Environmental effects on harbour porpoises

How environmental factors influence spatial distribution and foraging behaviour of harbour porpoises *(Phocoena phocoena)* within the Eastern Scheldt

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Summary

A small semi-isolated resident population of harbour porpoises (*Phocoena phocoena*) lives in the Eastern Scheldt tidal bay in Zeeland, the Netherlands. Harbour porpoises are protected under multiple Dutch laws, and international legislation, and therefore their foraging behaviour and spatial distribution needs to be better understood. However, little data is currently available about the environmental factors that affect the spatial distribution and foraging behaviour of harbour porpoises in the Eastern Scheldt. Research to investigate the factors that influence spatial distribution has already been conducted in the North Sea, but these two locations can hardly be compared due to the different environmental conditions. To provide this knowledge, this study has developed a spatial model to predict harbour porpoise occurrence within the Eastern Scheldt based on multiple environmental factors. This model has been developed using the species distribution modelling (SDM) program Maxent and ArcGIS, to determine which factors influence harbour porpoises' spatial distribution and foraging behaviour within the Eastern Scheldt. For this research, the factors bathymetry, chlorophyll-a level, sediment, tidal status, and the abundance of the prey species sand goby (*Pomatoschistus minutus*), whiting (*Merlangius merlangus*) and small sand eel (*Ammodytes tobianus*) were used. This study concludes that harbour porpoise foraging behaviour and its spatial distribution within the Eastern Scheldt are affected by multiple factors. The factor that affects the distribution and foraging behaviour of harbour porpoises most is bathymetry. Another factor that has an impact on harbour porpoise distribution is the type of sediment Although it is unsuitable for a spatial distribution model in the Eastern Scheldt, it affects the harbour porpoise distribution. The type of foraging behaviour that occurs is not correlated to any of the tested variables. The locations where this foraging occurs are, however, affected by bathymetry as this predominantly occurs in locations with deeper water (>20m) and a steep gradient.

Samenvatting

Een kleine semi-geïsoleerde populatie bruinvissen (*Phocoena phocoena*) leeft in de Oosterschelde getijdenbaai in Zeeland, Nederland. Bruinvissen worden beschermd door meerdere Nederlandse wetten en om die reden moet hun foerageergedrag en ruimtelijke verspreiding beter worden begrepen. Echter zijn er momenteel weinig gegevens beschikbaar over de omgevingsfactoren die de ruimtelijke verspreiding en het foerageergedrag van bruinvissen in de Oosterschelde beïnvloeden. In de Noordzee is al onderzoek gedaan naar de factoren die de ruimtelijke verspreiding beïnvloeden, maar door de verschillende omgevingsomstandigheden zijn deze twee locaties nauwelijks met elkaar te vergelijken. Om deze kennis te verschaffen, heeft deze studie met behulp van het soortdistributiemodellering (SDM) programma Maxent en ArcGIS, een ruimtelijk model ontwikkelt om het voorkomen van bruinvissen in de Oosterschelde, te voorspellen op basis van meerdere omgevingsfactoren. Om op die manier te bepalen welke factoren de ruimtelijke verspreiding en het foerageergedrag van bruinvissen binnen de Oosterschelde beïnvloedt. Voor dit onderzoek is gebruik gemaakt van de factoren bathymetrie, chlorofyl-a niveau, sediment, getijdentoestand en de abundantie van de prooisoorten dikkopje (*Pomatoschistus minutus*), wijting (*Merlangius merlangu*s) en kleine zandspiering (*Ammodytes tobianus*). Alle factoren in overweging genomen, concludeert deze studie dat het foerageergedrag van bruinvissen en de ruimtelijke verspreiding ervan binnen de Oosterschelde door meerdere factoren worden beïnvloed. De factor die de meeste invloed heeft op het verspreidings- en foerageergedrag van bruinvissen is bathymetrie. Een andere factor die grote invloed heeft op de verspreiding van bruinvissen is sediment. Hoewel sediment niet geschikt is voor een ruimtelijk verspreidingsmodel in de Oosterschelde, heeft het invloed op de verspreiding van de bruinvis. De verschillende foerageer gedragingen worden niet beïnvloed door omgevingsfactoren, de plekken waar dit gedrag voorkomt wordt daar in tegen beïnvloed door bathymetrie zo komen ze meer voor op locaties waar het dieper is (>20m) en een steile helling aanwezig is.

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1.| Introduction

The harbour porpoise (*Phocoena phocoena*) is one of the smallest existing cetaceans in the world. The global estimate of harbour porpoises is around 700.000 individuals and is therefore classified as a species of Least Concern by the IUCN Red List (Bjørge & Tolley 2009, Society for Marine Mammalogy, 2014, IUCN Red List, 2020). They are found in the temperate to sub-polar waters of the Northern hemisphere (figure 1) and have been observed in at least 36 countries around the globe (Hammond et al., 2008), where they are primarily found in waters shallower than 200 meters in depth (Gaskin 1992; Read 1999;), meaning that they usually live in waters where a continental shelf is apparent. They are also known to occur in estuaries, bays and river mouths.

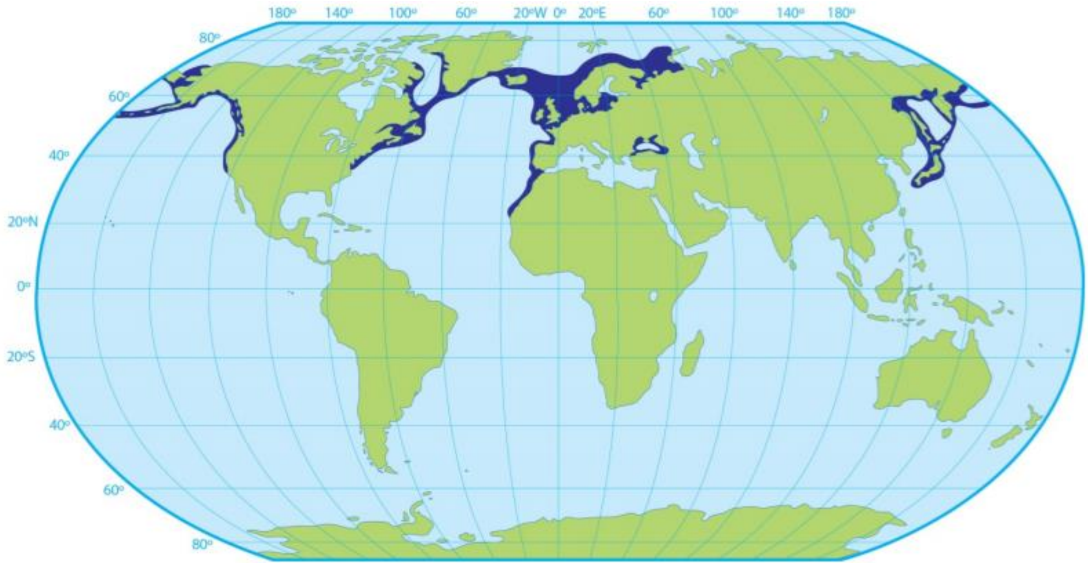

Figure 1. Distribution map of harbour porpoises (Phocoena phocoena). Map courtesy of Uko Gorter

Harbour porpoises are divided into four different subspecies with a diverse range of existence. The *Phocoena phocoena relicta* lives in the Black Sea. In contrast, the *Phocoena phocoena vomerine* and an un-named subspecies primarily live in the Eastern and Western Pacific Ocean. The *Phocoena phocoena phocoena* lives in the North- Atlantic waters (Hammond et al., 2008). This last subspecies is the species that is found in the European waters, including the Greater North Sea. With an estimated 350.000 individuals living in the Greater North Sea, it is the most occurring cetacean species in the North Sea and Dutch coastal waters (Geelhoed & Scheidat, 2018).

Harbour porpoise populations haven't always been as prominent in the North Sea as they are today. A severe decline in the harbour porpoise population occurred in the 1950s and 1960s. A combination of pollution with toxic chemicals in the North Sea, overfishing of prey and being caught as bycatch made this decline last until the 1980s (Ecomare, 2020). Before the severe decrease in population in the North Sea, a small population of harbour porpoises was observed in the Eastern Scheldt estuary in the province of Zeeland, the Netherlands. With the severe decline of harbour porpoises in the North Sea, so did the population in the Eastern Scheldt (see also https://rugvin.nl/oosterschelde/) . During this period, a Storm surge barrier (Oosterscheldekering) was built as a response to the flooding of the province of Zeeland, which potentially influenced the presents of harbour porpoises (Ministerie van Infrastructuur en Waterstaat, 2022). Resulting in no reported harbour porpoise sightings within the Eastern Scheldt for decades. However, the harbour porpoise population drastically increased in the 1990s and 2000s. This drastic increase in harbour porpoises is possibly due to an increase in prey availability, although this has not been proven yet (Camphuysen, 2004). A significant shift in the distribution of the harbour porpoises in the North Sea has also been seen, with an increase of animals in the Southern parts of the North Sea compared to the more Northern parts (Jung et al., 2009). This shift became apparent in the early 2000s as reports of harbour porpoise sightings within the Eastern Scheldt started coming in.

These incoming reports show that the Eastern Scheldt is a suitable area for the harbour porpoise and that the ecosystem is balanced because top predators like harbour porpoises will only be present in the area when the ecosystem is balanced (Fraser, 2011). This is especially the case for harbour porpoises as they are very energy demanding. This demand is high because they lose a lot of body heat due to their relatively small size in the rather cold waters. This makes them highly prey dependent since they need to be able to eat 10% of their body weight in food every day (Wisniewska et al., 2016; Camphuysen & Siemensa, 2011). According to research on stranded adult harbour porpoises in the Eastern Scheldt, the diet of harbour porpoises in the Eastern Scheldt primarily consists of sand goby (*Pomatoschistus minutus*), whiting (*Merlangius merlangus*) and small sand eel (*Ammodytes tobianus*) (Mairo, A., & Leopold, M., 2018). They feed in two ways, either at the surface or down in the water column, and need to eat between 5 and 62 times a day, depending on the season and the type of prey (Wisniewska et al., 2016). To better understand how harbour porpoises use their habitat while foraging, it is essential to get an idea of how the spatial distribution of harbour porpoises influences the foraging they perform.

In the Netherlands, harbour porpoises are protected under the Nature Protection Act and the Habitat Directive. These laws state that protective measures need to be taken to protect the habitat and the species within it (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2022). To preserve the harbour porpoise (within the Eastern Scheldt), knowledge about how their foraging behaviour and spatial distribution are affected by environmental factors is required. Cetaceans are often highly dependent on the environmental conditions and resources of the habitat (Correia et al., 2021). Predictive models of how harbour porpoises (and cetaceans in general) are affected by environmental factors on open seas have already been produced. The predictive models have incorporated many variables such as depth, sediment type, tidal range, salinity, water currents, water temperature, slope and chlorophyll-a concentrations (Giannoulaki et al., 2016; Correia et al., 2021). Similar research has to be conducted for the Eastern Scheldt to protect harbour porpoises in the Eastern Scheldt, as open seas differ a lot from the Eastern Scheldt when it comes to environmental conditions. This difference also suggests different habitat use of the harbour porpoise (Jansen, 2013). Predictive models of harbour porpoises in the Scottish waters have suggested that their distribution varies per season and is affected by steep bottom topography, distance from shore, depth, nitrogen & chlorophyll concentrations, sediment types, water temperature and currents (Embling et al., 2010). These factors are used as a guideline for this current study.

When trying to understand the role that environmental factors have on the spatial distribution and behaviour of harbour porpoises within the Eastern Scheldt, it is essential to consider the foraging behaviour of harbour porpoises. The foraging behaviour is essential as harbour porpoises spend a large part of their day foraging, making it one of the primary behaviours influenced by environmental factors (Wisniewska et al., 2016). This means that when the spatial distribution of harbour porpoises is affected by environmental factors, this often counts to harbour porpoises that are foraging. Therefore, when the factors that influence the spatial distribution of harbour porpoises are known, conclusions about the factors that affect the foraging behaviour can be drawn.

Occurrence data is fundamental for this type of research to be performed. Stichting Rugvin has been conducting field surveys and annual counting in the Eastern Scheldt since 2009. During these field surveys, Stichting Rugvin annotates environmental factors such as tide, wind, precipitation, as well as behaviour and occurrence data. Therefore, their research is crucial in understanding the spatial distribution and foraging behaviour of harbour porpoises within the Eastern Scheldt.

According to Dutch laws, harbour porpoises are protected. However, protecting a species can only be done when knowledge about a species is present. In the case of the harbour porpoise in the Eastern Scheldt, this knowledge is lacking regarding the environmental factors that influence the spatial distribution of harbour porpoises and how this distribution might change their foraging behaviour. With the use of spatial analysis techniques, answers can be provided and help to better understand the influencing environmental factors on the distributional preferences and foraging techniques of these porpoises to better protect them.

This research aims to gain more knowledge on how the spatial distribution and foraging behaviour of harbour porpoises are affected by multiple environmental factors and how the spatial distribution might affect the foraging behaviour of harbour porpoises.

To better understand the possible effect of environmental factors on the foraging behaviour and distribution of harbour porpoises, the following research question has been formulated:

"Which environmental factors potentially affect harbour porpoises' foraging behaviour and spatial distribution within the Eastern Scheldt?"

To answer this question, the following sub-questions have been formulated:

1. *"How are harbour porpoises distributed within the Eastern Scheldt?"*
2. *"Which environmental factors affect the distribution of harbour porpoises within the Eastern Scheldt?"*
3. *"To what extent is there a relationship between harbour porpoises' spatial distribution and foraging behaviour in the Eastern Scheldt?"*

2.| Materials and Methods

2.1 | Study area

The Eastern Scheldt is an approximately 350 km^2 large tidal bay located in the Province of Zeeland in the Netherlands (figure 5) (Nationaal Park Oosterschelde, n.d.; Sichting Rugvin , 2020).

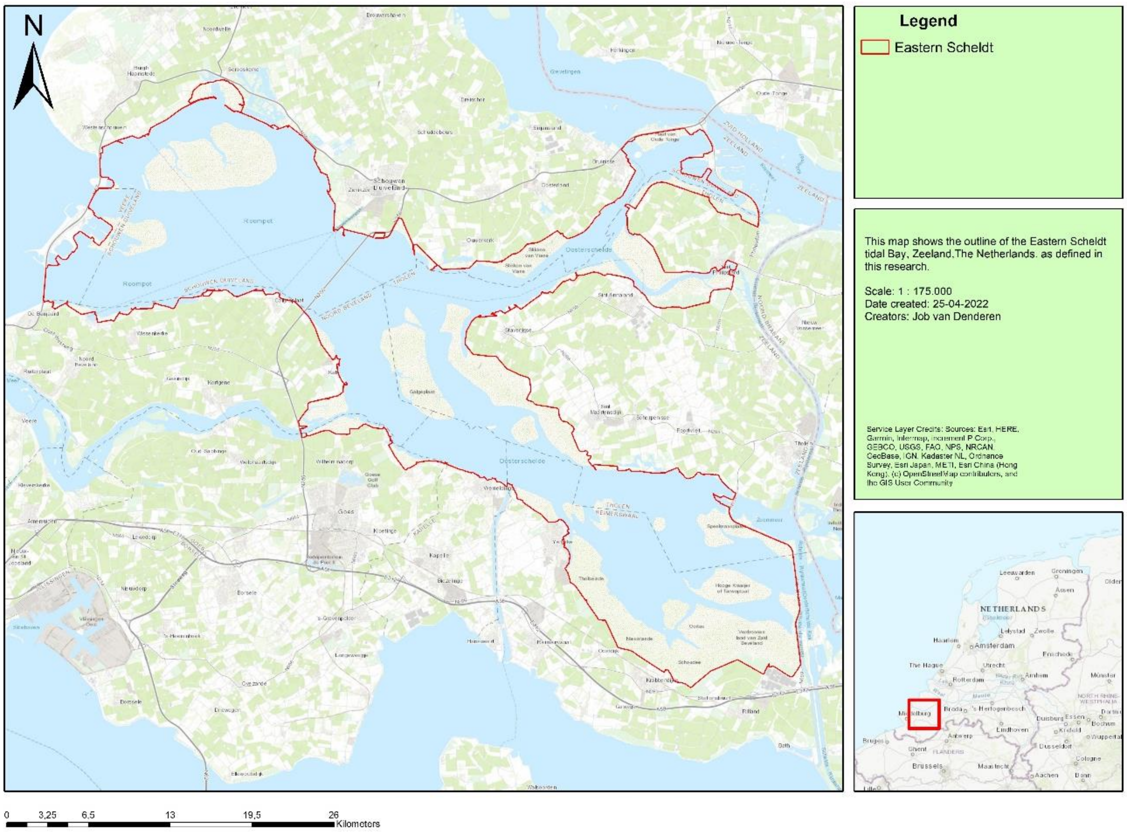

Figure 2. The Eastern Scheldt tidal bay in Zeeland, the Netherlands

The Eastern Scheldt is the largest national park in the Netherlands. It is rich in many species of fish, molluscs, algae, birds, anemones, sponges and marine mammals like harbour seals, grey seals and harbour porpoises (Van Dam, Solé, IJsseldijk, Begeman, & Leopold, 2017). The national park is part of the Natura 2000 network, a network of areas protected for their high biodiversity (Nationaal Park Oosterschelde, n.d). Between 1979 and 1986, a Storm Surge Barrier was built that turned this estuary into a semi-enclosed tidal bay. This barrier was constructed to protect the mainland of the Netherlands from periodically occurring high water and is only closed during emergency events, which is about once a year (Ministerie van Infrastructuur en Waterstaat, 2022). In addition, two auxiliary compartment dams were built further upstream and partially closed off the freshwater input from the rivers the Scheldt and the Rhine. These three dams changed the water displacement in the Eastern Scheldt area, causing morphological and ecological changes in the habitat, changing the habitat of many species, including the harbour porpoise. These changes, for example, provide different currents and different foraging locations.

2.2 | Research population

This research focuses on the harbour porpoises in the Eastern Scheldt seen during the encounters of field surveys conducted by Stichting Rugvin. Between 2009 and 2018, the number of individuals spotted during the annual survey has been fluctuating between 15 and 61 individuals (Stichting Rugvin, 2020), which means that the research population will most likely be between 15 and 61 individuals. The number of harbour porpoises in the Eastern Scheldt is relatively low compared to the North Sea population. The observed harbour porpoise density in the North Sea is around one (1,00) individual per km^2 compared to 0.14 per km^2 observed harbour porpoises in the Eastern Scheldt (annual count 2018) (S. C. Geelhoed, Janinhoff, Lagerveld, & Verdaat, 2018). This different might partially be due to the different counting methods used in the different locations. The Porpoises in the North sea where counted from a plane in comparison to counting from boats in the Eastern Scheldt. The limited amount of harbour porpoises in the Eastern Scheldt might be partially due to the low fish biomass in the Eastern Scheldt (van Dam, Solé, IJsseldijk, Begeman, & Leopold, 2017). Another factor limiting the population size within the Eastern Scheldt is the predation of harbour porpoises by grey seals (*Halichoerus grypus)* when comparing this area to the North Sea, where harbour porpoise predation by grey seals also takes place. It is harder for porpoises to avoid grey seal encounters due to the smaller area of existence (Podt, Stichting Rugvin) & IJsseldijk 2017).

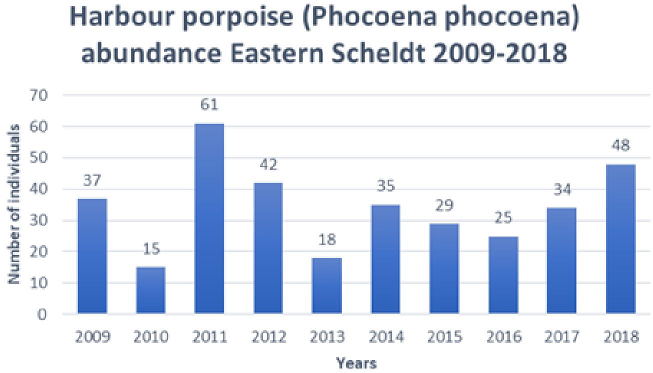

Figure 3. Harbour porpoise abundance Eastern Scheldt during annual count (Stichting Rugvin, 2020)

Theoretically harbour porpoises can swim in and out of the Eastern Scheldt as the barrier is open almost all year round. However, research has suggested that this storm surge barrier might function as an ecological trap (Jansen, 2013, Stichting Rugvin, 2014). Since the storm surge barrier obstructs the water passing through from the North Sea and the other way round. Squeezing the water between the pillars causes high flow rates of water. The water rubbing up against those pillars creates high-frequency underwater sounds. High frequently sound make it a significant obstruction to pass through the barrier for harbour porpoises, as harbour porpoises are very sensitive to high-frequency underwater sound and rely on sound for finding their way and preying on their prey (bottom-dwelling fishes and pelagic fishes) (Korpelshoek, 2011; Camphuysen & Siemensma, 2011). However, this does not mean that no porpoises will pass this barrier (Korpelshoek, 2011, Stichting Rugvin, 2014).

If these animals are indeed largely trapped, a sub-population could start to exist within the Eastern Scheldt, which means that the results of this research could give an insight into the differences between the North Sea population and the Eastern Scheldt population. This is, however, not the focus of this research.

2.3 | Data collection and preparation.

The collected data for this research has been implemented using the software ArcGIS 10.7.1 and Maxent 3.4.4. Within this research, ArcGIS is used to prepare the collected data, the data analysis is done using Maxent. ArcGIS is a geospatial processing program enabling users to analyse geographic data. Maxent is a software program that models species distribution and potential realised niches. Maxent does this with a maximum entropy modelling technique based on a number of different environmental factors, allowing users to make species distribution models. Maximum entropy modelling means predicting the probability of the distribution based on occurrence points and environmental factors (A. Smith, Page, Duffy, & Slotow, 2012). During this study, Maxent is used to give an estimate of how strong each of the different environmental factors affects the distribution of harbour porpoises within the Eastern Scheldt. Several requirements need to be met for these environmental factors to be used in Maxent. First, all environmental factors need to be imported to Maxent as a raster dataset, with the same output extent, cell size, number of rows and columns and coordinate system. For this study, the output extent was set to the sediment shapefile, as this file had the exact defined research area that the research uses. The cell size was set to 0.0001 decimal degrees (11.1 meters), and the coordinate system was set to WGS_1984. The cell size was set to 0.0001 decimal degrees to make the raster as accurate as possible. The coordinate system WGS_1984 was used as this is the global standard. This meant that when needed, datasets with RD New or WGS_1984_Web_Mercator_Auxiliary_Sphere as the projected coordinates systems were transformed to the geographic coordinate system WGS_1984 using the analysis tool project or project raster. Most of the datasets provided by third parties were provided in XLS Excel sheets. Any sheets provided in other formats such as .CSV, for instance, were transformed into XLS files. This applied to all the data types except shapefiles (ArcGIS). This is to standardise the data and make all the files suitable for use in ArcGIS. After all the datasets were transformed to raster data and met all of the requirements for Maxent, they could all be transformed into an ASCII file. ASCII (.ASC) files are a type of file that is needed for the raster data to be used within Maxent. So, the datasets were transformed with the ArcGIS tool "Raster to ASCII", and all were stored in the same folder.

2.3.1 | Occurrence data

The occurrence data of harbour porpoises within the Eastern Scheldt has been derived using 36 field surveys performed by Stichting Rugvin from 2019 to 2021. During these surveys, 148 interactions occurred. These field surveys were performed by multiple researchers and took part when weather conditions allowed it (no winds over Beaufort 5, no high waves, preferably no rain) between March and October. These surveys where not conducted via a linear transact but are partially based on the experience of the boat driver. During the surveys one researcher drives the boat while the other observes the animal and its behaviour while taking photos for later investigation and identifying the individual. During these field surveys, GPS locations, behaviour, number of individuals, and group composition were annotated (for a complete image of all the derived data, see Appendix I). This study used porpoise occurrence data from field surveys from March 2019 to October 2021. The data provided by Stichting Rugvin was provided in the form of analogue datasheets (Appendix I). The data needed to be digitalised in an Excel sheet for these datasheets to be useful in ArcGIS and Maxent. The datasheets were digitalised, and some of the missing GPS locations were added with the help of screenshots made of the GPS locations during the encounters. The GPS coordinates were then transformed from Degrees, Minutes Seconds to Decimal degrees to be compatible with ArcGIS. Because the harbour porpoise occurrence data is used in multiple maps, different data preparation methods have been used. For the data to be used in Maxent, the occurrence points of the different harbour porpoises were exported to an individual Excel file. In this Excel file, only the species name, latitude and longitude were present (Appendix III).

Finally, the data was imported in ArcGIS and using the coordinates plotted on the map. The data was visually checked to see if all data points were within the Eastern Scheldt, had a tidal status and had a foraging behaviour. The incomplete data, as well as the data that were not in the Eastern Scheldt were removed and excluded from the analysis.

2.3.2 | Tidal status

Different tidal statuses have influenced harbour porpoise densities in the Bay of Fundy in Canada. During rising and high tides, densities increased, most likely due to changes in prey distribution (Johnston et al., 2005). The Bay of Fundy has the biggest tidal differences in the world (3,5 meters to 17 meters) (NASA, 2006). This tidal difference is way more significant than the tidal difference in the Eastern Scheldt. Therefore, it is expected that these two different locations will have different effects on the harbour porpoises. To find out if this is indeed the case, the influences of different tidal statuses on harbour porpoises' distributional and foraging behaviour have been analysed within this study. The tidal range of the observed harbour porpoises within the Eastern Scheldt was annotated during the encounters of the field surveys performed by Stichting Rugvin. Stichting Rugvin annotated four different tidal statuses: High, Low, Rising and Falling tide. Tidal status data of field surveys from March 2019 to October 2021 were used for this study. This data was the same as used for the porpoise occurrence data and thus was provided as analogue datasheets. The harbour porpoise occurrence data plotted in ArcGIS was used to make the tidal status map. This data was visually checked if all the occurrence points had a correct GPS notation (outliers were removed) and tidal status. The tidal status data of this research was not used in Maxent. Because the four different tidal statuses need to be compared, it was impossible to use these maps in Maxent as this will only use one map per environmental factor.

2.3.3 | Sediment

Since harbour porpoises use echolocation for finding prey and finding their way in murky waters, the reflection of the soundwaves of the different types of sediment might affect the distribution of harbour porpoises (Miller & Wahlberg, 2013). Different sediment types reflect sound waves in different ways. Harder substrates will send stronger soundwaves back than the softer substrates (Taylor Smith & Li, 1966). Other studies have suggested that harbour porpoise distribution is influenced by sediment type (Embling et al., 2010; Brookes, Bailey, & Thompson, 2013). This factor has been used for this research to determine if sediment type also influences harbour porpoise distribution within the Eastern Scheldt. For this research, ecotopen kaart_Oosterschelde_WGS a sediment map from Rijkswaterstaat (n.d.) has been used. The sediment shapefile first had to be recategorized with the use of a field calculator and was split up into six different sediment types, namely (other (1), hard substrate (2), soft substrate (low dynamic) ((3), fine sand (High dynamic)(4), silt (low dynamic, higher clay concentration) (5), salt march(6)).

2.3.4 | Bathymetry

The occurrence of many species of cetaceans has shown a strong correlation with bathymetry/depth, with many species only occurring in areas with a specific depth (Cañadas, Sagarminaga, & García-Tiscar, 2002). As the Eastern Scheldt estuary is relatively shallow, with more profound valleys, it is vital to determine if harbour porpoises prefer specific depths. This is important to be able to predict the occurrence so that these areas can be better protected. Bathymetry could be crucial in understanding this pattern when determining which factors affect the distribution patterns. The bathymetry data of the Eastern Scheldt used in this study has been derived from Brand, N., Kothuis, B. L. M., & van Prooijen, B. C. (2016). Bathymetry data was provided in the form of a depth map (JPEG) and had to be georeferenced in ArcGIS to be able to use the data in Maxent. When georeferencing, the internal coordinate system of the digital map will be linked to the image (in this case, WGS_1984). This image has been placed on top of the base map, and with the use of multiple points, the map is referenced on the coordinate system that the base map exhibits (figure 4). This way, the georeferenced image can provide data about the research area (USGS, 2018). After the map was georeferenced, the layer was masked using the "extract by mask" tool. The feature mask data was set to the sediment layer. Which means that the image was extracted to the exact extent of the sediment layer.

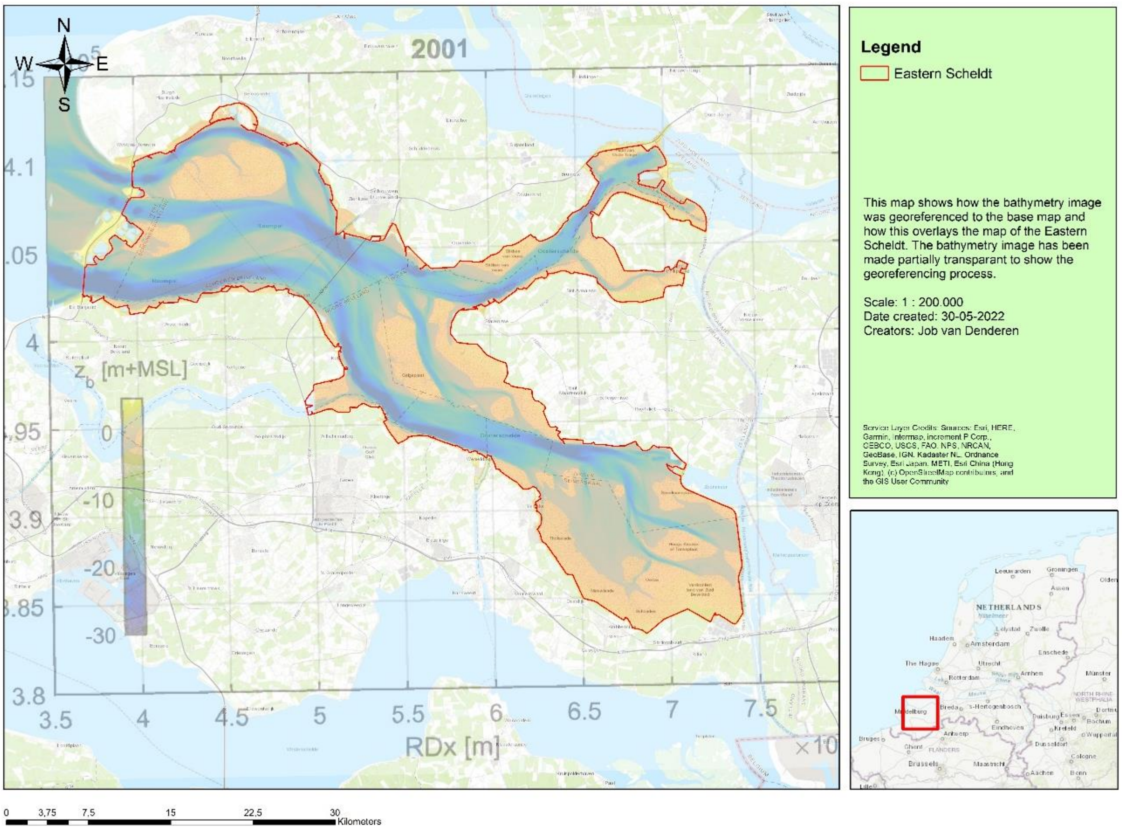

Figure 4. Bathymetry georeferencing map

2.3.5 | Chlorophyll-a

Correlations between the chlorophyll-a level and cetacean abundance have been found on multiple occasions and locations around the globe. More cetaceans are observed in areas with high chlorophyll-a levels (Smith, R.C., Dustan, P., Au, D. et al., 1986). The levels of chlorophyll within the Eastern Scheldt have been requested to and provided by Rijkswaterstaat. This chlorophyll-a level was measured at the surface in three outer corners of the Eastern Scheldt (figure 5) and was provided in an Excel sheet. This datasheet contain chlorophyll -a levels that have been measured every ten minutes between March 2019 till October 2021. The average of these measurements for each of the locations has been imported to an excel sheet and was linked to the different coordinates of the measuring locations. This data was imported to ArcGIS using the given coordinates in the Excel file, after which it was converted to raster format to be able to use in Maxent using the analysis tool Spline. Spline uses an interpolation method that estimates values to minimise overall surface curvature with the help of a mathematical function. This results in a smooth surface that passes through the input locations (ESRI, 2022).

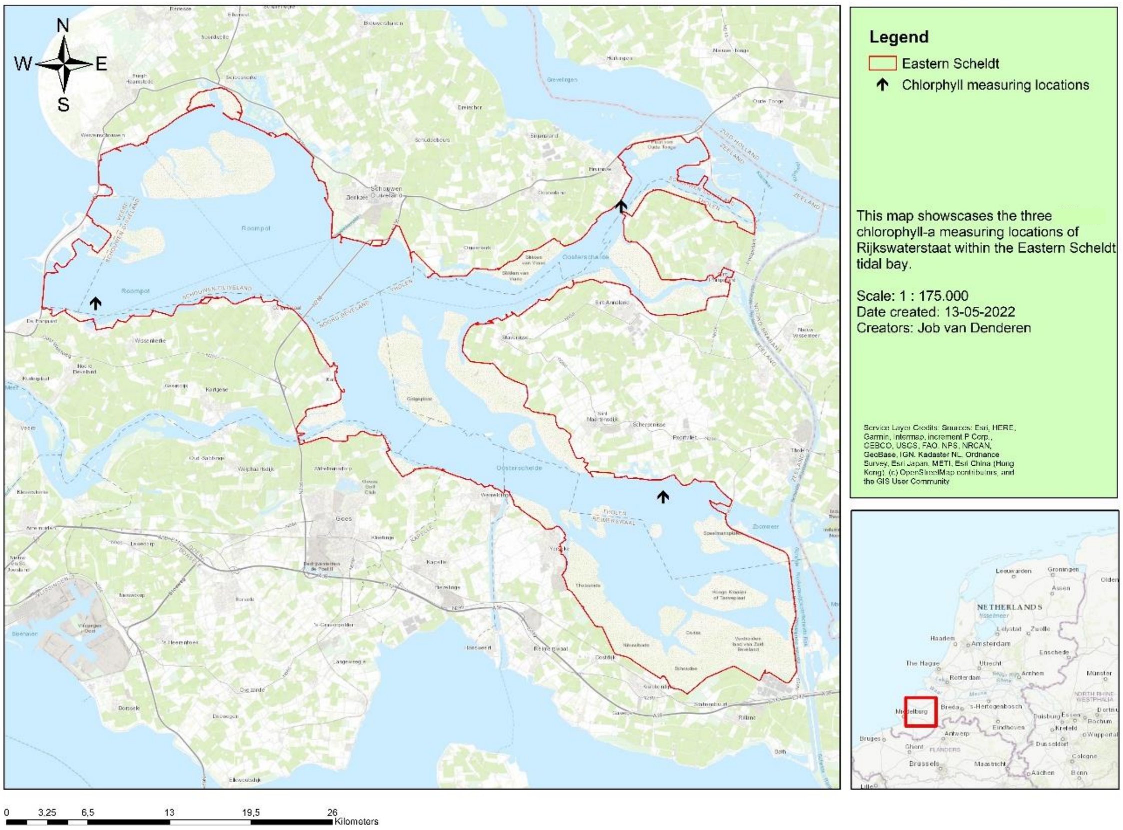

Figure 5. Chlorophyll-a measuring locations Eastern Scheldt

2.3.6 | Fish data

Cetacean occurrence is often correlated to prey occurrence. With the primary prey species of harbour porpoises within the Eastern Scheldt being the sand goby *(Pomatoschistus minutus),* whiting (*Merlangius merlangus*) and small sand eel (*Ammodytes tobianus)* data was used to get a clear view of the occurrence of these species within the Eastern Scheldt (Mairo, A., & Leopold, M., 2018). Data about the occurrence of these three species were obtained via NDFF (Nationale Databank Flora en Fauna). NDFF provided data in the form of Excel documents and Shapefiles (ArcGIS) collected with the help of divers of Stichting Anemoon, Private divers and RAVON (Reptielen, Amfibieën en Vissen Onderzoek Nederland). The shapefiles were imported into ArcGIS as the Shapefiles had a large inaccurate projection of the different sightings; therefore, the shapefile had to be remade. In the datasets of these shapefiles, the centre coordinates of each sighting were given. These centres were projected using add XY, which gave the data an accurate location. After that, the shapefiles were transformed into vector data. The data was transformed to raster data using "inverse distance weighted (IDW)". IDW is a tool that uses the multiple locations where observations have been made to create a raster format. The further away from any observation of that species, the lower the value on the map. The IDW tool has been chosen rather than the spline tool because fish abundance data will not occur almost the same throughout the Eastern Scheldt. For factors like Chlorophyll-a, which are present in the water column throughout the Eastern Scheldt spline is used as this will build a raster-based on the available data without decreasing when it goes further away from the measuring locations.

2.3.7 | Salinity

Salinity is a factor that often sections habitats for aquatic species, as changes in salinity can cause problems for many marine species (Solan & Whiteley, 2016). The Eastern Scheldt tidal bay has water input from multiple freshwater sources, changing salinity levels throughout the tidal bay. When trying to understand the distribution of the harbour porpoises, it will be helpful to see how significant the effect is that salinity has on the distribution of the harbour porpoises. Salinity data from the Eastern Scheldt has been requested to and provided by Rijkswaterstaat in an Excel sheet with salinity data. After the data was plotted on a map to check for any discrepancies, the salinity dataset was deemed not usable due to the three measuring locations of salinity all being in one corner of the Eastern Scheldt (figure 6), which would give biased data. Therefore, the factor salinity was not used to prevent biased data from affecting the rest of the research.

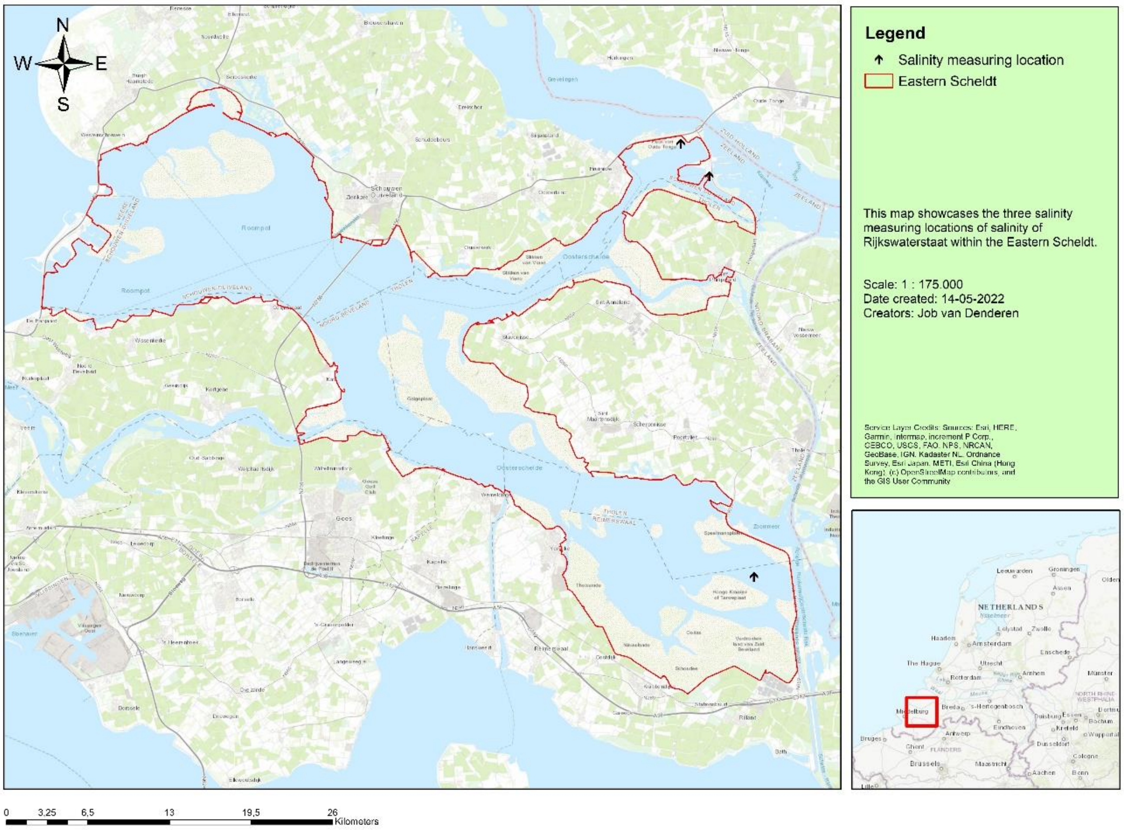

Figure 6. Salinity measuring locations Eastern Scheldt

2.4 | Data analyses

2.4.1 | Spatial relative densities

To model the spatial distribution of the harbour porpoises in the Eastern Scheldt. The Kernel Density tool has been used within ArcGIS. This tool calculates the density of vector features in an area around those features (ESRI, n.d.). The output extent of the map was set to match the research area, with an output cell size of 0.0001 decimal degrees (11.1 Meters) and a search radius of 0.03 decimal degrees (3,33KM). The search radius was defined using the trial and error method, as this gave the most accurate results. The output of the kernel density map was then reclassified with the tool "reclassify". The output was divided into six different groups: 0, 1-2, 2-5, 5-10, 10-25, 25-50. Each of these groups stands for the number of harbour porpoises that have been seen in a search radius of 0.03 decimal degrees during the field surveys of Stichting Rugvin. This was done to make the density of the porpoises clear.

2.4.2 | Ecological niche modelling

For modelling the potential ecological realised niches of the entire Eastern Scheldt, Maxent was used. Maxent models the ecological realised niche of the species and maps the habitat suitability score in the whole research area (Eastern Scheldt). With the habitat suitability score, areas that are favourable to the harbour porpoise can be pointed out.

Maxent uses samples combined with different environmental variables to predict a potential occurrence of a species. The environmental factors used for this Maxent model were bathymetry, chlorophyll a, sediment, sand goby, small sand eel and whiting. All the layers were set to continuous data except for sediment type, which was set to categorical due to multiple sediment categories. In the basic settings, the number of replicates was set to ten. This allows the model to run ten times and then average the run results to get a more stable output (Hameed, 2021). In the advanced settings, the maximum iterations were changed from 500 to 5000 to provide the model with adequate time for convergence. This was done to ensure that the model would not over or under predict the relationships between the environmental factors and the harbour porpoises (Phillips, Anderson, & Schapire, 2006). For all the Maxent settings, see Appendix V.

2.4.3 | Mapping

The effect that different tidal statuses have on the spatial distribution of harbour porpoises, as well as the relationship between the foraging behaviour and the spatial distribution of harbour porpoises within the Eastern Scheldt, was analysed with the use of ArcGIS. The foraging behaviour of harbour porpoises was one of three options: Surface, Deepwater, or Surface/Deepwater. The last category was used to point out locations where both foraging behaviours were apparent. All the sightings of each of the three categories were plotted on the different maps. This was done with the select by attribute tool and was then transformed to a raster using the Kernel density tool. This tool calculates the density of vector features in an area around those features (ESRI, n.d.). The output extent of the map was also set to match the research area and has an output cell size of 0.0001 decimal degrees and a search radius of 0.03 decimal degrees. This was done as this radius would give the most accurate distribution of the harbour porpoises during the different foraging (discovered via trial and error). These three maps were then added to a layout to be easily compared. For the tidal status maps, the same process was conducted for each of the four different tidal statuses. These maps are essential to compare the effects of the different tidal statuses on the spatial distribution. All tidal and foraging maps are transformed into so-called heat maps with the kernel density tool. These heat maps can easily show differences in patterns which would be hard to distinguish when using only point data.

3. | Results

This chapter presents the results of this study. It is divided into four paragraphs. First, the data used for this study are summarised in the data summary. Then, a density map of the harbour porpoises in the Eastern Scheldt can be found in the paragraph distribution and density. Then, in the paragraph affecting factors, the results of the effects of the different environmental factors concerning the distribution of harbour porpoises within the Eastern Scheldt are presented. At last, in the paragraph patterns in foraging behaviour, the results of the distribution of the different foraging behaviours are presented.

3.1 | Data summary

Data from 36 field surveys from 2019, 2020 and 2021 were used. During these 36 field surveys, 148 interactions have occurred, resulting in an average of 4.1 encounters per field survey. Maps of multiple different environmental factors and prey fish have been obtained. These environmental factors are sediment type, bathymetry, chlorophyll-a level, tidal statuses and the prey species whiting (*Merlangius merlangus*), small sand eel (*Ammodytes tobianus*), and sand goby (*Pomatoschistus minutus*).

3.2 | Distribution and Density

Using the harbour porpoise sightings data and the analysis tool kernel density, the map in figure 7 was produced. This map shows the distribution of harbour porpoises in the Eastern Scheldt and the number of porpoises that have been seen in the area. The red marks show that 25 to 50 harbour porpoises have been seen within a 3.33-kilometre radius. Showing us that the harbour porpoises primarily occur in two locations in the centre of the Eastern Scheldt. This is important to know as this will also influence how the potential realised niche is constructed. According to the Maxent model, environmental factors in locations where harbour porpoises are observed are preferable

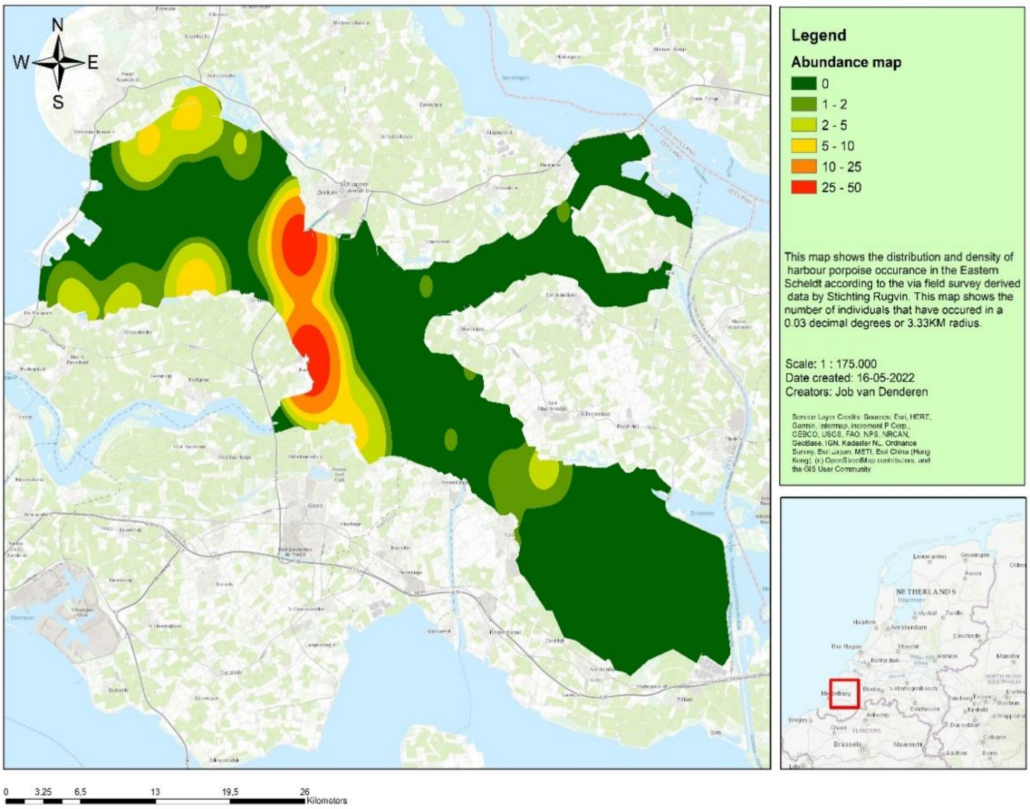

Figure 7. Distribution and density map of harbour porpoises within the Eastern Scheldt tidal bay

3.3 | Affecting factors

To determine the potential distribution, a total of 89 presence records out of 148 from the research dataset were used, and 10088 points were used to determine the Maxent distribution. Not all the presence records of the research were used as these records contained discrepancies or were projected outside of the research area. As a result, the Maxent model obtained an average AUC of ≥ 0.876 with a standard deviation of 0.055 over ten replicates (figure 8), indicating an excellent model fit over a random prediction of 0.5.

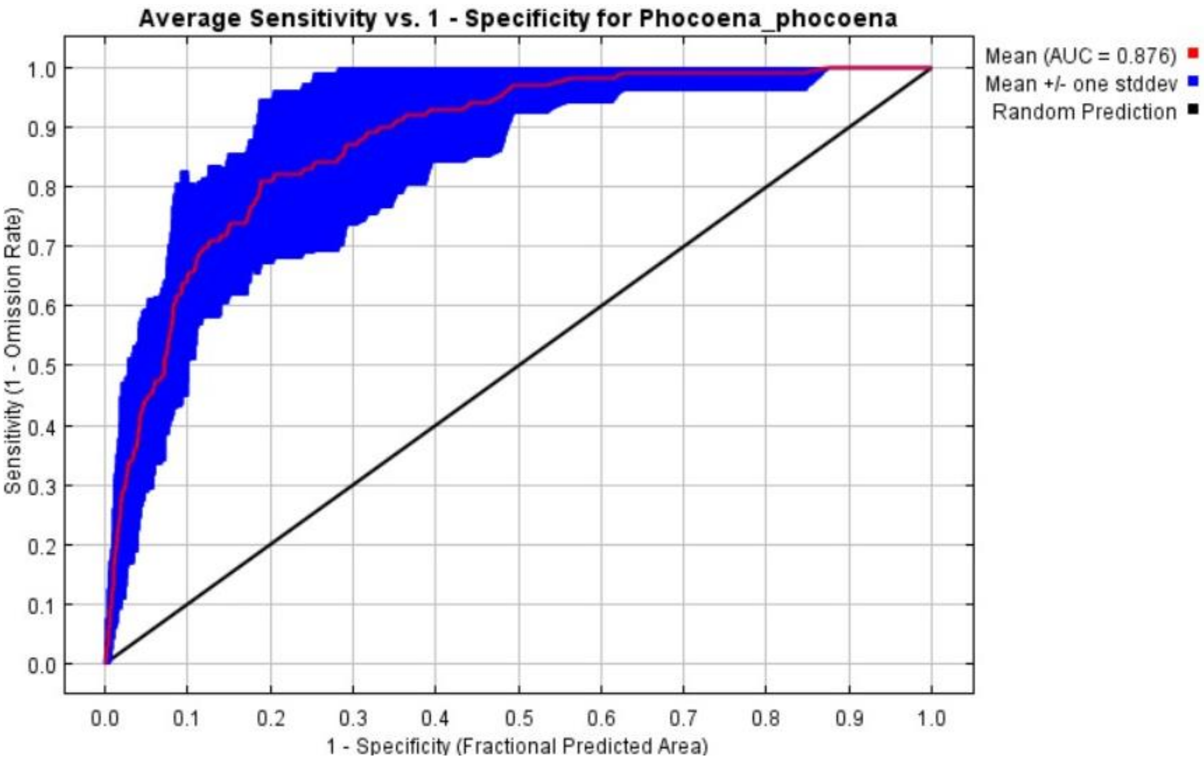

Figure 8. Maxent output ROC curve

A Jackknife of test gain was performed to determine how the different variables influence the distribution of the harbour porpoise. The Jackknife of test gain shows how much influence each environmental factor has on the distribution both separately and combined (figure 9).

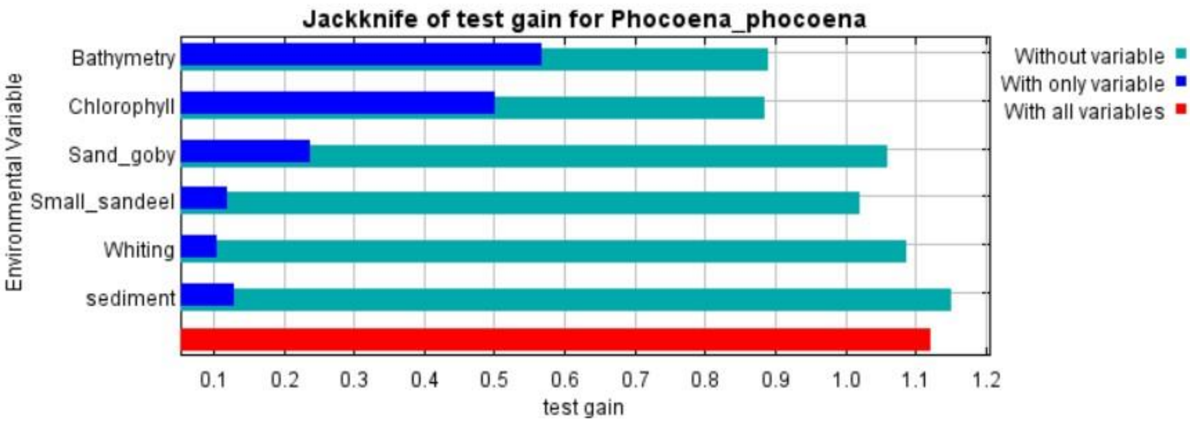

Figure 9. Jackknife of test gain for harbour porpoises with the environmental factors that were used within Maxent

A table of the presential importance of the variables used to model the ecological realised niche was provided with the Maxent output (figure 10). This table showed that bathymetry had an overall contribution of 42.1%, followed by chlorophyll a with a contribution of 32.5%, Small sand eel with a contribution of 9.7%, sand goby with a contribution of 6.9%, whiting with a contribution of 4.6% and sediment with a contribution of 4.2%. These factors combined created a map that shows the ecological realised niche of the harbour porpoise in the Eastern Scheldt.

Variable	Percent contribution	Permutation importance
Bathymetry	44.6	42.1
Sand_goby	20.1	6.9
Chlorophyll	18.5	32.5
Small_sandeel	10	9.7
Whiting	4.3	4.6
sediment	2.4	4.2

Figure 10. Presential importance of variables

When looking at the Jackknife of test gain, the sediment layer negatively affects the strength of the distribution model. When running Maxent without sediment as a factor, an AUC score of ≥ 0.881 is present (Appendix V), meaning this score is higher than the one with sediment included.

The Maxent model was also performed without the variable chlorophyll-a because this factor strongly contributed to the spatial distribution of harbour porpoises according to the Jackknife test. But when looking at the chlorophyll-a measuring map, only three locations were used. Therefore, it was checked if this factor did indeed have a significant contribution. The Maxent model without chlorophyll-a had an AUC ≥ 0.834 (Appendix V), meaning that its score is lower than with chlorophyll-a used in the model.

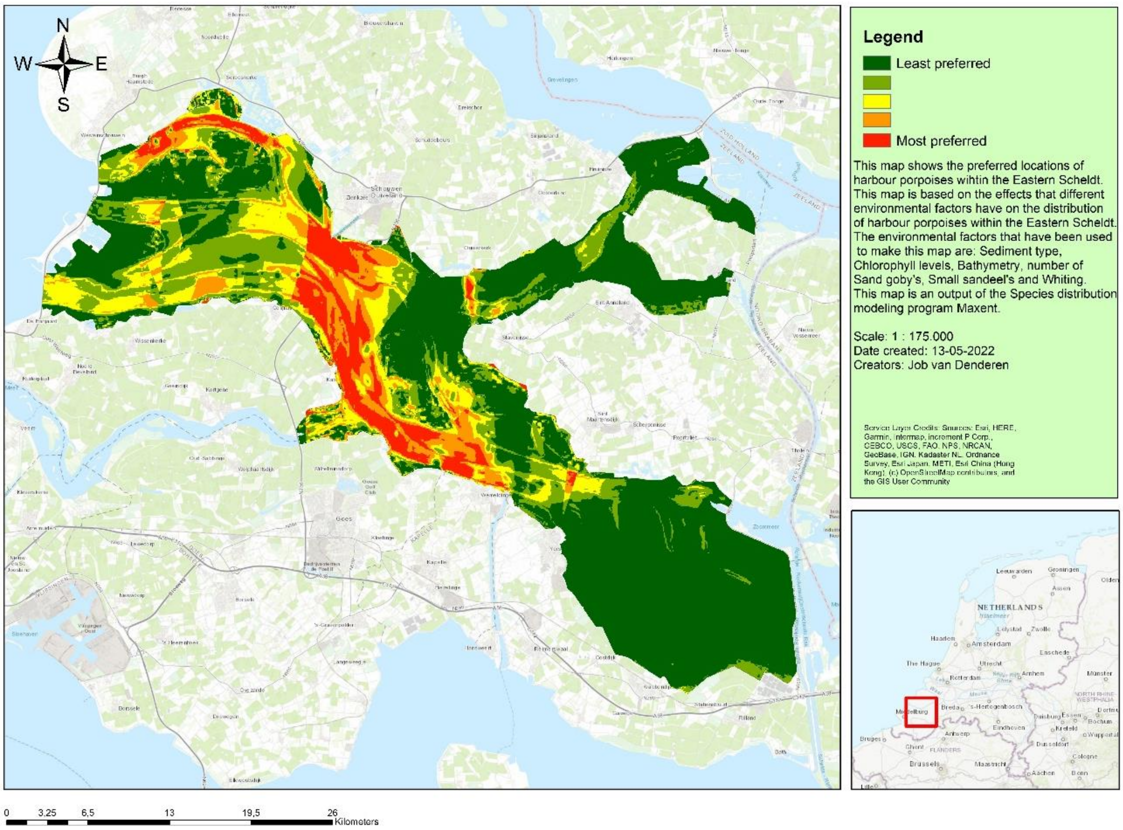

Figure 11. The ecological realised niche of harbour porpoises within the Eastern Scheldt

With the use of harbour porpoise sightings data, the in Maxent implemented environmental factors, and the modelling software Maxent, the map in figure 11 was produced. This map shows the potential ecological realised niche map of harbour porpoises in the Eastern Scheldt. This map makes predictions for suitable areas for harbour porpoises based on the environmental factors and prey species that occurred at the locations where harbour porpoises were observed. When comparing this map with the distribution map of harbour porpoises in the Eastern Scheldt, the data largely overlaps. This overlap is because the ecological realised niche map is based on the environmental conditions at those occurrence points.

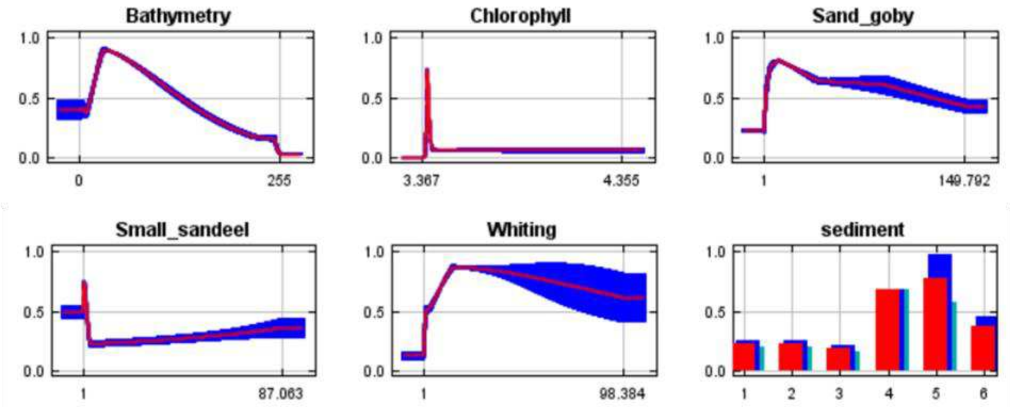

Figure 12. Response curves of the environmental factors used for the potential ecological niche model

The response curves of the different environmental factors used to calculate the potential ecological realised niche are shown in figure 12. These graphs show the most preferred amount or category of each of the environmental factors that figure 11 is based upon. When looking at the bathymetry score of the response curve, a high suitability level is present when bathymetry has a value below 100. These are areas where the depth of the Eastern Scheldt is deeper than 20 meters (NV Charts, 2021). A strong peak of habitat suitability is also presented around a chlorophyll-a level of 3.4 ug/l according to the response curves. Suitability levels increased with the first few sand goby's, whiting and small sand eels. As the number of fish increased, the habitat suitability for the harbour porpoise decreased. With an increase in the number of small sand eels, a rapid decrease in habitat suitability is present. Sand goby and whiting show a slight but relatively steady decrease in habitat suitability as the number of fish increases. The sediment response curve shows that sediment types four (soft) and five (silt) have the highest suitability score of all sediment types.

Since tidal status could not be implemented within Maxent, it is shown as a separate result. Using the kernel density tool, the spatial distribution and density of the harbour porpoises during the different tidal statuses are projected. Each of the different maps in figure 13 shows a different tidal status. When comparing the maps with each other, during all of the tidal statuses, the spatial distribution of harbour porpoises is more or less in the same locations. A significant difference in the number of observations during the tidal statuses can also be observed.

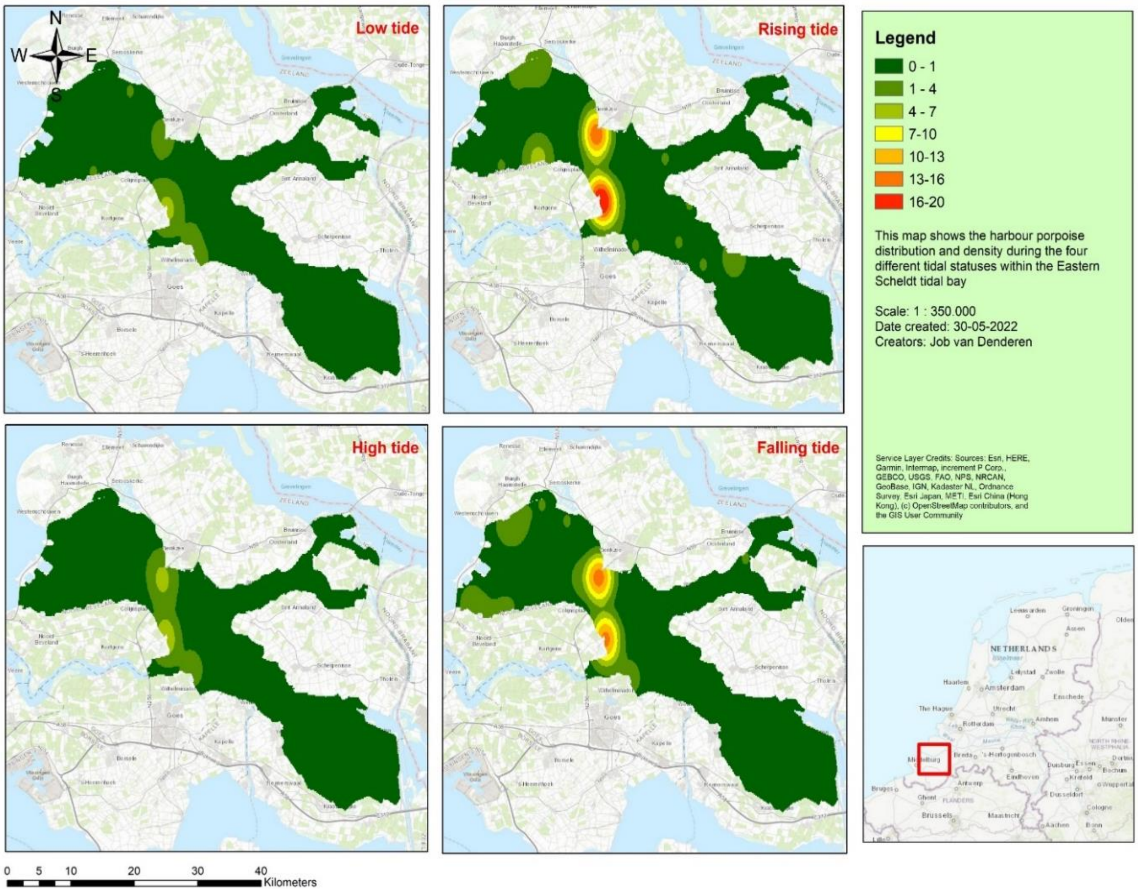

Figure 13. Harbour porpoise distribution during different tidal statuses

3.4 | Patterns in foraging behaviour

With the use of the foraging types and the kernel density tool the map in figure 14 has been produced. The maps shown in figure 14 show that surface foraging predominantly occurs in one location in the Eastern Scheldt. This location is close to the harbour of Kats. Deepwater foraging seems to occur mainly in two areas, which are close to the harbour of Zierikzee and the harbour of Kats. Unlike surface foraging, deep water foraging occurs throughout the Eastern Scheldt but is mainly centred in two locations. The locations where both surface and deep-water foraging occur tend to primarily be in front of the harbour of Zierikzee. It can also be seen that deep water foraging occurred a lot more during the observations made by Stichting Rugvin.

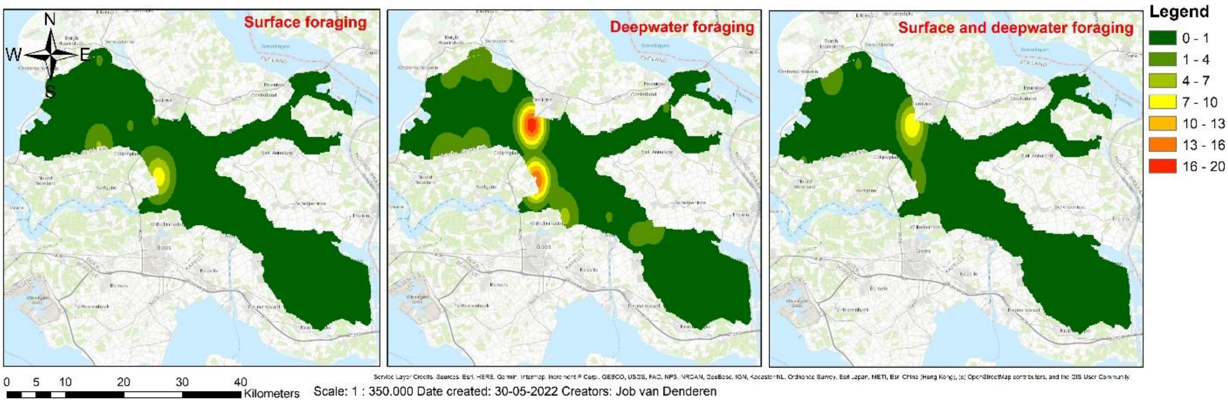

Figure 14. Spatial distribution of harbour porpoise foraging behaviour

4. | Discussion

The goal of this study was to identify which environmental factors potentially affect harbour porpoises' foraging behaviour and spatial distribution within the Eastern Scheldt. The environmental factors that were used to identify the potential influencing factors were tidal status, sediment type, bathymetry, chlorophyll-a, sand goby, whiting and small sand eel.

It is important to consider that Stichting Rugvin operates from the harbour of Kats. Meaning that during every survey, the vessels pass the area in front of Kats twice, which makes the chance of observing individuals twice as big. On a regular basis during the surveys, a visit is made to the buoy of “studio bruinvis” (this buoy records underwater sounds of harbour porpoises and allows visitors to listen to the sounds of the porpoises) located in front of the harbour of Zierikzee. Meaning that there is a bias for these two locations as sightings will occur more often.

To draw more precise and definite conclusions, more data is needed. Data from only three years during 36 trips have been used because the data of the trips before 2019 from Stichting Rugvin was lost due to a hardware failure. Since Stichting Rugvin is a relatively small foundation, it does not always have all the gear to register coordinates properly. Stichting Rugvin has been using screenshots of google maps when no dedicated GPS device was present to solve this problem (Frank Zanderink personal communication). When transforming these coordinate notations from DD:HH:MM to Decimal degrees for implementation, the data locations slightly move. This slight movement also happened when the data was changed to a different coordinate system. This movement occurs since the data of Stichting Rugvin is collected on the coordinate system RD New. This is a coordinate system that gives the most precise locations within the Netherlands. RD New is a cartesian coordinate system which means that it is based on a flat surface, in contrast to WGS_1984, which is a geographic coordinate system which is based on a sphere. This causes shifts in data and will, in turn, cause data to be expressed in different locations (TU Delft, 2020). When data is plotted in different locations it is also plotted on land sometimes when a sighting is close to the shore. Data plotted on land is invalid as changing the data to be plotted on the water again would bias the data. Therefore, the data points plotted on land have not been used for this study.

In previous studies, additional environmental variables have been used, such as temperature, nitrogen concentrations, currents, distance from shore and salinity (Giannoulaki et al., 2016; Correia et al., 2021). Almost all of these factors have been found to play a role in the distribution of harbour porpoises in Scottish waters (Embling et al., 2010). In this research, temperature was not taken into account since the average temperature in the Eastern Scheldt does not differ more than two degrees between the different locations (Rijkswaterstaat, 2022). The nitrogen levels have not been used either, as nitrogen and chlorophyll-a levels have a very high correlation due to nitrogen being the second most crucial nutrient for chlorophyll-a in coastal waters (after phosphorus) (Canfield, Linda, & Hodgson, 1985). Data on currents have not been used in this research as no dataset about currents in the Eastern Scheldt was available or could be provided by the contacted institutions. Images of currents within the Eastern Scheldt had a resolution that was too low to be used to georeference to the Eastern Scheldt. Comparing the distribution of harbour porpoises within the Eastern Scheldt and the current map of the Eastern and Western Scheldt figure 15, it can be seen that the areas where harbour porpoises are present are the areas with stronger currents. Current influences the bathymetry as it causes erosion and suppletion and therefore affects at least one of the environmental factors used in this study (bathymetry) (de Vet, van Prooijen, & Wang, 2017).

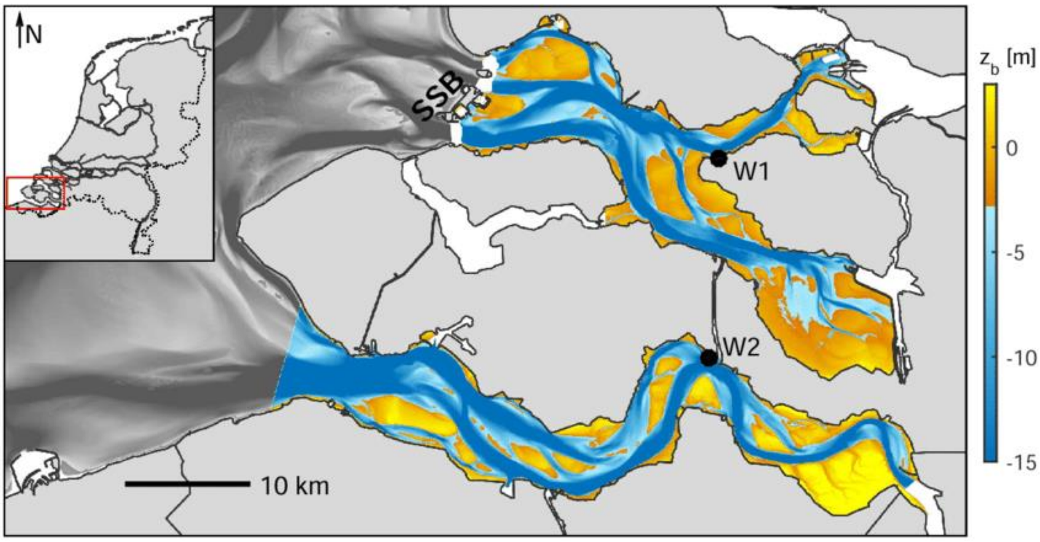

Figure 15. A current map of the Eastern and Western Scheldt (de Vet, van Prooijen, & Wang, 2017)

Multiple attempts have been made to make a distance to shore map using the "Euclidean Distance" tool in ArcGIS. However, this map could not be produced to the same cell size and output extent as the other files due to hardware limitations. At last, the factor salinity was not used as mentioned due to the measuring locations all being in the same corner of the Eastern Scheldt. When looking at the salinity data provided by Rijkswaterstaat, it becomes apparent that the salinity within the Eastern Scheldt does not differ much as the levels in the three locations are all between 28 and 30 ppt. Another factor that could influence harbour porpoise behaviour is the high frequencies of underwater sound created by boats or water rubbing up against the pillars of the storm surge barrier. Since this factor is unpredictable (as many boats pass all the time), it is hard to draw a map based on the abundance of underwater sound. Therefore, this factor has not been used in this study. However, this factor could be important for upcoming studies as underwater noise increases every year. This means that this noise's possible effects could also start to become worse and worse (Marley, Salgado Kent, Erbe, & Parnum, 2017). But because this study did not include this factor due to the lack of information about underwater noise within the Eastern Scheldt, no conclusions can be drawn about this factor regarding the effect on the spatial distribution of harbour porpoises within the Eastern Scheldt.

The bathymetry map used for this research is a map from 2001. During the years, the bathymetry of the Eastern Scheldt has slightly changed due to erosion and sand suppletion. This makes the shallower areas of the Eastern Scheldt less accurate. However, the changes have been limited and focus primarily on keeping the tidal flats from eroding away (Rijkswaterstaat, 2020). Meaning that the deeper areas of the Eastern Scheldt have stayed mostly the same, reducing the impact that this erosion and suppletion has on the study.

The cell size of the different environmental factors used of Maxent within this research was set to 0.0001 decimal degrees. This was done so that the raster data would be as accurate as possible. This meant that the shapefile of sediment had to be changed to a smaller cell size, which meant that a more detailed dataset was made from the courser sediment dataset. This made the raster dataset less accurate instead of more accurate as it was intentioned to be.

The results of this study suggest that harbour porpoise occurrence in the Eastern Scheldt is primarily determined by bathymetry and chlorophyll-a level. Looking at the occurrence map (figure 7), it is immediately visible that there are two "hotspots". Those hotspots are in front of the harbour of Zierikzee and the harbour of Kats. These areas are two areas with a depth of 25 - 52 meters in front of

Zierikzee and 25 - 39 meters in front of the harbour of Kats and are, therefore, relatively deep areas in the Eastern Scheldt (NV Charts, 2021). When looking at the contribution table in figure 10, It can be seen that bathymetry contributes 42,5% to the ecological niche model. It correlates a lot with the number of harbour porpoises and, therefore, most probably influences the spatial distribution of harbour porpoises within the Eastern Scheldt. When looking back at the predictive modelling research conducted in the Scottish waters, it can be seen that steep bottom topography and depth were also found to influence harbour porpoise distribution, which are both part of bathymetry (Embling et al., 2010). When comparing this data with other studies, it can be seen that multiple studies have found a positive correlation between harbour porpoise occurrence at a depth of 50 to 150 meters (Goodwin & Speedie, 2008; Marubini, Gimona, Evans, Wright, & Pierce, 2009). Since the Eastern Scheldt only has a maximum depth of 52 meters, this correlation is not possible in the Eastern Scheldt. Still, when looking at the results, it can be concluded that harbour porpoises prefer the deeper areas in the Eastern Scheldt (NV Charts, 2021).

According to the contribution table (figure 10), chlorophyll contributed 32.5% to the ecological niche model. Upon further inspection of the results and looking at the chlorophyll-a levels of the chlorophyll-a map in Appendix IV, it can be concluded that this 32.5% contribution did not change the ecological niche model as much as was suggested by the Jackknife of test gain. When running the Maxent model without chlorophyll-a, a slight decrease in the AUC score is present from .876 to .834, indicating that the model is less suitable. However, the decreasing size shows that the map's suitability is not influenced as much as the Jackknife test suggested. The map strongly indicates the small change because the difference between the two extreme values is only 1ug/l.

In comparison, in the North Sea, the chlorophyll-a levels from close to shore to the open sea vary from <5 to 40ug/l (European Environment Agency, 2019), showing how little the difference is within the Eastern Scheldt is. Cetaceans are often correlated with increased numbers of chlorophyll-a and nitrogen. This is because these food sources attract microfauna, which attracts higher trophic levels. Chlorophyll-a attracts cetaceans, but cetaceans also produce a lot of nitrogen suitable for chlorophyll-a production (Smith, Dustan, Au, Baker, & Dunlap, 1986). When looking at the substantial spike of the suitable chlorophyll-a level in the Eastern Scheldt, the "preferred" chlorophyll-a level is very slim according to the Maxent model. This gap is this small because the chlorophyll-a level of this map is based on the year's average and is based on only three points within the Eastern Scheldt.

To conclude distribution based on chlorophyll-a levels, more measurements would be needed, or different data should be derived using remote sensing. With remote sensing, accurate chlorophyll-a level data can be taken of the whole Eastern Scheldt at any given time. The disadvantage of this method is that this type of data collection has very large grid cells meaning less data. Making the data less reliable in smaller research areas like the Eastern Scheldt (Eremeev, Jukov, Piontkovski, & Sizov, 2011). Another disadvantage is that this type of data collection is relatively expensive (Lechner, Foody, & Boyd, 2020).

Sediment had a meagre 4.2% contribution to the ecological niche model. According to the Jackknife of test gain, the model would have been stronger without sediment (AUC ≥0.881). Nevertheless, the response table of sediment points out that soft sediment and silt sediment are often in areas with a high suitability score. This is probably because almost all the harbour porpoise observations were made in these areas. Other studies have suggested that sediment is a valuable factor for predicting the occurrence of harbour porpoises (Embling et al., 2010; Brookes, Bailey, & Thompson, 2013). But none of the studies gives precise results on which sediment type is preferred. Looking at the response table, it can be concluded that the sediment types soft sediment and silt sediment are preferred sediment types by the harbour porpoises in the Eastern Scheldt. Because an extensive area of the

Eastern Scheldt consists of these sediment types, it is not a good predictor for harbour porpoise occurrence in the Eastern Scheldt.

Considering the contribution of prey species to the ecological niche model, the prey species have a combined contribution of 21.2%, divided over 9.7% for the small sand eel, 6.9% for the sand goby and 4.6% for the whiting. But when looking at the Jackknife test gain results, it can be seen that these factors had a very low test gain. Meaning that the contribution of 21.2% of the different species is most likely not significant. The response curves showed that the higher the number of fish, the lower the suitability for harbour porpoises. Other research has suggested that small sand eels tend to avoid areas where a percentage of more than 10% silt/clay is present, as harbour porpoises tend to be in areas where soft sediment and silt sediment is present (Bailey & Thompson, 2009). This could point to a reason for the small sand eels not being present in these areas. Cetaceans (and many other species) are often found close to their prey.

For this reason, it would make sense for the prey species to predict the occurrence of harbour porpoises better than is currently happening. As mentioned in the introduction, the research that examined the prey species used stranded porpoises. The fact that the investigated porpoises were all stranded might give biased results, as healthy harbour porpoises will not strand without reason (IJsseldijk, & ten Doeschate, 2019). This could mean that healthy harbour porpoises consume other species of fish compared to the individuals that have been stranded, which means that the prey species used for the research should be supplemented with the other species that are preyed on by harbour porpoises. Which could affect the influence that prey species have on the distribution of harbour porpoises within the Eastern Scheldt. Other studies have found multiple other species preyed upon by harbour porpoises within the Eastern Scheldt. These species are bib (*Trisopterus luscus*), Black gobies (*Gobius niger)* and Sand smelt (*Atherina presbyter*) (van Dam, Solé, IJsseldijk, Begeman, & Leopold, 2017). To be able to draw any conclusions regarding the influence of prey species on the harbour porpoises' spatial and foraging behaviour, these species need to be considered.

The maps of the distribution of harbour porpoises during the different tidal statuses in the Eastern Scheldt all show a relatively similar pattern (figure 13). During all the tidal statues, most of the harbour porpoise sightings are in the centre of the Eastern Scheldt, shown on the map as the area where the number of porpoises is high, indicating a preference for this area. The harbour porpoises' spatial distribution did not noticeably change during the different tidal statuses. On the other hand, the harbour porpoise density changed during the different tides. During low and high tides, the number of observed harbour porpoises was a lot lower than with rising and falling tides. This could be due to the times the surveys were conducted, as the harbour porpoises cannot all just disappear. This could also be due to the periods of high and low tide being relatively short (Approx. 30 min) in comparison to the rising and falling tide (Approx. 6 Hours). When comparing this tide with the tidal change in the Bay of Fundy Canada, it can be concluded that a tidal influence does not change harbour porpoise behaviour as much or even at all within the Eastern Scheldt. But because the tidal difference is totally different in the two locations, this result is to be expected. Meaning that even though different tidal statuses did influence harbour porpoise distribution in the bay of Fundy, this does not count for the Eastern Scheldt.

The foraging distribution of harbour porpoises presented in figure 14 shows an interesting difference between the three different maps. Based on the sightings used for this research, surface foraging seems to occur only in specific areas of the Eastern Scheldt but is focused on the area in front of the harbour of Kats. On the other hand, the deep water foraging map shows that harbour porpoises perform deep water dives in almost the whole extent of the Eastern Scheldt. When comparing the bathymetry map of the Eastern Scheldt (Appendix IV) with the deep water foraging occurrences (figure 14), it can be seen that they mainly occur in relatively deep areas (20-52meters) (NV Charts, 2021).

Because deep water foraging in this research is defined as foraging where the porpoises angle their body downwards to forage, this foraging method could happen in waters of only 5 meters deep. This means that even though this type of foraging could happen in most of the Eastern Scheldt, it primarily happens in water with a much greater depth than the minimum depth for this foraging method. When comparing the surface and deep-water foraging map with the other two maps, this pattern is almost the opposite of the surface foraging map as the locations where the foraging occurs are primarily in front of the harbour of Zierikzee. Showing that the water in front of Zierikzee and Kats attracts a lot of harbour porpoises and are a preferred location for foraging harbour porpoises. Comparing the maps of figure 14 with the maps of the different environmental factors (Appendix III), it can be noticed that only bathymetry correlates with the locations where foraging occurred but that the different foraging types were not correlated to the depth of the area.

When comparing the occurrence map of the prey species (Appendix III) and the different foraging types, it can be concluded that the amount of fish does not correlate with the type of foraging or even the locations where the harbour porpoises forage. Part of the reason for this is that the number of fish has been counted over many years and has not been recorded at the moment of the encounter. In addition, the areas where most of the deep-water foraging occurs are located right in front of the harbours of Zierikzee and Kats, therefore, many divers are not allowed to dive within these areas and thus, there is little knowledge about fish occurrence in these areas. A more accurate map could be created with the help of looking at the locations where most commercial fishery takes place regarding the prey species of the harbour porpoise within the Eastern Scheldt. This could give a more up to date image of how the prey species are distributed within the Eastern Scheldt.

5. | Conclusion

Considering all the factors and results, it can be concluded that harbour porpoises primarily occur in the deeper areas of the Eastern part of the Eastern Scheldt. This distribution is affected by multiple factors. The factor that has the largest effect on the distribution and foraging behaviour of harbour porpoises is bathymetry. Not only does bathymetry have the biggest contribution to the ecological niche model, but also all the foraging locations are in deeper water (>20m) with a high gradient and thus affected by bathymetry. Sediment type also influences the spatial distribution of harbour porpoises. Even though it is not suitable for prediction models within the Eastern Scheldt, it does affect the distribution of the harbour porpoises. The tidal status did not influence harbour porpoises' spatial distribution as a similar pattern occurred during all different tidal statuses. The way chlorophyll-a levels were used in this research does not show any clear response of harbour porpoise occurrence. Only three locations were measured and was, therefore, not one of the factors that influences harbour porpoise behaviour within the Eastern Scheldt. With the use of the locations where prey fish species of the harbour porpoise were found, it can be concluded that there is no correlation between the described occurrence of these species and the harbour porpoises in the Eastern Scheldt. To draw more definitive conclusions about the relation between fish occurrence and harbour porpoise behaviour, fish stocks should be measured at the locations where the occurrence of harbour porpoise is high. When looking at the relationship between the spatial distribution and foraging behaviours of harbour porpoises within the Eastern Scheldt, it can be concluded that none of the environmental factors used in the study influences the type of foraging behaviour that occurs. The location where foraging takes place, however, is correlated to the factor bathymetry.

6. | Acknowledgements

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Glossary

Storm surge barrier	A barrier that stops high water from flooding the mainland via rivers or estuaries
Environmental	Related to the environment
Anthropogenic	Human influence on nature
Morphological	Structure
Geomorphological	The form or features of the earth
Deepwater foraging	The porpoise's tail is angled downwards, sending the animal down, longer duration between surfacing 3 to 4 breaths before the animal swims downwards again.
Surface foraging	The porpoise is hunting close to the surface, fish are jumping around, and the harbour porpoise often surfaces.
Maxent	Maxent is a software program that models species distribution and potential realised niches. Maxent does this with a maximum entropy modelling technique based on a number of different environmental factors, allowing users to make species distribution models
ArcGIS	ArcGIS is a geospatial processing program enabling users to analyse geographic data..

Appendix I: Materials and collected data

RUGVIN

Encounter Data Sheet 2021

Start encounter:

Survey number:		Encounter number:	
Date (dd/mm/yy):	_ _ - _ _ - _ _	Start time (hh:mm):	_ _ - _ _
Start GPS (N):	5 1 _ _ _ _ _ _	Start GPS (E):	0 _ _ _ _ _ _ _

During encounter:

Time and GPS location if number of individuals changes during encounter.

Time (hh:mm): _ _ : _ _ GPS: N 51 _ _ _ _ _ _ E 3 _ _ _ _ _ _ _

Time (hh:mm): _ _ : _ _ GPS: N 51 _ _ _ _ _ _ E 3 _ _ _ _ _ _ _

Time (hh:mm): _ _ : _ _ GPS: N 51 _ _ _ _ _ _ E 3 _ _ _ _ _ _ _

Time (hh:mm): _ _ : _ _ GPS: N 51 _ _ _ _ _ _ E 3 _ _ _ _ _ _ _

End encounter:

End time (hh:mm):	_ _ - _ _	Weather during encounter:	Fog
End GPS (N):	5 1 _ _ _ _ _ _	End GPS (E):	0 _ _ _ _ _ _ _
Beaufort during encounter:	0 1 2 3 4	Tide during encounter:	high falling low rising

Estimated number of individuals during encounter: Min: Max: Best:

Primary behaviour during encounter	Foraging	Travelling	Resting
Secondary behaviour during encounter	Foraging	Travelling	Resting
Type of foraging (multiple options possible)	Surface	Deep water	n/a
Behaviour towards boat (multiple options possible)	Curious	Neutral	Evasive
Group composition (multiple options possible)	Tight	Lose	n/a
Group together during entire encounter	Yes	No	n/a
Calf present	Yes		No
ID photos taken	Yes		No
Possible mating attempts seen (aerial behaviour)	Yes		No
Initiated the end of encounter	The team		The porpoise(s)

General remarks:

Identified porpoises: Name Number

1.

2. ....

Stichting rugvin

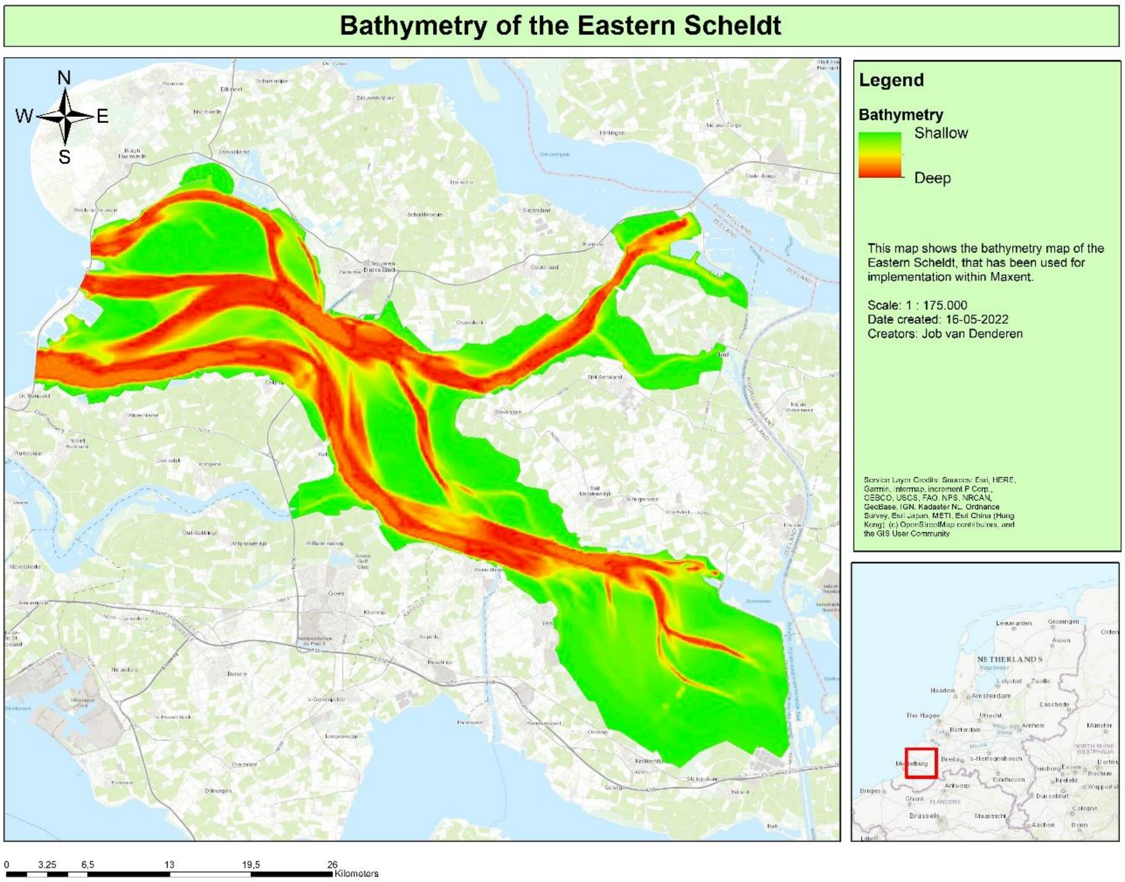
Materials

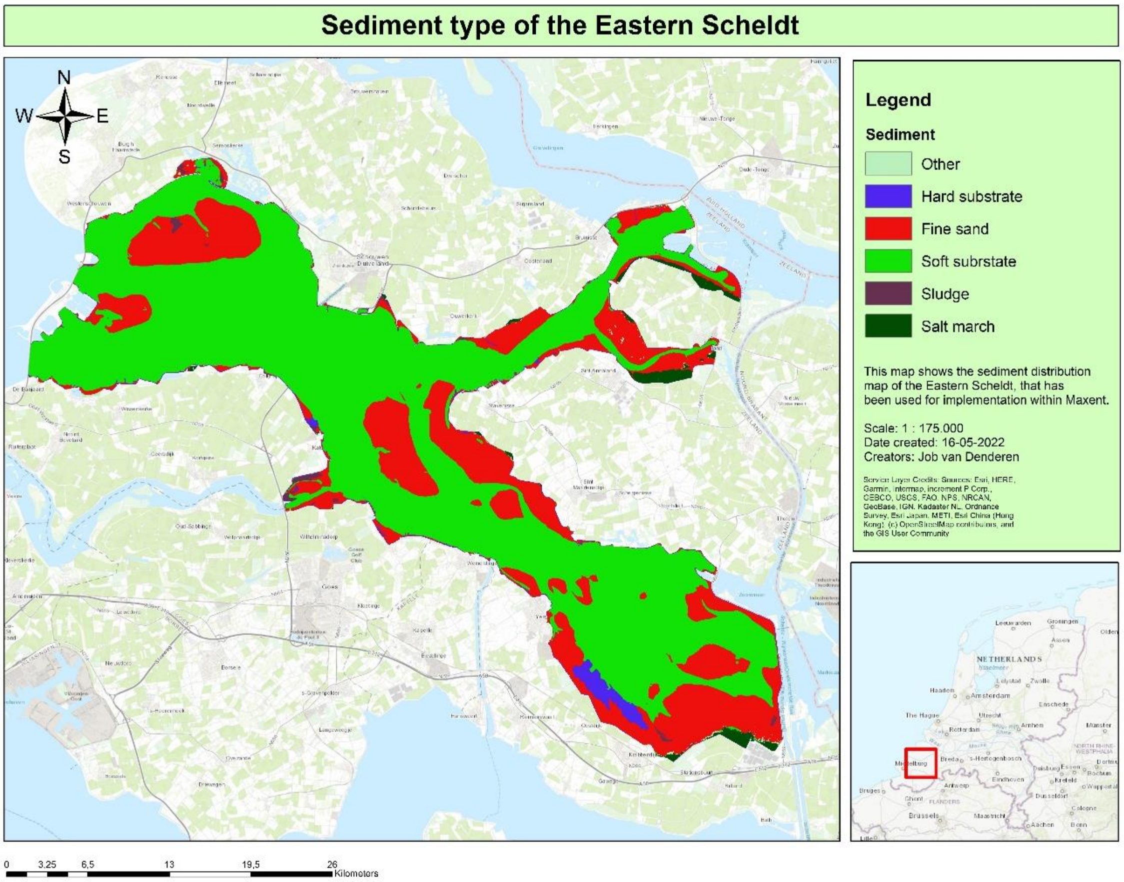
- RIB Boat (5,2 meters) with an outboard engine of 25HP
- Datasheets
- Pen
- Clipboard
- Computer
- Cartography program (ArcGIS)
- Species distribution modelling program (Maxent)
- GPS
- Microsoft Word
- Microsoft Access
- Database Stichting rugvin

Appendix II: Occurrence points

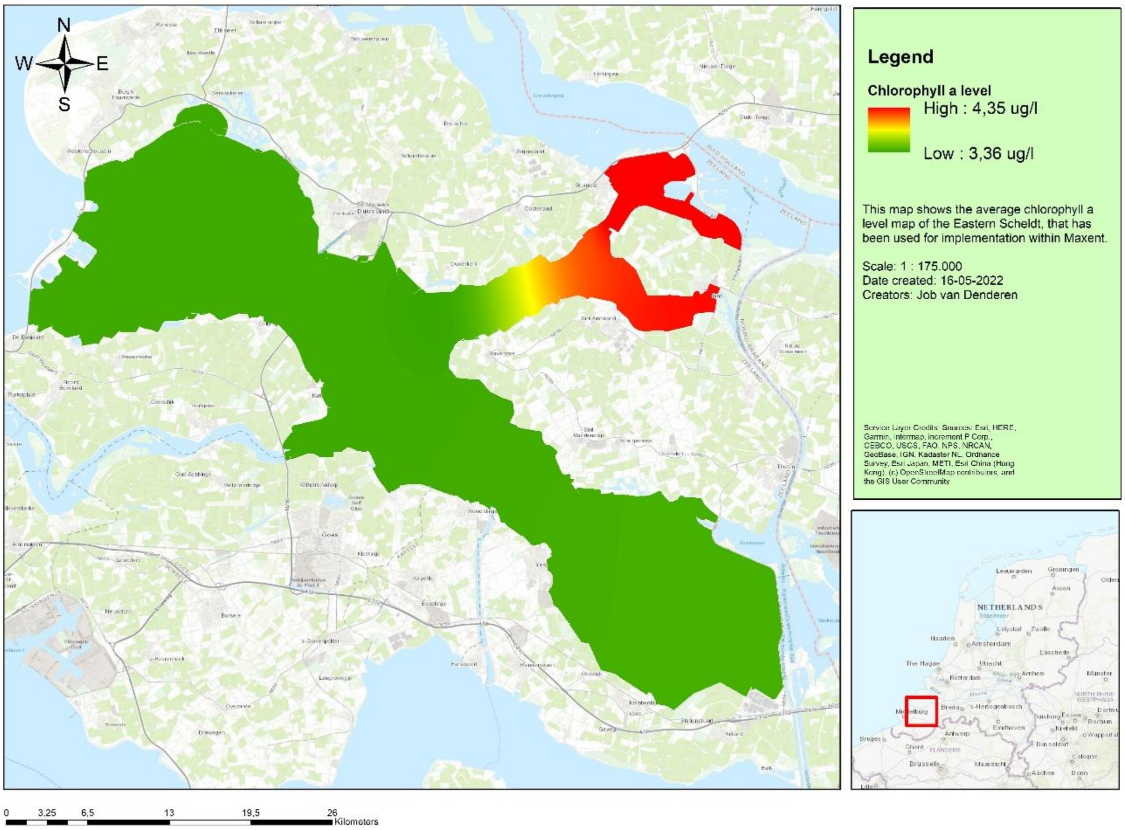
	A	B	C	D	E
1	Species	latitude	Longtitude		
2	Phocoena	51,5783	3,8947		
3	Phocoena	51,6318	3,888		
4	Phocoena	51,5777	3,8942		
5	Phocoena	51,5738	3,8945		
6	Phocoena	51,6296	3,8906		
7	Phocoena	51,6325	3,8881		
8	Phocoena	51,6296	3,8906		
9	Phocoena	51,584	3,8924		
10	Phocoena	51,6213	3,888		
11	Phocoena	51,6217	3,8765		
12	Phocoena	51,6235	3,8903		
13	Phocoena	51,5747	3,8929		
14	Phocoena	51,6305	3,8886		
15	Phocoena	51,6298	3,8899		
16	Phocoena	51,6203	3,8874		
17	Phocoena	51,5712	3,893		
18	Phocoena	51,6194	3,8878		
19	Phocoena	51,5671	3,9018		
20	Phocoena	51,5671	3,9013		
21	Phocoena	51,5706	3,9023		
22	Phocoena	51,571	3,9011		
23	Phocoena	51,6044	3,7885		
24	Phocoena	51,6194	3,8877		
25	Phocoena	51,575	3,8902		
26	Phocoena	51,559	3,9026		
27	Phocoena	51,5224	4,0624		
28	Phocoena	51,5241	4,0823		

Appendix III: Environmental rasters

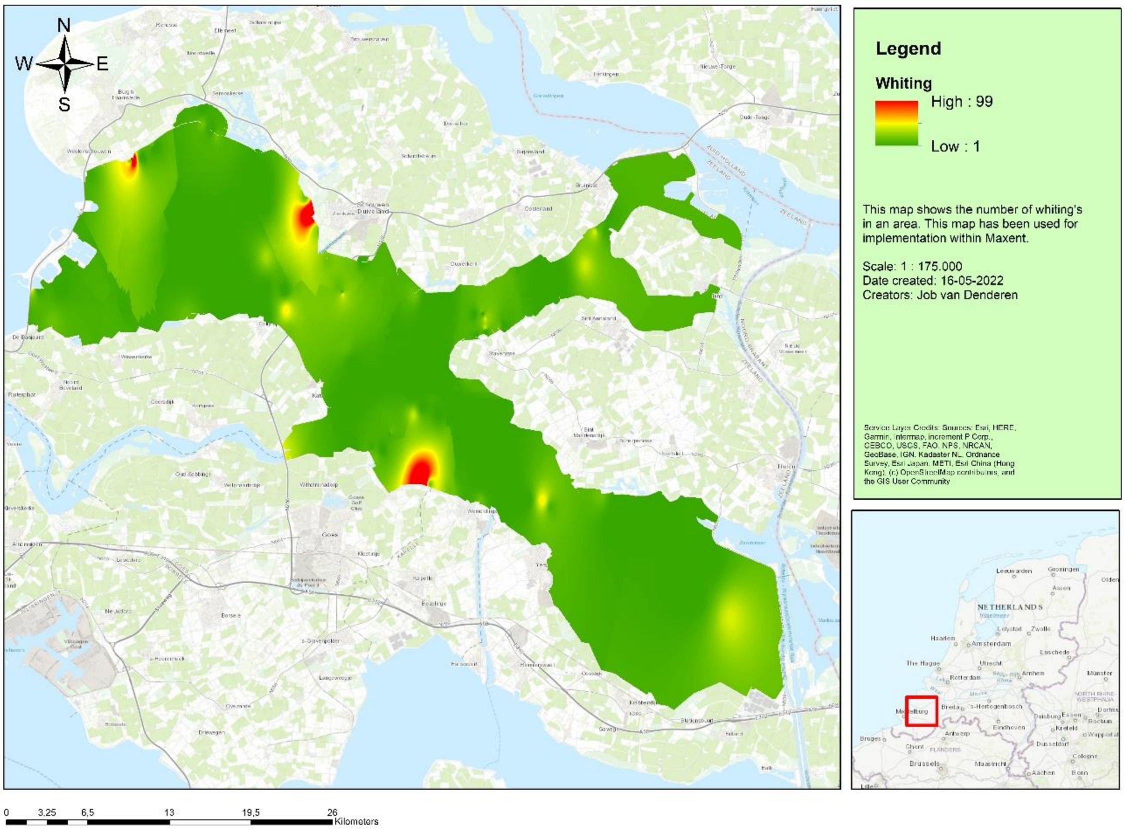




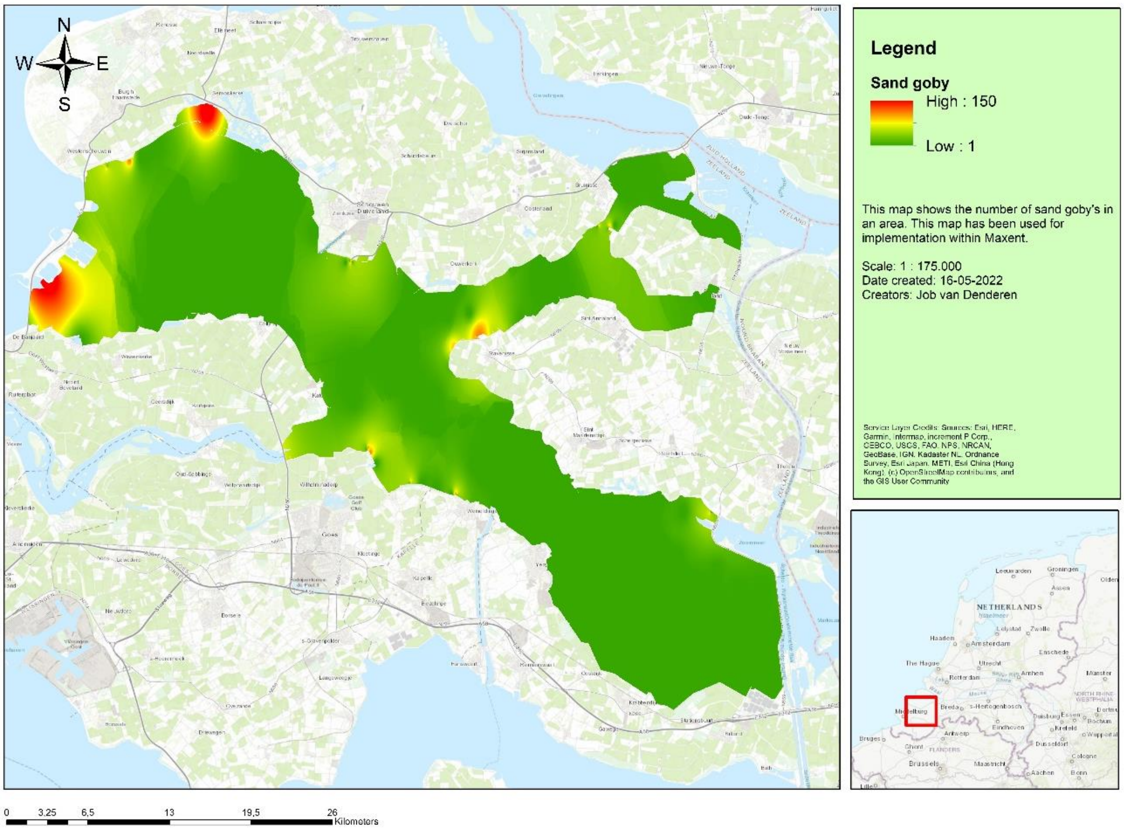
Average chlorophyll a level of the Eastern Scheldt



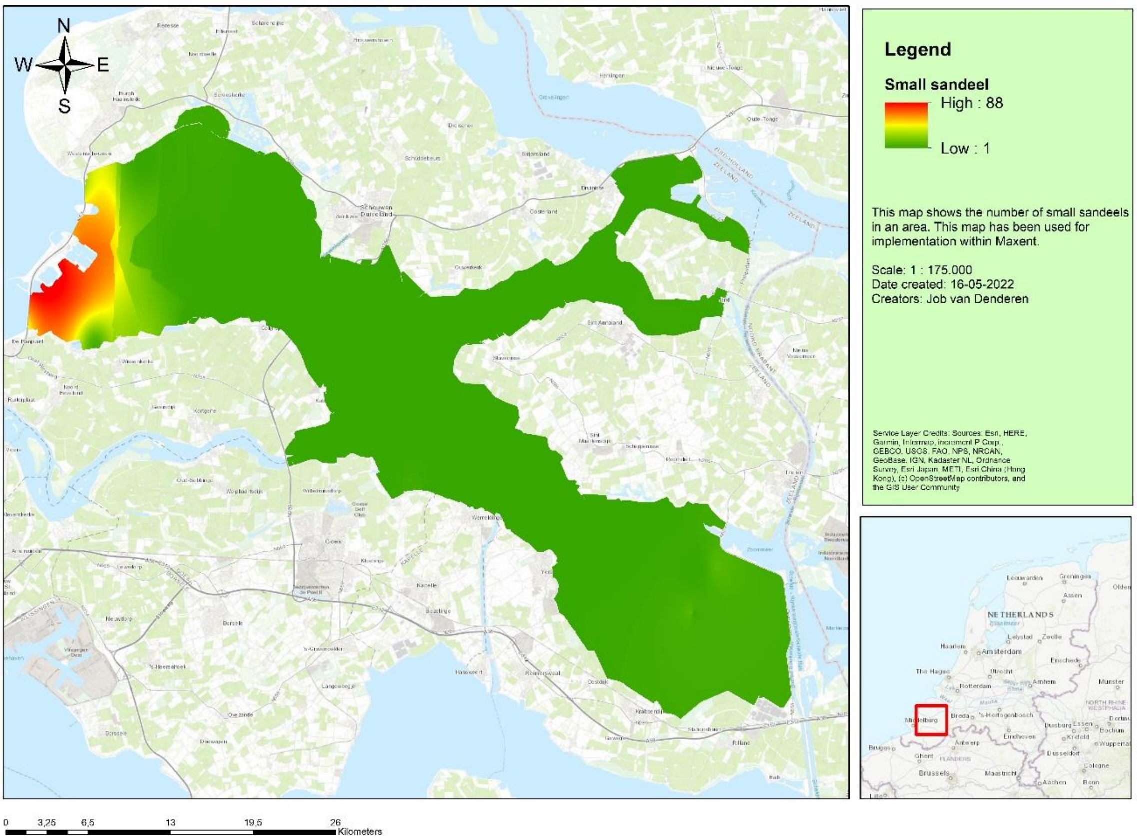
Number of whiting's in the Eastern Scheldt



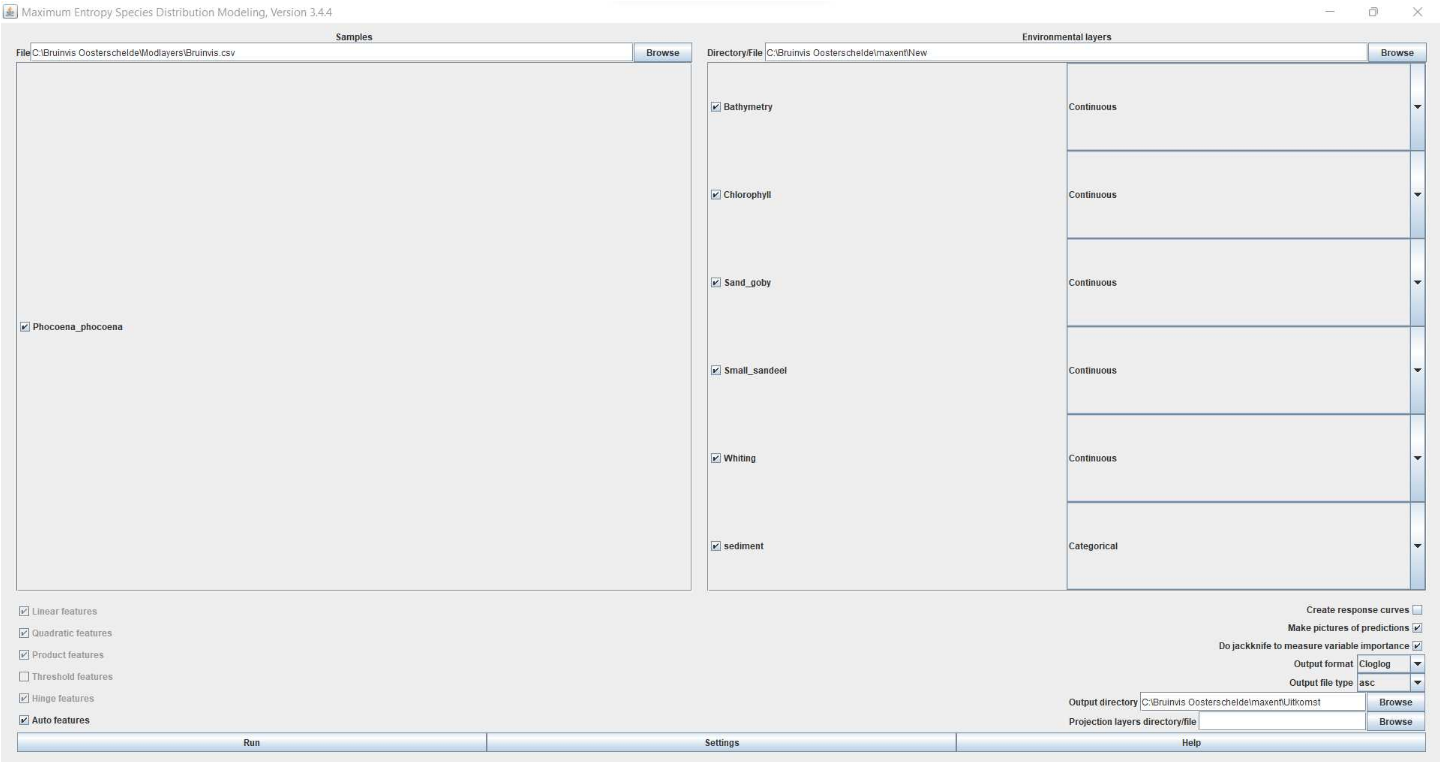
Number of sand goby's in the Eastern Scheldt

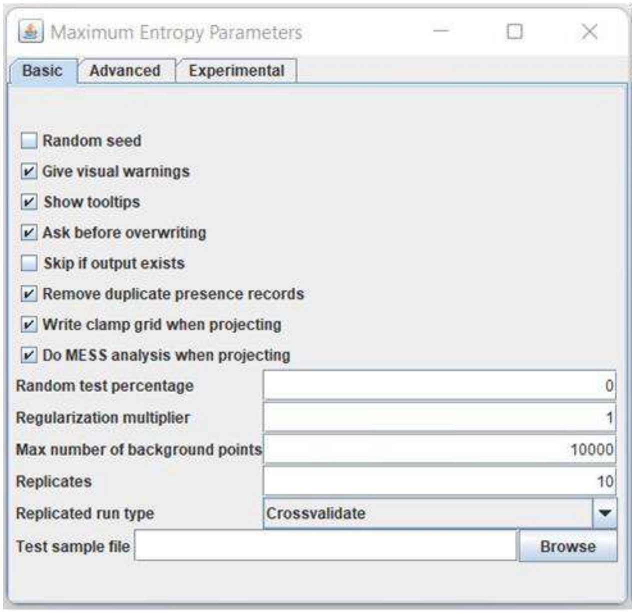


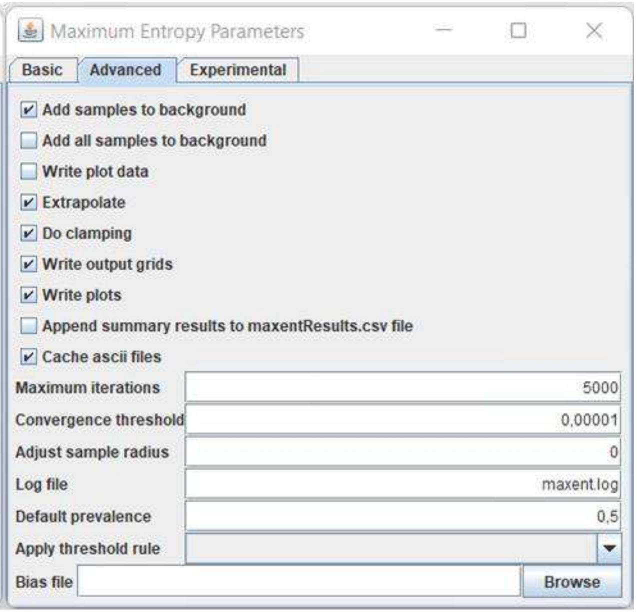
Number of small sandeels in the Eastern Scheldt



Appendix IV: MAXENT Input

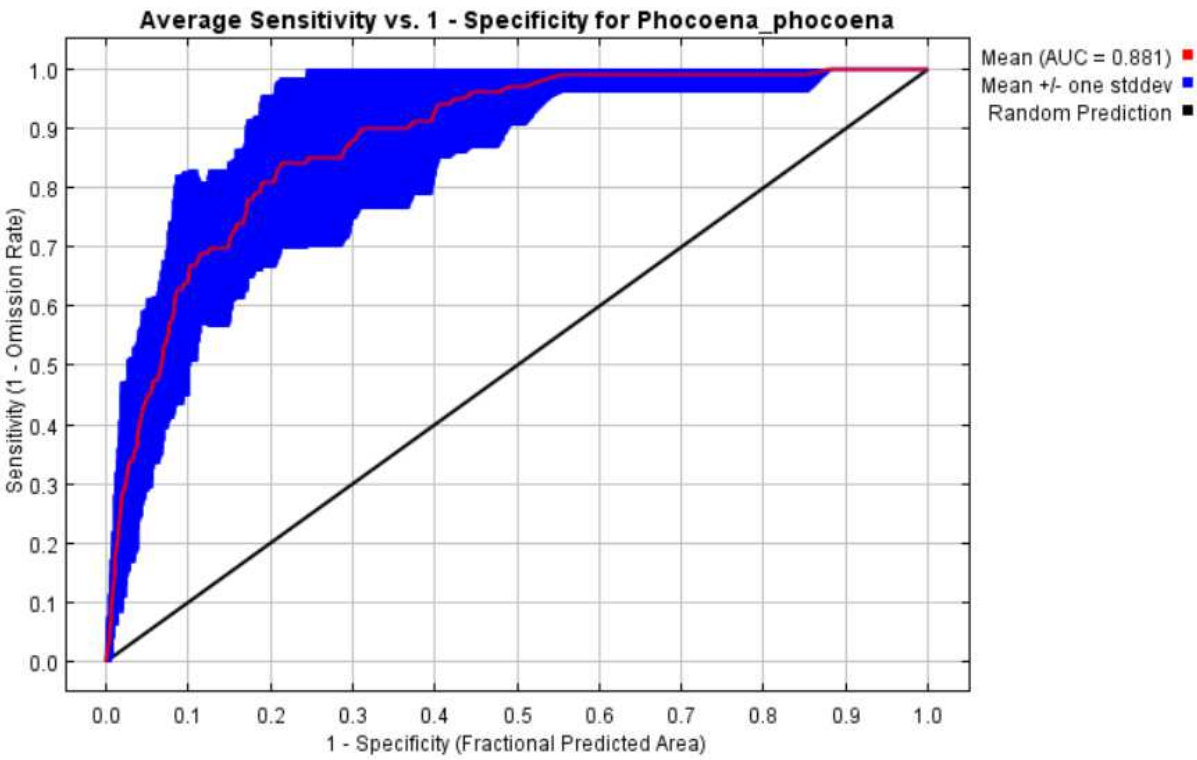






Appendix V: MAXENT Output

Results without sediment



Results without Chlorophyll-a