behaviour appears to be limited to certain locations in the Eastern Scheldt, with an emphasis on the area near the Kats harbour. In contrast, the deep-water foraging map reveals that harbour porpoises engage in 'deep-water dives' throughout the entire Eastern Scheldt area. By examining the bathymetry map of the Eastern Scheldt and comparing it to the areas where deep-water foraging takes place, it becomes evident that these occurrences predominantly take place in areas of significant depth, ranging from 20 to 52 meters.[26]

Deep water foraging refers to the behaviour of porpoises tilting their bodies downwards to forage. This behaviour can occur in waters as shallow as five meters. This indicates that while this particular type of foraging can occur in different parts of the Eastern Scheldt, it predominantly occurs in water with a deeper than the minimum prerequisite for this method, notably exceeding five meters. When comparing figure 10 with figures 9 and 11, it becomes apparent that the pattern observed in figure 11 is the reverse. In this case, the foraging activities primarily take place in front, and around the entrance, of the Zierikzee harbour. The water in front of Zierikzee and Kats is highly attractive to harbour porpoises, making it a preferred foraging location for them.

In the Eastern Scheldt, the primary sources of food for the harbour porpoise, such as sand goby, whiting, and small sand eel, are mainly found in the lower part of the water column, usually near the seabed.[32] The Sand Goby (*Pomatoschistus minutus*) is a type of fish that inhabits the benthic zone, which refers to the area near the bottom of the water column. These fish are commonly found in substrates that are sandy or muddy in nature. They are typically encountered in shallow coastal waters and estuaries, where they can maintain proximity to the seabed.[36,40] Whiting, scientifically known as (*Merlangius merlangus*), is a species of benthic fish. They inhabit the area just above the ocean floor. They are commonly located in regions characterised by sandy or muddy substrates, where they may feed on benthic invertebrates. Whiting are predominantly found in the Eastern Scheldt in shallow waters, where they tend to stay near the bottom.[37] The Small Sand Eel (*Ammodytidae*) is a type of benthic fish and is recognised for its habit of digging into sandy substrates. They primarily inhabit the seabed, where they either swim in large groups near the bottom or dig into the sediment to evade predators. As a result, they become vulnerable to benthic feeders such as the harbour porpoise.[38]

The sand goby, whiting, and small sand eel predominantly inhabit benthic and demersal regions, frequently near sandy or muddy surfaces in shallow to moderately deep aquatic environments.[36, 38, 39] These habitats offer the essential conditions for these species to flourish. Harbour porpoises tend to prefer areas with a high abundance of these prey species. Porpoises display diving behaviours to search for food in the areas near the seabed where these fish are found. Harbour porpoises are attracted to deeper waters or specific substrate types, such as sandy bottoms, where prey is present.[39] This leads to an increased presence of harbour porpoises in these areas.[36, 38, 39] Harbour porpoises in the Eastern Scheldt may prefer deeper waters for various reasons, such as the concentration of prey caused by tidal currents or to avoid human activities, even though their main source of food is more commonly found in shallower areas.[39, 40]

4.3 Group Composition and Social Interactions

Upon comparing figure 12 and figure 14, it is apparent that these interactions predominantly occur in the deep water, specifically between 25 and 52 meters. This observation seems to be prevalent and related to foraging locations. Therefore, the relationship between bathymetry and social behaviours or interactions remains unclear due to the interference of this data with foraging behaviours. Additional data specifically focusing on the social interactions of individuals and the composition of groups will be necessary in order to obtain more comprehensive results.

5. Conclusion

Based on the comprehensive analysis of various factors and outcomes, it could be determined that harbour porpoises predominantly inhabit the gradient rich regions of the Eastern Scheldt. Bathymetry is the primary factor that significantly influences the foraging behaviour and spatial distribution of harbour porpoises. Bathymetry not only has the greatest impact on ecological factors, but all foraging locations are also situated in water deeper than 20 metres, defined by a steep gradient, and consequently influenced by bathymetry. However, the tidal conditions did not appear to have an impact on the spatial distribution of harbour porpoises, as a consistent pattern was observed regardless of the tidal status. After examining the connection between the spatial arrangement and feeding habits of harbour porpoises in the Eastern Scheldt, it can be concluded that neither tidal conditions nor the depth of the water affect the type of feeding behaviour observed. However, bathymetry is an environmental factor that affects where foraging occurs. Deep water feeding sites were the main locations for social interactions. However, it remains uncertain whether the bathymetry directly influences social interactions or if these interactions predominantly arise from heightened foraging activities and unintentionally occur in that particular "hot spot". Further investigation of social interactions is necessary to ascertain this. There is no apparent correlation between tidal status and social interactions.

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I am truly honoured to have worked on this project and been given such a remarkable opportunity to work with these astounding researchers. This study, while a small segment in the broad domain of cetacean research, stands as a significant personal achievement, contributing valuable insights into these extraordinary marine mammals.

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8. Appendix:

8.1 Sightings by Month and Behaviours

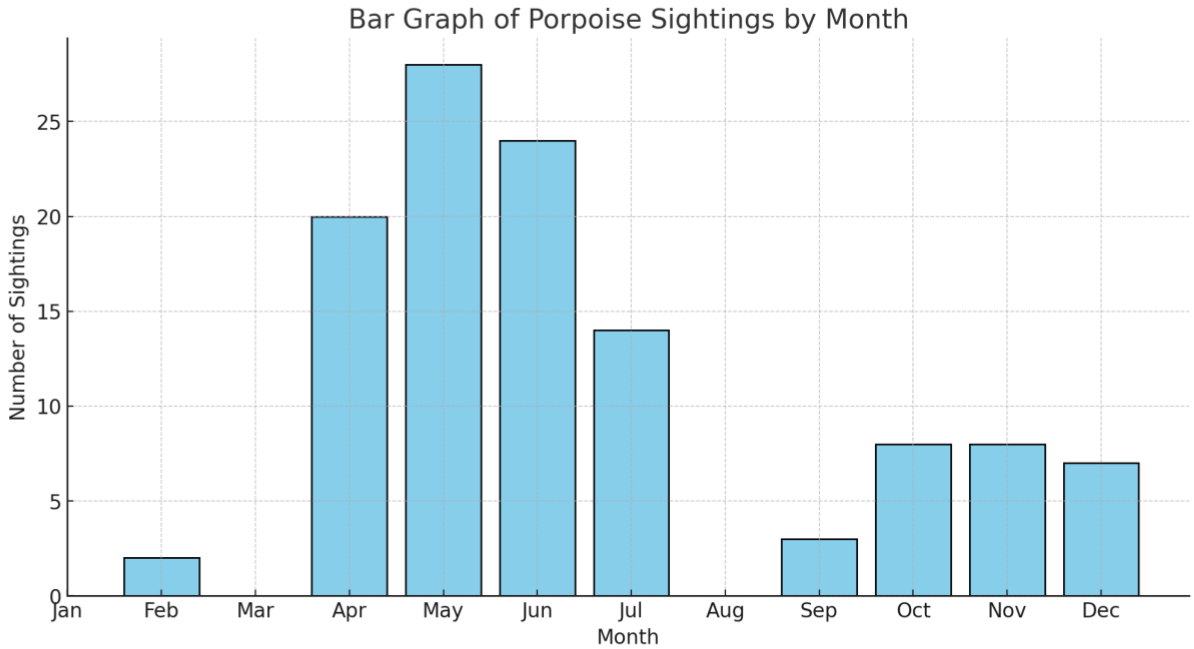


Figure A1: This bar graph depicts the porpoise sightings per month from the years 2020-2023. These numbers are based off 74 surveys, and 226 total observations within this period.

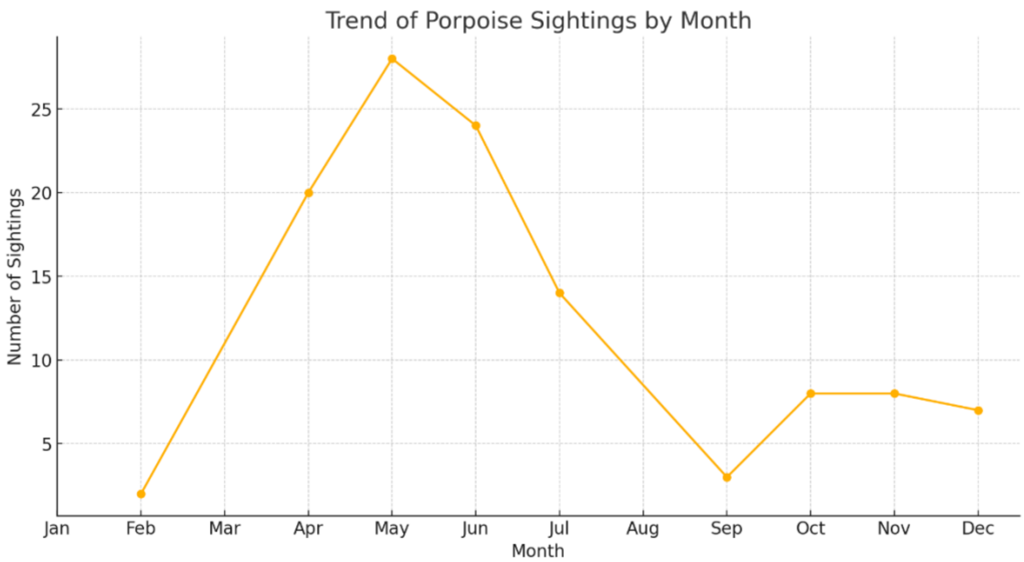


Figure A2: This line graph depicts the trend of porpoise sightings by month from the years 2020-2023. These numbers are based off 74 surveys, and 226 total observations within this period.

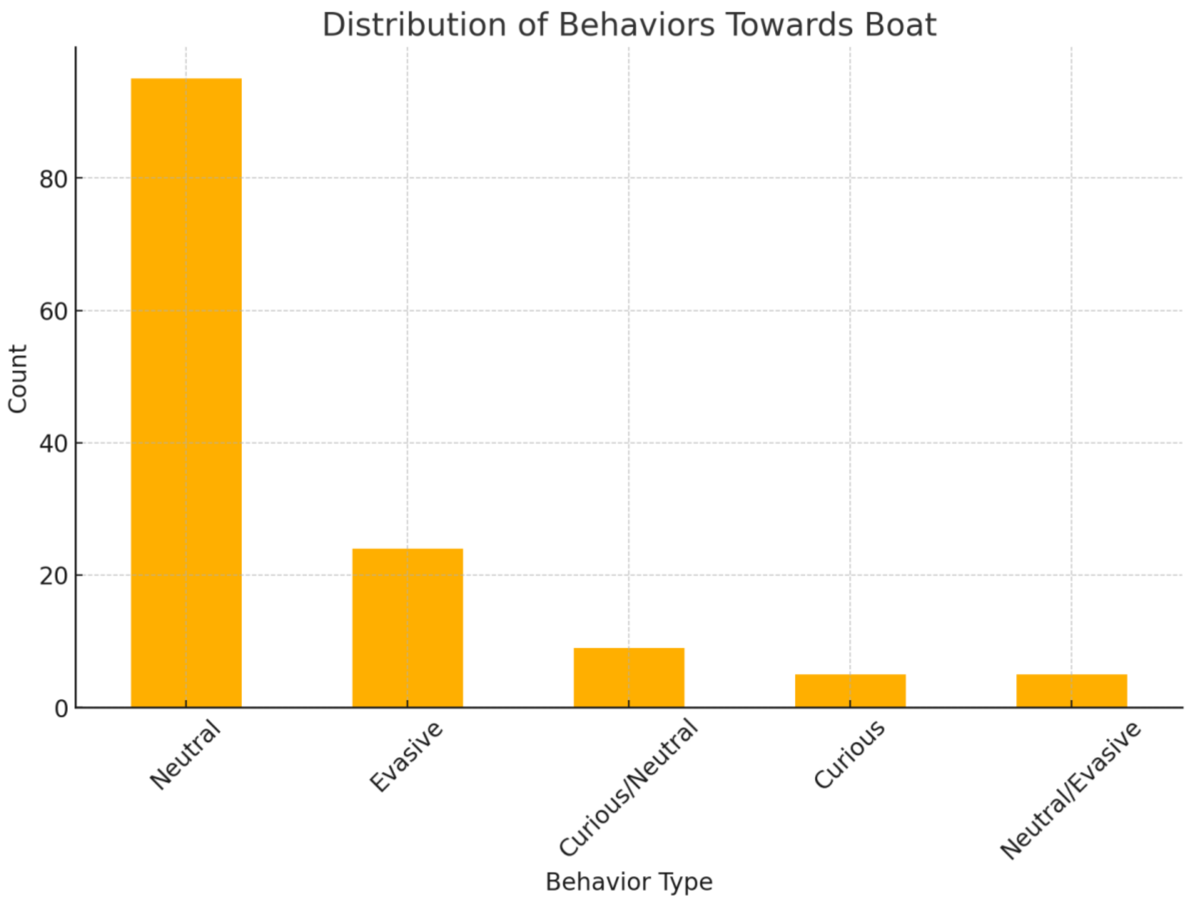


Figure A3: This is a bar graph created in R that shows the Harbour Porpoise Behaviours towards the boat. The following shows the distribution numbers of each behaviour type: Neutral: 95 instances, Evasive: 24 instances, Curious/Neutral: 9 instances, Curious: 5 instances, Neutral/Evasive: 5 instances

8.2 Summary of Interactions by Year

Table A1: This table shows the individuals that were spotted together in 2020.

Summary of Interactions by Year 2020				
Date	Porpoise Code	Porpoise Code 2	Location	Location 2
20/05/2020	L013R053	L014R054	(51.5449, 3.9336)	(51.5448, 3.9337)
02/06/2020	L015R055	L016R056	(51.5726, 3.8958)	(51.5727, 3.8957)
04/08/2020	L017R057	L018R058	(51.6296, 3.8906)	(51.6295, 3.8907)
07/12/2020	L019R059	L020R060	(51.5713, 3.8915)	(51.5714, 3.8914)

Table A2: This table shows the individuals that were spotted together in 2021.

Summary of Interactions by Year 2021				
Date	Porpoise Code	Porpoise Code 2	Location	Location 2
04/04/2021	L021R061	L022R062	(51.674668, 3.752028)	(51.674669, 3.752029)
13/05/2021	L023R063	L024R064	(51.6865, 3.8054)	(51.6866, 3.8055)
13/06/2021	L025R065	L026R066	(51.5536, 3.9045)	(51.5537, 3.9046)
25/07/2021	L027R067	L028R068	(51.6334, 3.8857)	(51.6335, 3.8858)
06/09/2021	L029R069	L030R070	(51.6045, 3.8062)	(51.6046, 3.8063)

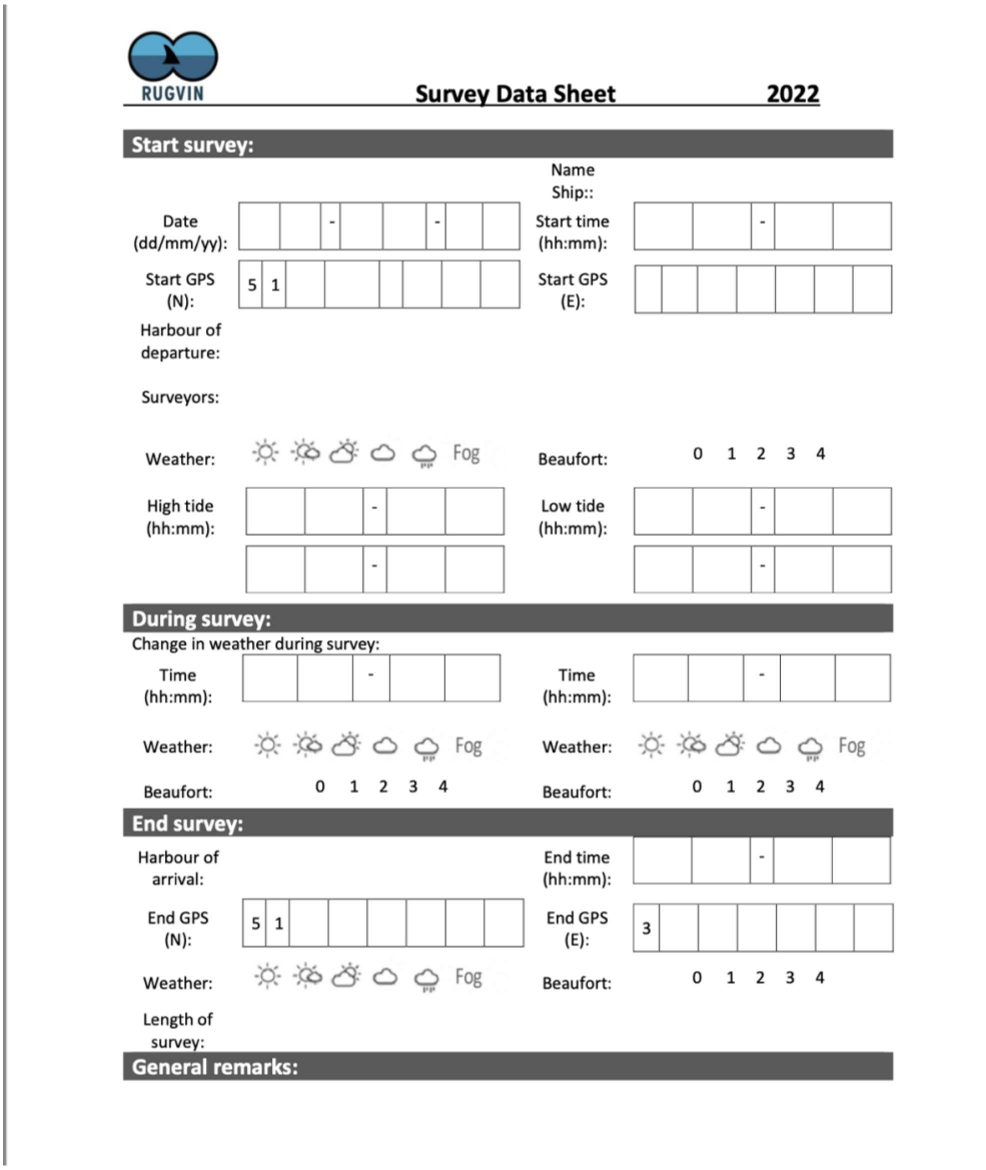
Table A3: This table shows the individuals that were spotted together in 2022.

Summary of Interactions by Year 2022				
Date	Porpoise Code	Porpoise Code 2	Location	Location 2
10/04/2022	L031R071	L032R072	(51.6813, 3.755)	(51.6814, 3.7551)
15/04/2022	L033R073	L034R074	(51.6843, 3.747)	(51.6844, 3.7471)
16/04/2022	L035R075	L036R076	(51.651, 3.925)	(51.6511, 3.9251)
04/05/2022	L037R077	L038R078	(51.34251, 3.53523)	(51.34252, 3.53524)
09/05/2022	L039R079	L040R080	(51.6518, 3.9146)	(51.6519, 3.9147)
14/05/2022	L041R081	L042R082	(51.656, 3.894)	(51.6561, 3.8941)
22/05/2022	L043R083	L044R084	(51.6542, 3.8958)	(51.6543, 3.8959)
02/06/2022	L045R085	L046R086	(51.6463, 3.7476)	(51.6464, 3.7477)
16/06/2022	L047R087	L048R088	(51.515, 3.405)	(51.5151, 3.4051)
18/06/2022	L049R089	L050R090	(51.515, 3.405)	(51.5151, 3.4051)
22/07/2022	L051R091	L052R092	(51.63168, 3.889845)	(51.63169, 3.889846)

Table A4: This table shows the individuals that were spotted together in 2023.

Summary of Interactions by Year 2023				
Date	Porpoise Code	Porpoise Code 2	Location	Location 2
22/06/2023	L055R095	L056R096	(51.630935, 3.887865)	(51.630936, 3.887866)

8.3 Encounter Sheet Surveys


RUGVIN

Survey Data Sheet **2022**

Start survey:

Date (dd/mm/yy): __ __ - __ __ - __ __

Name Ship::

Start time (hh:mm): __ __ - __ __

Start GPS (N): 5 1 __ __ __ __ __ __

Start GPS (E): __ __ __ __ __ __ __

Harbour of departure:

Surveyors:

Weather: Fog

Beaufort: 0 1 2 3 4

High tide (hh:mm): __ __ - __ __ / __ __ - __ __

Low tide (hh:mm): __ __ - __ __ / __ __ - __ __

During survey:

Change in weather during survey:

Time (hh:mm): __ __ - __ __ | Time (hh:mm): __ __ - __ __

Weather: Fog | Weather: Fog

Beaufort: 0 1 2 3 4 | Beaufort: 0 1 2 3 4

End survey:

Harbour of arrival:

End time (hh:mm): __ __ - __ __

End GPS (N): 5 1 __ __ __ __ __ __

End GPS (E): 3 __ __ __ __ __ __

Weather: Fog

Beaufort: 0 1 2 3 4

Length of survey:

General remarks:

Noteer svp alle stops A- K. "Encounter #" komt overeen met # van Encounter form en worden aangegeven door Waypoints. Zet de letters op kaart en trek lijnen, de vaarroutes, naar volgende locatiepunt. Zie voorbeeld in map.

Locatie #	Locatienaam	Encounter #	Tijd van… tot ….	Opmerkingen
A				
B				
C				
D				
E				
F				
G				
I				
J				
K				

Voorbeeld tabel

A	Kats		10.30 uur	
B	Wemeldinge	1	11.05 – 11. 45	Ook zeehond

RUGVIN

Bruinvis waarnemingen Citizen Science formulier

Allereerst hartelijk dank voor het doorsturen van uw waarneming. Voor een goede verwerking van deze waarneming hebben we van u de volgende gegevens nodig.

Voorbeeld:

Datum waarneming	7 januari 2022
Tijdstip eerste waarneming	15.37
Tijdstip laatste waarneming	15.55
Locatie	Oostpier van Burghsluis
Aantal waargenomen bruinvissen Minimaal	1
Aantal waargenomen bruinvissen Maximaal	2
Foto's genomen? Verzonden naar Rugvin	Ja. Op 8 januari 2022
Activiteit van de bruinvis(sen)	Foerageren, verplaatsing naar (?) paring of anders.

Uw waarneming:

Datum waarneming	
Tijdstip eerste waarneming	
Tijdstip laatste waarneming	
Locatie	
Aantal waargenomen bruinvissen - Minimaal	
Aantal waargenomen bruinvissen - Maximaal	
Foto's genomen? Verzonden naar Rugvin op	
Activiteit van de bruinvis(sen)	

Overige opmerkingen:

Naam waarnemer:

Uw emailadres (optioneel) voor eventuele vragen van onze kant:

8.4 Metadata of Sightings and Locations

Table A5: These tables depict the Metadata file available for all sightings (74 surveys, 226 observations) from 2020-2023. This provides insight to the time, date, location, behaviours, tidal status, group composition, porpoise codes, and whether a calf was present.

Encounter	Date	Porpoise Code	Start time	Decimal degrees N	Decimal degrees E	End time	Weather during encounter	Beaufort during encounter	Tide during encounter	Estimated number of individuals Min	Estimated number of individuals Max:
1	04-08-2020		11:38	51.573800	3.894500	12:11	Partialy Cloudy	1	Rising	1	1
2	04-08-2020		12:38	51.629600	3.890600	13:15	Partialy Cloudy	1	Rising	3	5
3	04-08-2020		13:30	51.632500	3.888100	14:45	Sunny	0	Rising	3	7
4	04-08-2020		14:45	51.629600	3.890600	15:07	Sunny (heiig)	0	Rising	3	3
5	04-08-2020		15:47	51.584000	3.892400	15:50	Sunny (heiig)	1	Rising	1	3
1	16-04-2020		11:02	51.621300	3.888000	11:06	Sunny	1	High	2	2
2	16-04-2020		11:30	51.621700	3.876500	13:25	Sunny	1	Falling	8	9
3	16-04-2020		14:02	51.623500	3.890300	16:13	Partially cloudy	1	Falling	12	15
4	16-04-2020		16:45	51.574700	3.892900	16:50	Partially cloudy	1	Low	1	1
1	25-04-2020	L013R053	13:15	51.630500	3.888600	13:46	Partially cloudy	2	Low	2	3
2	25-04-2020		15:05	51.629800	3.889900	16:10	Partially sunny	2	Rising	3	3

Estimated number of individuals Best:	Primary behaviour during encounter	Secondary behaviour during encounter	Type of Foraging	Behaviour towards boat	Group composition	Group together during entire encounter	Calf present	ID photos taken	Possible mating attempts seen
1	Foraging	Travelling		Evasive			No	Yes	No
3	Foraging	Foraging	Surface	Neutral	Lose	No	No	Yes	No
5	Foraging	Resting	Surface/ deep water	Neutral	Lose	No	No	Yes	No
3	Foraging	Foraging	Surface/ deep water	Neutral	Lose	Yes	No	Yes	No
1	Travelling	Travelling		Evasive			No	Yes	No
2	Travelling	-		Neutral	Lose	No	No	Yes	No
8	Foraging	Resting	Surface/ deep water	Neutral	Lose	No	No	Yes	No
13	Foraging	Travelling	Surface/ deep water	Curious	Lose	No	No	Yes	Yes
1	Foraging	-	Deep water	Neutral			No	Yes	No
3	Foraging	-	Surface/ deep water	Neutral	Lose	No	No	Yes	No