Carrying capacity of the southern North Sea for seabirds: a review of data requirements and availability

Plan of Action for MONS desktop study

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Preface

In 2020 the North Sea Agreement (NSA) was drafted, which led to the program Monitoring Research of Nature Recovery and Species Conservation (MONS). This research program aims to study the impact of changing anthropogenic use of the North Sea on its carrying capacity. For seabirds, the MONS program aims to develop an integral and systematic monitoring of the health and sustainability of coastal and offshore seabird populations.

As part of the MONS project, the ministry of Infrastructure and Water Management contracted Bureau Waardenburg to draft a Plan of Action for a desktop study on the food supply, food availability and foraging areas of seabirds in the North Sea.

The project team of Bureau Waardenburg consisted of dr. A. Potiek, dr. T.M. van der Have and drs. R. Fijn.

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Nederlandse samenvatting

In het kader van het Noordzeeakkoord is het integrale en systematische MONS onderzoeksprogramma opgezet om vast te stellen of het veranderende gebruik van de Noordzee past binnen de ecologische draagkracht van dit gebied. Het MONS programma richt zich op fysische, chemische en biologische basisparameters voor het functioneren van het ecosysteem en de aanwezigheid van bodemdieren, vissen, vogels, zeezoogdieren en vleermuizen. Dit rapport omvat een plan van aanpak voor de uitvoering van een bureaustudie naar het voedselaanbod en –beschikbaarheid (ID 62) en de ligging van foerageergebieden (ID 60) voor kust- en zeevogels in het Nederlandse deel van de Noordzee.

De centrale kennisvragen voor deze bureaustudie zijn als volgt geformuleerd:

(1) Welke factoren bepalen in tijd en plaats de aanwezigheid van kust- en zeevogels in de Noordzee, zoals voedselkeuze, voedselaanbod en -beschikbaarheid, connectiviteit met gebieden met een andere functie, verstoring, enz.

(2) Waar liggen de belangrijkste gebieden voor kust- en zeevogels, en welke functie (e.g. foerageren, rui, doortrek) hebben deze gebieden voor verschillende ecologische groepen kust- en zeevogels?

Het plan van aanpak bevat (1) een overzicht van de voedselkeuze, het voedselaanbod en een korte review van de factoren die de beschikbaarheid voor kust- en zeevogels bepalen en (2) een overzicht van de belangrijkste factoren die de verspreiding van kust- en zeevogels in tijd en ruimte bepalen, zoals de levenscyclus, abiotische en biotische factoren. Voor elk thema zijn voorlopige onderzoeksvragen geformuleerd (c 40 in totaal), en wordt een overzicht gegeven van te raadplegen databronnen, zoals databases, expertsystemen en literatuur.

Het rapport geeft ook een indicatie van de kwaliteit en beschikbaarheid van data over de belangrijkste abiotische en biotische factoren. Voor een aantal thema’s, zoals klimaat, visbestanden en visserij, is aangegeven dat deze in andere MONS-projecten worden geanalyseerd en dat een wederzijdse afstemming van belang is voor een efficiënte uitvoering van het MONS-programma.

1 Introduction and research questions

A healthy North Sea is important for all users of the North Sea. Various forms of anthropogenic use are in transition (e.g. increasing numbers of offshore windfarms, changing fisheries, increasing sand mining) and this change should comply with the carrying capacity of the North Sea. This has been agreed upon in the North Sea Agreement (NSA), in which the need for more scientific knowledge was acknowledged, leading to the set-up of the programme Monitoring Research of Nature Recovery and Species Conservation (MONS). The central question in this research programme is whether and, if so, how the change in anthropogenic use fits within the carrying capacity of the North Sea. For seabirds, which largely depend on the North Sea for food and survival, the MONS programme aims to develop an integrated and systematic monitoring of the health and development of coastal and offshore seabird populations. The general research questions of this part of MONS are:

- What is the carrying capacity of the Dutch part of the North Sea for coastal and offshore seabirds?
- How is this carrying capacity influenced by climate change and anthropogenic use (fisheries, offshore wind farms, sand mining and other pressure factors) and the interactions therein?

To answer the general research question with regard to seabirds within MONS, a few 'no-regret' studies have been planned before and during the duration of the programme. One of these no-regret studies is a desk-study into where foraging areas of seabirds are in the North Sea, and what the impact of abiotic and biotic factors is on the food availability within those areas. These topics are formulated as project-ID 60 and 62, respectively, within the MONS programme (Asjes *et al.* 2021). The central research question in this desk-study will be:

- What is the **food supply** for coastal and offshore seabirds? What is their diet, which factors determine the **food availability**, how do they find their food and how do they utilize it? What is the connectivity with other areas with other functions, e.g. breeding and moulting? What is the importance of multi-species foraging associations (MSFAs)?
- What are the most important foraging and staging areas for seabirds in the offshore and coastal North Sea? How do food supply and availability and other factors such as disturbance determine the functions of these areas in space and time? Are certain **foraging and staging areas** more important than others? Can we identify areas where MSFAs occur more frequently?

Prior to this desk-study, a Plan of Action needs to be drafted providing information to data availability and methods to answer the above-mentioned research questions. The document at hand forms this Plan of Action. In here, we give attention to a **bottom-up** approach (what determines the density, distribution, quality and availability of food) and a **top-down** approach (how do seabirds find their food, to which extent do they compete with predatory fish and mammals for forage fish, what is the impact of disturbance, among others) as well.

Several themes and research questions overlap with or are addressed in other MONS-projects (e.g. stock size and spatial and temporal distribution of forage fish, spatial and temporal distribution of fisheries). These research questions are marked with an asterisk*. It is recommended to evaluate the links with other MONS-projects during the preparation of the desktop study of the food and foraging areas of seabirds for exchange of information and cross compliance of analysis methods within the MONS-programme.

This Plan of Action has the following structure:

Chapter 1	Aim of the Plan of Action
Chapter 2	Materials and methods used in drafting the Plan of Action
Chapter 3	Overview of the food supply and which factors determine the availability to seabirds. This includes a review of the food requirements of the functional groups and the factors determining food availability, such turbidity, weather and prey quality.
Chapter 4	Review of data required to map the foraging areas.
Chapter 5	Conclusions of the Plan of Action
Chapter 6	Overview of the methods to analyse the data with the help of an effect chain and relation models including the abiotic and biotic factors determining the food supply and availability and foraging areas. In addition, this chapter drafts how the results of the desktop study will provide answers to the original research questions and aims of the MONS programme.

2 Materials and methods

2.1 Process

This Plan of Action is based on an overview of the current knowledge on foraging seabirds and factors affecting the suitability and quality of an area for foraging. We collected the information in this project from our **own data and experience**, **literature search** and **interviews** with key experts. This gave insight in the most important factors affecting the carrying capacity of the North Sea for seabirds. For each of these factors, the data availability was assessed. The interviewed experts are presented in Table 2.1.

Table 2.1 Interviewed experts for overview factors affecting the suitability and quality of an area for foraging.

Name	Affiliation	Field of expertise
Prof. Dr. Peter Herman	Deltares	Marine ecology
Dr. Rob Witbaard	Netherlands Institute for Sea Research (NIOZ)	Marine ecology, benthos, fish
Dr. Eric Stienen	Research Institute for Nature and Forest (INBO)	Bird ecology
Dr. Ingrid Tulp	Wageningen Marine Research (WMR)	Fish ecology, bird ecology
Dr. Mardik Leopold	Wageningen Marine Research (WMR)	Marine ecology, birds, mammals
Prof. dr. Robert Furness	University of Glasgow	Seabird ecology
Dr. Aonghais Cook	British Trust for Ornithology (BTO)	Seabird ecology

2.2 List of bird species

We started the preparation of this Plan of Action by defining a list of target species of interest based on the description of the MONS programme (Table 2.2; Asjes *et al.* 2021). The bird species on this list were attributed to three different functional groups:

1. Offshore species (that forage through diving or at the surface)
2. Coastal diving foraging species
3. Coastal surface foraging species

Following this categorization, we described the diet of these species. In addition, we describe whether data on this species are available from MWTL surveys (standardized transect counts by arial surveys) and/or SOVON/trektellen (fixed coastal observation locations aimed at counting migrating birds; Hornman et al., 2020), and waterbird counts of the species included in the conservation goals of the Natura 2000 areas (SOVON.nl). The latter counts are aimed to cover all birds staging in the coastal Natura 2000-areas (Noordzeekustzone, Voordelta, Vlakte van de Raan). Trends are available for most focal species which occur in substantial numbers (Table 2.2, indicated with 1). No trends are available for scarce species (Table 2.2, indicated with 0).

Table 2.2 Functional/ecological groups of offshore (1) and coastal (2,3) seabirds (32 species), their diet and monitoring programmes (0=only numbers available, 1=trends available). Species selection is made in an earlier stage within the MONS programme; see Asjes et al. (2021). See §2.2 for more information on species selection.

Species	Ecological group	Distribution	Diet	MWTL	SOVON/ trektellen	N2000
Atlantic puffin	1. offshore diving/surface	widespread	forage fish	1	1	
Black-legged kittiwake	1. offshore diving/surface	widespread	forage fish/discards	1	0	1
Common guillemot	1. offshore diving/surface	widespread	forage fish	1	0	1
Great skua	1. offshore diving/surface	widespread	forage fish/discards	1	1	1
Northern fulmar	1. offshore diving/surface	widespread	forage fish/discards	1	0	
Northern gannet	1. offshore diving/surface	widespread	forage fish/discards	1	0	1
Razorbill	1. offshore diving/surface	widespread	forage fish	1	0	1
Common scoter	2. diving	Coastal	benthic prey	1	0	1
Black-necked grebe	2. diving	Coastal	forage fish		1	
Black-throated diver	2. diving	Coastal	forage fish		1	1
Great cormorant	2. diving	Coastal	forage fish	1	0	1
Eider	2. diving	Coastal	benthic prey	1	0	1
European shag	2. diving	Coastal	forage fish		0	
Great crested grebe	2. diving	Coastal	forage fish	1	0	1
Long-tailed duck	2. diving	Coastal	benthic prey		1	
Red-necked grebe	2. diving	Coastal	forage fish		1	
Red-throated diver	2. diving	Coastal	forage fish	1	1	1
Scaup	2. diving	Coastal	benthic prey	1	0	1
Slavonian grebe	2. diving	Coastal	forage fish		1	1
Velvet scoter	2. diving	Coastal	benthic prey	1	1	1
Arctic tern	3. surface feeding	Coastal	forage fish	1	1	
Black tern	3. surface feeding	Coastal	forage fish		0	
Black-headed gull	3. surface feeding	Coastal	mixed/discards	1	0	
Common gull	3. surface feeding	Coastal	mixed/discards	1	0	
Common tern	3. surface feeding	Coastal	forage fish	1	0	1
Great black-backed gull	3. surface feeding	Coastal	mixed/discards	1	0	
Herring gull	3. surface feeding	Coastal	mixed/discards	1	0	
Lesser black-backed gull	3. surface feeding	Coastal	mixed/discards	1	0	
Little gull	3. surface feeding	Coastal	mixed	1	1	1
Little tern	3. surface feeding	Coastal	forage fish		1	1
Sandwich tern	3. surface feeding	Coastal	forage fish	1	1	1
Totals (32 overall)				23	13	18

2.3 Geographical scope

The focal geographical area within the North Sea is shown in Figure 2.1. The area is best described by the ICES-regions IVc (southern) and IVb (middle). The Dutch Continental Shelf (NCP) overlaps with both regions and several age classes of forage fish migrate within and between these regions.

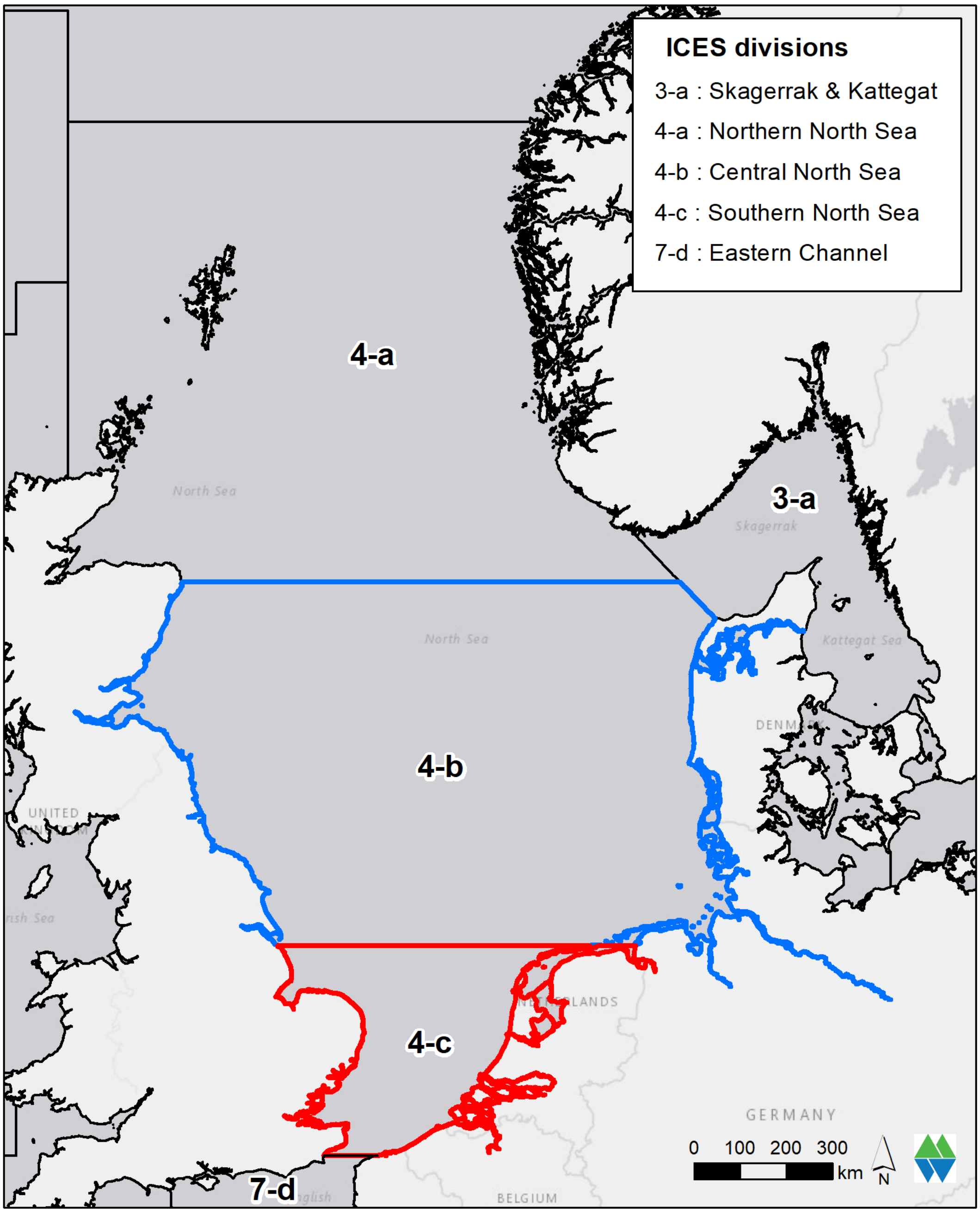

Figure 2.1 Geographical scope of the study area. Areas of interest are the Central North Sea and Southern North Sea (ICES areas 4b and 4c, shown with blue and red lines).

3 Food requirements and food supply

3.1 Introduction

The carrying capacity of the North Sea for seabirds is determined by both food demand of seabirds and food supply from lower trophic levels. Hence, it is important to gain insight in the major themes and topics relevant to the food demand and availability.

Within this chapter, we identify important biotic and abiotic factors affecting the food demand and supply. For each factor, we give a preliminary research question, and indicate possible data sources. In addition, the impact of climate change and anthropogenic use are taken into account as well.

An important term that is used in this chapter is '**Forage fish'**. This is a widely used term for small, pelagic fish, also known as bait fish or prey fish, which are eaten by larger predators, such as predatory fish, seabirds and marine mammals, including herrings, sardines, anchovies, sprats (*Clupeiformes*) and other small fish, such as sandeels, smelt and capelin.

3.2 Food web

Seabirds, together with marine mammals and predatory fish and fisheries, are the apex or top-predators in the food web and represented by trophic levels 4-5 (Pint *et al.* 2021; Figure 3.1). Their main prey, forage fish (including herring, sprat, sandeel) is represented by trophic level 3, the benthic prey (shellfish) by level 2.5. This implies that the main competitors of seabirds in the southern North Sea are predatory fish and fisheries and to a lesser extent marine mammals on forage fish. In other words, in order to understand the carrying capacity of the North Sea for seabirds, the level of competition with predatory fish and fisheries needs to be understood as well.

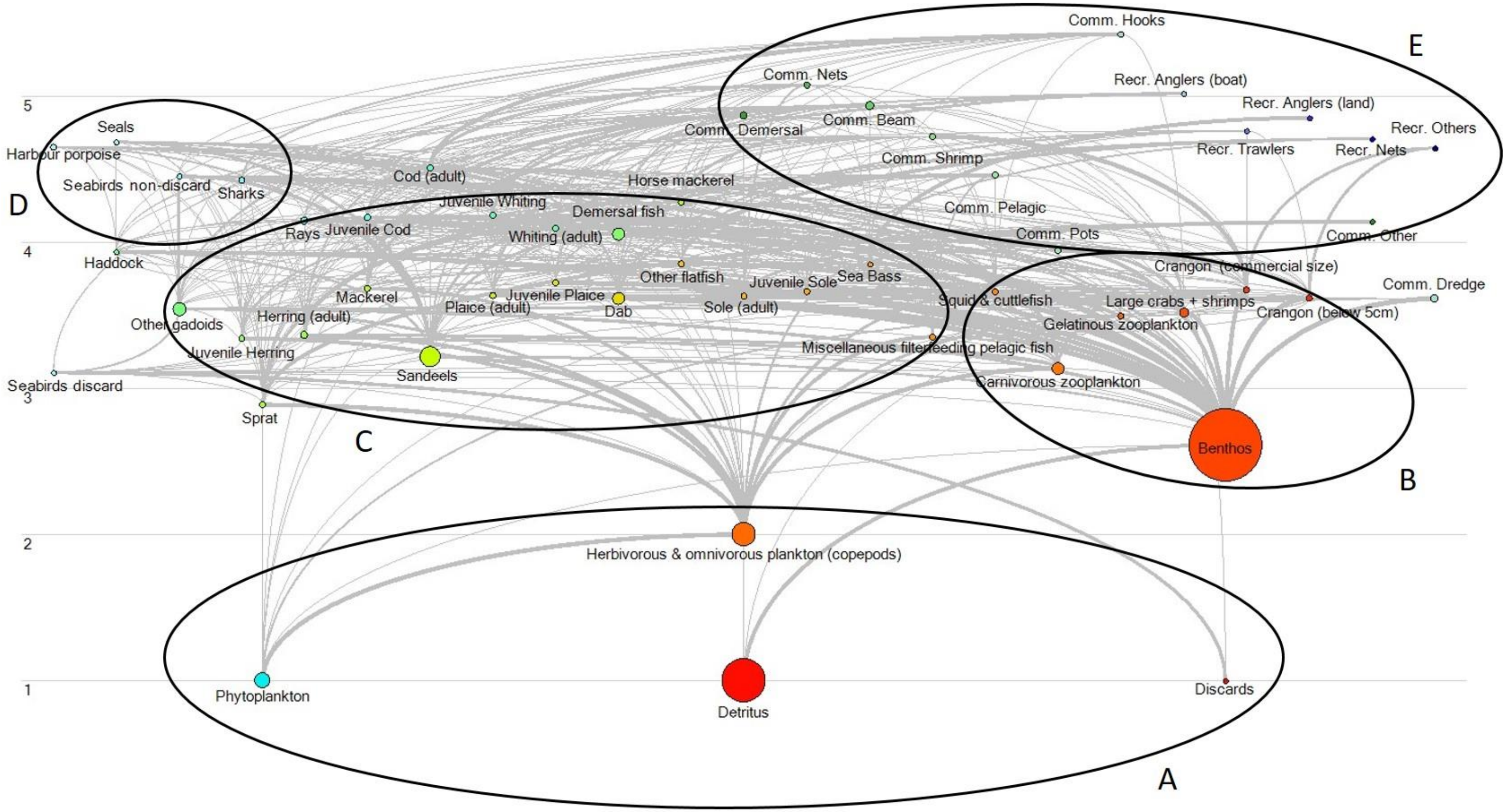

Figure 3.1 *An illustration of the southern North Sea food web and its interactions and trophic levels (1-5). The size of circles represents the biomass included in that functional group. The ellipses show related functional groups, indicated with A to E. A: functional groups at the bottom of the food web. B: invertebrates in the food web with a trophic level higher than 2. C: fish-related functional groups in the food web. D: top-predators in the model, with a trophic level between 4 and 5. E: fishing fleets included in the food web. Source: Pint et al. (2021)*

3.2.1 Food requirements of functional groups

Three different functional groups are defined within the MONS program (Asjes *et al.* 2021):
1. Feeding by diving and surface feeding in offshore areas;
2. Feeding by diving in coastal areas;
3. Surface feeding in coastal areas.

Following the species list from the MONS programme (Asjes et al. 2021), a total of 32 focal species emerges (Table 2.2). Seven species belong to the functional group 'offshore diving / surface feeding', 13 species to 'diving in coastal areas', and 11 species to 'surface feeding in coastal areas'.

Depending on the species, the main food source can be either forage fish, benthic prey, discards, or a combination of these sources. For each species of interest, the main types of prey items are preliminary presented in Table 2.2. It is advisable to present more details in the Desk study.

In this section we present an overview of the general factors which determine the food requirements of these seabirds, and describe how these factors differ between seasons.

3.2.2 Quantitative and qualitative aspects of food requirements: research questions and data availability

Seabirds meet their daily energy requirement by foraging efficiently for, preferably, high quality prey items. This implies that the suitability of an area for foraging depends on the density of prey as well as the quality (suitable size, high energy / fat content) and catchability of prey (clear water for forage fish, shallow water for benthic prey).

Prey density as well as quality can vary due to natural, abiotic causes (weather), biotic causes (fish predation) or fisheries. These factors apply to both coastal and offshore areas and to all functional groups.

Prey density

- Research question: what are the prey densities typically occurring in the North Sea for seabirds?

- Data sources
  - Forage fish: stock assessments
  - Benthic prey: stock assessments
  - Discards: depending on fishing methods (ICES métiers), legislation, etc.

Prey choice

The major prey classes (diet) of the 32 focal species are presented in Table 2.2. Within the desk study, the following follow-up questions should be answered or at least addressed:

- Research question for fish-eating bird species: what is the percentage of forage fish and discards in their diet?
- Research question for benthos-foraging species: what is the proportion of shellfish in the diet?

- Data sources:
  - seasonal, decadal and spatial variations in diet – see for example Church *et al.* (2018) for decadal change in diet composition.
  - literature research
  - diet studies during different season
  - Many diet work on various seabirds has been done at Dutch institutes.
  - data availability on diet from UK studies: UKCEH has diet data for species on the Isle of May. Ruedi Nager (Glasgow University) also has diet data for herring gulls. Liam Langley (Exeter University) has diet data from lesser black-backed gulls at Walney.
  - Unpublished data on stomach and fecal composition of breeding terns and wintering beach-washed auks are available at INBO. In addition, INBO has quite some stomachs of wintering auks stored in the freezer.
  - contact with experts.

Prey quality

Size and energy content (fat) are the major determinants of prey quality for seabirds as the energy content of the prey should match the daily energy requirements and the effort it takes to acquire the prey (Wanless *et al.*, 2004; 2005).

- Research question:
  - What are the sizes and energy content of forage fish (herring, sprat, sandeel) and benthic prey?

- Data sources:
  - Fisheries
  - Literature research on caloric content of prey.

Prey catchability

Water depth is a major determinant of the profitability of benthic prey. In case of pelagic prey, water turbidity mainly determines the profitability. Other factors include weather and distance from the breeding colony in the breeding season.

- Research questions:
  - Which factors determine offshore prey catchability of forage fish?
  - For each functional group: what is the quantitative relationship between the above-mentioned factors and prey catchability?

- Data sources:
  - Depth distribution of forage fish and shellfish.
  - Water turbidity and related factors such as phytoplankton biomass, resuspension of silt: spatial distribution and quantitative impact.

- Weather: seasonal and annual variation; available at KNMI and other weather institutes.

Interaction with other species

- Research questions:
  - Which species interact with birds in MFSAs, including marine mammals and predatory fish?
  - Which forage fish species are involved or trigger the occurrence of MFSAs?
  - Do certain areas more often contain MSFAs?

- Data sources:
  - Kees Camphuysen (NIOZ) carried out a boat survey to identify MFSAs in 2020.
  - ESAS and MWTL surveys contain data on MSFAs as well.

3.2.3 Temporal aspects

Breeding

Breeding seabirds mainly act as central-place foragers and their foraging range is constraint to a certain radius around their breeding localities (Box 1, Figure 3.2). In addition, during the breeding season, the higher food demand for reproduction and energy demands of chicks can result in a change in diet and foraging strategies. As a result, the impact of the factors affecting food supply is likely to differ between breeding season and non-breeding season.

- Research questions:
  - What are the most important factors affecting food density, quality and availability during the breeding season?
  - What is the variation in foraging trips (direction, distance, average, maximum, etc.) and total foraging range during breeding?

- Data sources:
  - Literature research
  - Potentially additional analysis of foraging range (a.o. to get insight in variation between individuals).

Wintering

During winter energy requirements are higher due to lower water and air temperatures and higher storm frequencies. However, prey may be easier to catch due to lower water temperatures and seabirds are not constrained to central place foraging.

- Research questions:
  - What are the most important factors affecting food density, quality and availability during winter?

- Data sources:
  - Literature research.

Moult

The energy demand of birds is also higher during the annual moult period, when most body and wing feathers are replaced.

- Research question:
  - When and where do the focal species moult most of their feathers? And what are the characteristics of these moulting areas?
  - What are the most important factors, influencing food density, quality and availability during moult?

- Data sources:
  - Literature research

BOX I – Example of the spatial analysis of foraging areas during breeding season

Based on a study by Wakefield *et al.* (2013), different colonies of northern gannets in the UK use non-overlapping areas for foraging during the breeding season (Figure 3.2). These colony-specific home ranges are determined by density-dependent competition. In addition, this segregation may be enhanced by individual-level public information transfer (e.g. timing and direction of foraging flights), leading to cultural evolution and divergence among colonies.

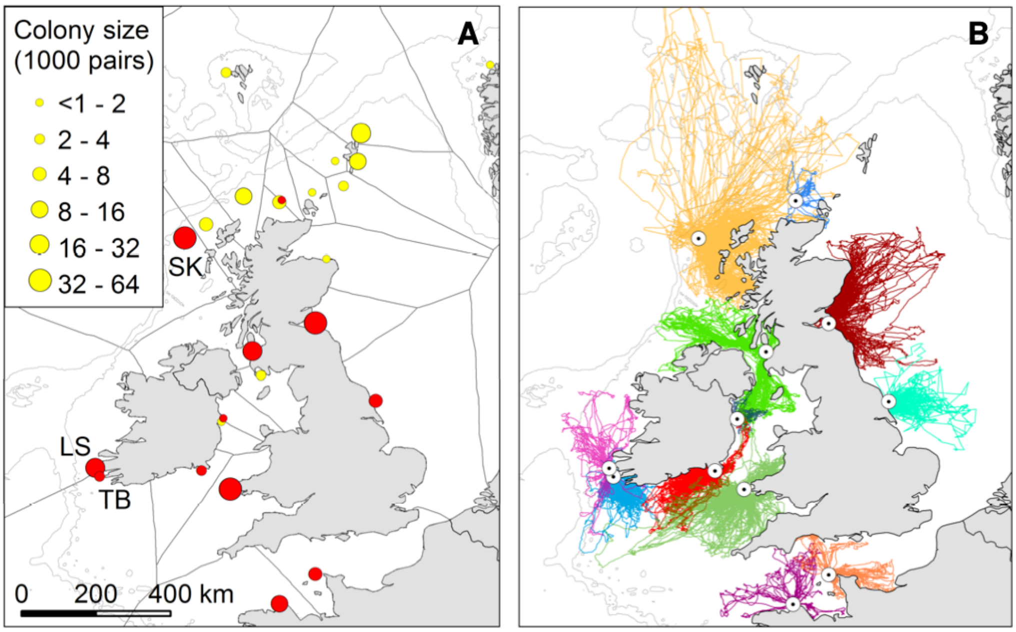

Figure 3.2 *Colonies of Northern gannets within the UK (A) and tracks during the breeding season from these different colonies, with specific colors per colony (B). Source: Wakefield* et al. *(2013).*

3.3 Factors affecting food supply and availability

A so-called *effect chain plot* can give a clear overview of the abiotic and biotic factors which influence the carrying capacity of the Dutch part of the North Sea for coastal and offshore seabirds. An example of such an effect chain plot is shown in Figure 3.3. This figure gives an overview of the most important (semi)natural factors, such as water quality, water dynamics and climate, together with anthropogenic use (conservation, fisheries, sand mining, discharges, offshore wind farms, and other pressure factors) and the interaction between these factors. As mentioned in the food web section, the fish relevant for top-predators (predatory/demersal fish, birds, mammals) are mainly forage fish. The benthos most relevant for seabirds are shellfish. "Plankton” is mainly zooplankton and “algae” represents phytoplankton. Within this example of an effect chain, discards are not included. However, if relevant for specific functional groups, this factor can be included as well.

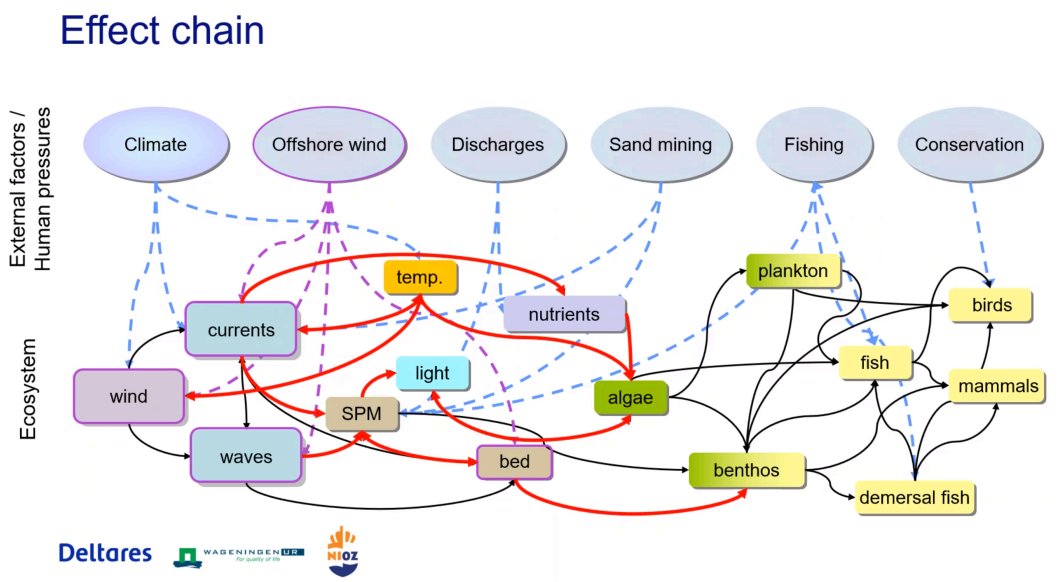

Figure 3.3 *WOZEP effect chain. Fish = mainly pelagic fish, including forage fish; SPM – Suspended Particulate Matter. Source: Deltares/WMR.*

Within the desk study, it is useful to draft a more detailed and specific relation model for each functional group. This relation model can be used to rank the impact of the various factors on the food supply and food availability for the different functional groups. For example, wind and suspended particulate matter (SPM) lead to lower visibility, and therefore negatively affect the accessibility of forage fish for birds. On the other hand, in very clear water forage fish may move towards deeper water during daytime to evade seabird predation. Such effects on accessibility of prey are not included in effect chain shown in Figure 3.3.

3.3.1 Abiotic factors

Different age classes of forage fish migrate to different depths in reaction to the depth variation of plankton. The annual variation of forage fish stocks depends on primary production, temperature, predation and fisheries. The catchability of forage fish to seabirds is determined by currents, temperature stratification, turbidity and weather. The spatial distribution of these factors in the North Sea would give more insight in the variability of food supply and food availability of seabirds.

- Research questions:
  - Which factors determine the availability of forage fish to seabirds and what is the variation within (seasonality) and among years?
  - Which factors determine the availability of benthic prey (shellfish) to seabirds and what is the variation within (seasonality) and among years?
  - What is the spatial distribution and seasonal variation of these factors?
  - Are wind and storm patterns changing as a result of climate change?

- Data sources:
  - Annual variation in Sea Surface Temperatures 1970-2020 - Copernicus database
  - Spatial distribution of SST in recent years
  - Spatial distribution of stratification in recent years – Stratification from Deltares 3D model of the North Sea.
  - Spatial distribution of currents and upwelling areas - Currents from Deltares 3D model of the North Sea.
  - Spatial distribution of suspended matter (water clarity) in recent years and seasonal variation – determining food availability to seabirds
  - Bathymetry and depth distribution of benthic prey – determining availability to diving birds.
  - Wind and storm patterns and frequencies 1970-2020.
  - Data layers describing bathymetry, topography, grain size distribution of the sediment, temperature are available from a compilation study by van der Reijden *et al.* (2018). The data sets in this publication can be freely downloaded.
  - NIOZ – ERSEM BFM database, hydrographical factors, weather data, primary production, SPM (J. van der Molen).
  - Lists of (abiotic and biotic) pressures and threats are provided to the European Commission as part of statutory reporting of Natura 2000 features. For UK, these reviews are published regularly by JNCC.
  - Modelling study by Wakefield *et al.* (2017) in the UK for European shag, black-legged kittiwake, guillemot and razorbill. In this study, the following environmental covariates were used: (1) depth, (2) seabed slope, (3) minimum distance to coast, (4) proportion of gravel, (5) sand:mud ratio, (6) potential energy anomaly (PEA), (7) proportion of time water column stratified, (8) sea surface temperature, (9) standardised sea surface temperature, (10) thermal front gradient density (TFGD), and (11) net primary production (alpha-chlorophyll). Used datasets can be found in the paper.

BOX II – Example of Abiotic Factor: Annual variation in mean Sea Surface Temperature (SST)

The annual mean seawater temperature varies with up to 2-3 ºC from year to year (Figure 3.4). Around 1990, the 5-yr smoothed data increased approximately 1.0 ºC, which in retrospect was a sign of climate change. The seasonal variation is between approximately 4 °C in winter and 18 °C in summer and depends on the water depth and occurrence of stratification. Between 1983 and 2012, the water temperature increase was slightly stronger in coastal areas compared to offshore areas (Figure 3.5). This shows a location-specific effect of climate change.

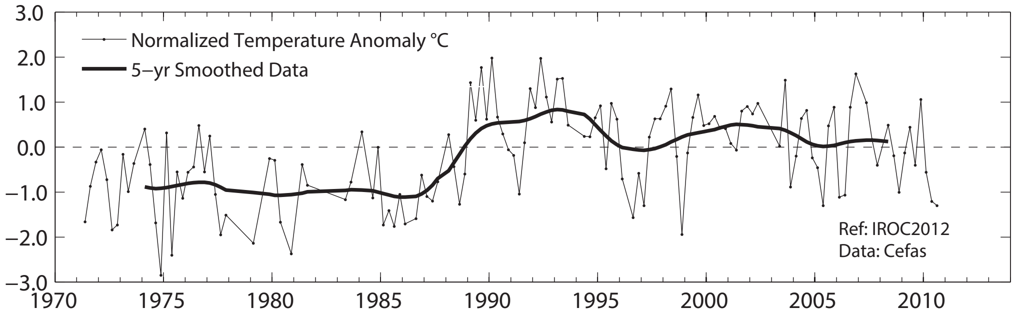

Figure 3.4 *Annual mean seawater temperatures (normalized anomaly °C) of the offshore Southern North Sea (Dye et al. 2013).*

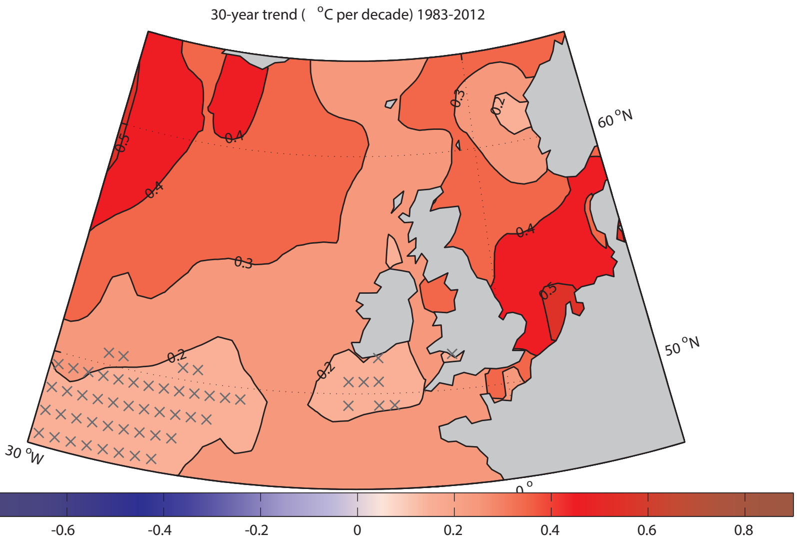

Figure 3.5 *The trend in annual average sea-surface temperature offshore (degrees Celsius per decade). Source: Dye* et al. *(2013).*

3.3.2 Biotic factors: plankton and macrobenthos

The spatial and seasonal distribution of forage fish are mainly determined by distribution of phyto- and zooplankton (e.g. Gao et al., 2021). The stock size and reproduction also depend on the primary production and availability of zooplankton (e.g. copepods) depending on age class and species. Therefore, spatial and temporal trends in these factors will give insight in the availability (and predictability) of the occurrence and catchability of forage fish. The spatial distribution and seasonal variation in primary production is available through modelling.

*The research questions below marked with an asterisk are also addressed in or overlap with other themes in the MONS programme. They are also formulated here to provide a link between these themes and a motivation to share information.

- Research questions*:
  - What is the spatial and temporal variation in primary production and how does this affect the stock size and availability of forage fish?
  - What is the spatial and temporal variation in zooplankton and how does this affect the stock size and availability of forage fish?

- Data sources:
  - Primary production
  - Zooplankton – Continuous plankton recorder: Database Alistair Hardy Foundation, Plymouth.
  - Zooplankton: contact Robbert Jak (WMR).
  - Fisheries data
  - At a larger spatial scale, use of EMODnet Biology product on abundance of macrobenthos in the North Sea and Baltic (https://www.emodnet-biology.eu/blog/data-product-numerical-abundance-benthic-macroinvertebrates-north-sea-and-baltic-sea). Probably also the product on presence/absence of macrobenthos in the Greater North Sea (https://www.emodnet-biology.eu/blog/summary-presenceabsence-maps-macro-endobenthos-greater-north-sea).
  - Belgian part of the North Sea: Macrobenthos monitoring at long-term monitoring stations between 1979 and 1999; temporal patterns for stations 115b and 330.
  - LifeWatch observatory data: zooplankton observations by imaging (ZooScan) in the Belgian Part of the North Sea.

- Additional research question*:
  - Which data sources are available to map the distribution and abundance of other prey species such as swimming crabs and *Nereis* worms for some of the gulls among the focus species?

- Data source:
  - EMODnet product on macrobenthos. Note that data from epibenthic sledges are not incorporated into that product; hence, extension may be needed.
  - Continuous plankton recorder data provide long-term evidence of changes

- Lists of (abiotic and biotic) pressures and threats are provided to the European Commission as part of statutory reporting of Natura2000 features. For UK, these reviews are published regularly by JNCC.
- Expert knowledge Stefan Garthe.

3.3.3 Biotic factors: forage fish

The stock size of forage fish in the North Sea is assessed by ICES (Figure 3.6), which is mainly based on the industrial fisheries on the Dogger Bank and North Sea coastal zone (Figure 3.7). Several forage fish species declined in stock size over recent decades, and stock sizes vary due to annual variation in seawater temperature, climatic effects and fisheries (Clausen et al., 2017; Dickey-Collas et al., 2010; Gröger et al., 2009; Henriksen et al., 2021; ICES, 2020a,b,c; Lindegren et al., 2017). Note that, although only a proportion of stocks are of suitable size to be eaten by seabirds, the total stock size may be a good proxy of the availability of forage fish.

*The research questions below are also addressed in or overlap with other themes in the MONS programme. They are also formulated here to provide a link between these themes and a motivation to share information.

- Research questions*:
  - What is the spatial and temporal variation in stock size of forage fish?
  - What is the spatial and temporal variation in quality (size, energy content) of forage fish?

- Data sources:
  - ICES stock assessments indicate stock biomass and age structure, but do not measure availability to seabirds. Availability would be better assessed from seabird behaviour. For example, TDR deployments provide data on numbers of dives by guillemots in North Sea that quantify foraging effort – which is possibly a better index of availability than is stock biomass (as availability is influenced by factors such as whether sandeels are in the water column or buried in the seabed, for example).
  - Swimway project – Pelagic fish Wadden Sea – North Sea coastal zone; upward sonar, fukes.
  - Sandeel - MWTL database (Brown Bank/ Brown Ridge).
  - NIOZ – sandeel monitoring North Sea coastal zone, Forage Fish project.
  - MWTL after 2019.
  - WOT shellfish survey, picks up sandeel with dredge (bodemschaaf), data not yet available.
  - Energy content is currently being carried out by Bram Parmentier (NIOZ).
  - Flyland (MARE) surveys, “Vogels en vis”.
  - Bruine bank and Frisian Front surveys, EGS2.
  - Several acoustic surveys by WMR, contact Ingeborg de Booijs.

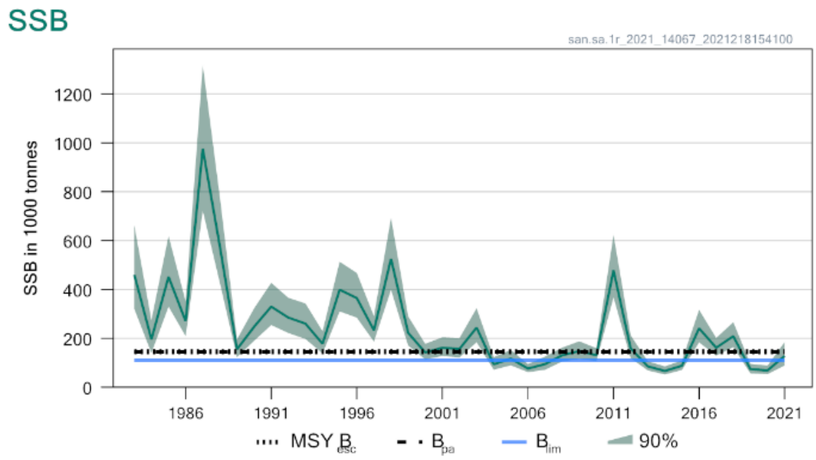

Figure 3.6 *Stock size (SBB) of sandeel in the central (IVb) and southern (IVc) North Sea, 1983-2021 (ICES, 2021).*

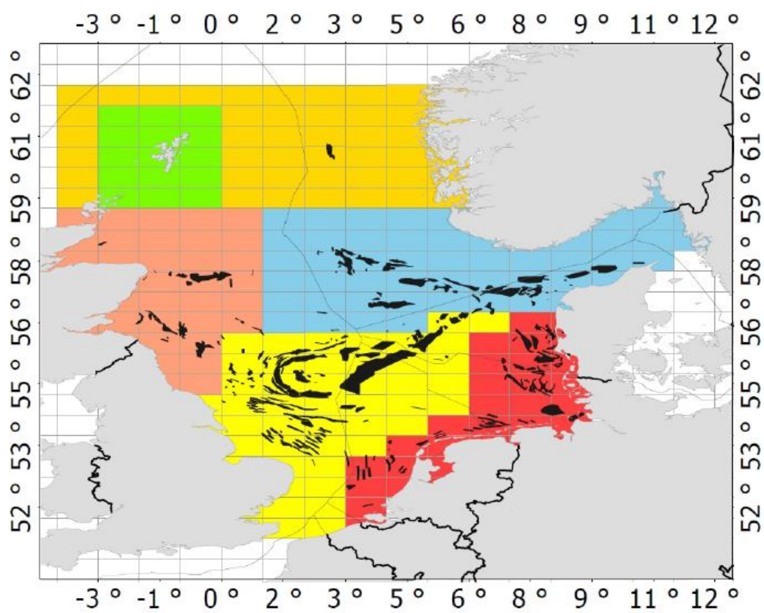

Figure 3.7 *Sandeel assessment areas in the North Sea as used by ICES since 2009. The main fishing grounds are marked in black within each division (Furness, 2020).*

Biotic factors: predatory fish

Predatory fish are the main, natural competitors of seabirds for forage fish (Figure 3.8). These predatory fish species includes gadoid species, like cod, haddock, saithe and whiting, and many others. All predatory fish species together annually consume approximately 60-70% of the forage fish stock in biomass.

- How much of the forage fish stock is predated by each species of predatory fish? In other words: what are the main (natural) competitors of seabirds?

- Data source:
  - ICES models of predation of forage fish by predatory fish.
  - ICES stock assessments of predatory fish.
  - Competition of predatory fish with birds can be modelled using methods such as Ecosim, in order to assess likely influences of change in top-down impacts of predatory fish on forage fish.

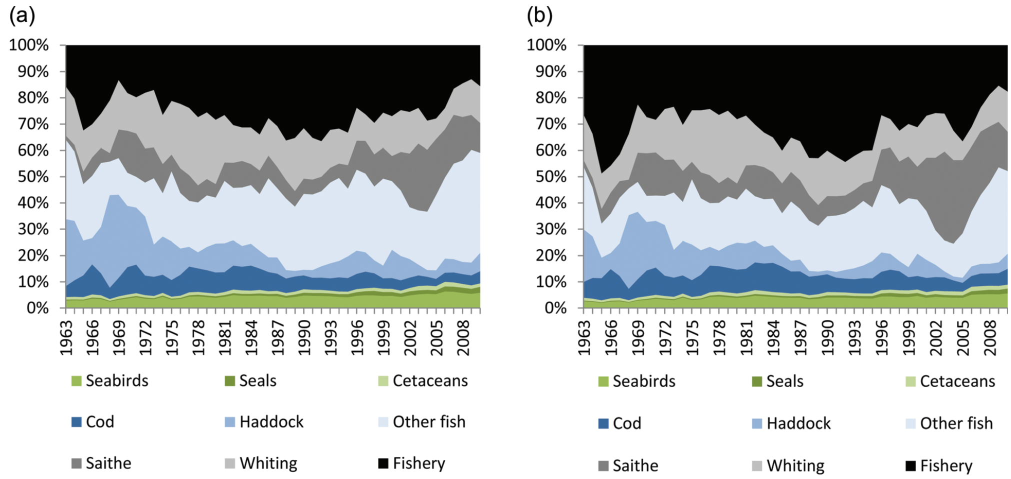

Figure 3.8 *Removals by different predators and the fishery of North Sea foraging fish per year (1963–2010).(a)Proportion of foraging fish removed as a percentage of total removals by weight per year. (b) Proportion of value (Euros) of removals of foraging fish by source per year (right). Output from the SMS model (ICES, 2011). c 60-70% of forage fish is predated by large (ground) fish, 20% by fisheries, 10% by birds, 10 % by mammals.*

3.3.4 Biotic factors: shellfish

- Research questions:
  - What is the spatial and temporal variation in population size and density of benthic prey (shellfish) for seabirds?
  - What is the spatial and temporal variation in quality (size, energy content) of shellfish for seabirds?

- Data sources:
  - Shellfish - energy content.
  - *Spisula* WOT stock assessment and distribution.
  - *Ensis* WOT stock assessment and distribution.
  - Potentially MWTL boxcorer, but limited coverage.
  - Potentially a literature review BTO carried out on behalf of SNH “Inshore wintering waterfowl in marine proposed Special Protection Areas (pSPAs): - literature review of dietary and habitat preferences and foraging constraints” – SNH can be contacted for a copy of this.

3.4 Fisheries

Forage fish fisheries compete with seabirds, marine mammals and predatory fish for the same resource (Figure 3.1). Therefore, it is important to know how the fishery activities interfere with the spatial and temporal distribution pattern of seabirds. In addition, fisheries can impact the availability of different age- and size classes, which can interfere with the preferred size and quality of forage fish for seabirds.
*The research questions below are also addressed in or overlap with other themes in the MONS programme. They are also formulated here to provide a link between these themes and a motivation to share information.

3.4.1 Forage fish

- Research questions*:
  - What is the spatial and temporal variation in fisheries on forage fish?
  - What is the spatial and temporal variation in fishing pressure?
  - What is the spatial and temporal effect on the prey availability of seabirds?

- Data sources:
  - Herring - ICES stock assessment, recruitment and fishing pressure.
  - Sprat - ICES stock assessment, recruitment and fishing pressure.
  - Sandeel - ICES stock assessment, recruitment and fishing pressure.
  - AIS-data of fishing vessels – ICES.
  - Sandeel fishery closed in North Sea coastal zone and Bruine Bank. Dogger Bank – industrial fishing Danish vessels.
  - Global Fishing Watch data.

3.4.2 Shellfish

- Research questions:
  - What is the spatial and temporal variation of shellfish fisheries and its effect on the availability of shellfish for seabirds?
- Data sources:
  - *Spisula sp.* WOT stock assessment and distribution.
  - *Ensis sp.* WOT stock assessment and distribution.

3.4.3 Discards

The estimate of number of seabirds supported by discards in the North Sea was 5,9 million in 1990 and decreased to an estimated 3 million in 2010 (Sherley et al., 2019; Figure 3.9). Discards are monitored by the fisheries sector under supervision of independent observers (van Overzee et al., 2021).
*The research questions below are also addressed in or overlap with other themes in the MONS programme. They are also formulated here to provide a link between these themes and a motivation to share information.

- Research questions*:
  - What is the spatial and temporal variation in the abundance of discards?
  - What is the effect of spatial and temporal variation in the abundance of discards on seabirds?
  -
- Data sources: WOT-programme discard monitoring (Centre for Fisheries Research, Wageningen).

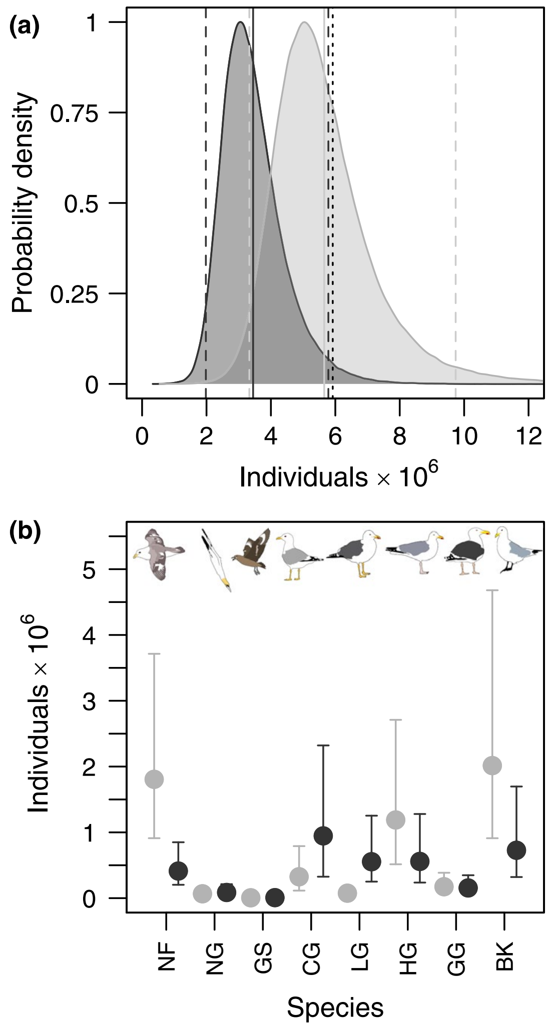

Figure 3.9 *(a) Posterior probability density (polygon), mean (solid line) and 95% CI (dashed lines) for the total estimated number of seabirds consuming fishery discards in the North Sea in 1990 (light grey lines and polygon) and 2010 (dark grey lines and polygon). A previous estimate of 5.9 million individuals supported by discards in 1990 (Garthe et al., 1996) is also shown (black dotted line) and (b) Posterior means (circles) and 95% CI (whiskers) for the estimated number of individuals consuming discards in the North Sea in 1990 (light grey) and 2010 (dark grey) for the eight focal species: BK, black-legged kittiwake; CG, common gull; GG, great black-backed gull; GS, great skua; HG, herring gull; LG, lesser black- backed gull; NF, northern fulmar; NG, northern gannet (Source: Sherley et al., 2019).*

3.5 Climate change

Climate change is best represented by time series of at least 30 years (Figure 3.10). For example, the seawater temperature in UK coastal waters gradually increased since 1870 and more rapidly after 1990. The general weather pattern in the offshore North Sea and North Atlantic shows a cyclical pattern also known as the North Atlantic Oscillation, during which temperature, wind pattern and storm frequencies are correlated on a large geographical scale. Temperature, in particular, has a profound impact on all ectothermic organisms within the marine food web. Seabirds must deal with top-down effects as well as bottom-up effects. Top-down effects include for example intra- and interspecific competition among seabirds, competition with predatory fish and changing weather patterns, while bottom-up effects include for example decreasing fat content and size of forage fish with increasing seawater temperatures (Furness, 2013). For example, seawater temperature was an important predictor of kittiwake breeding success in east Scotland (Figure 3.10), possibly mediated by changes in sandeel densities, size and fat content (Furness, 2020).

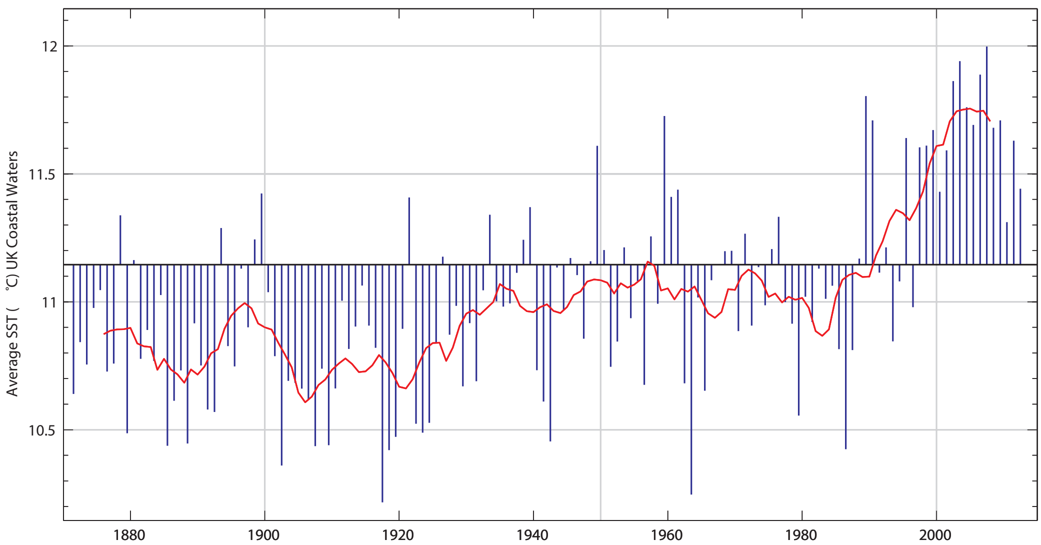

Figure 3.10 *Time series of average SST in UK coastal waters. The blue bars show the annual values relative to the 1971-2000 average and the smoothed red line shows the 10-year running mean. Data are from the HadISST1.1 data set (Rayner et al. 2003). Source: Dye et al. (2013).*

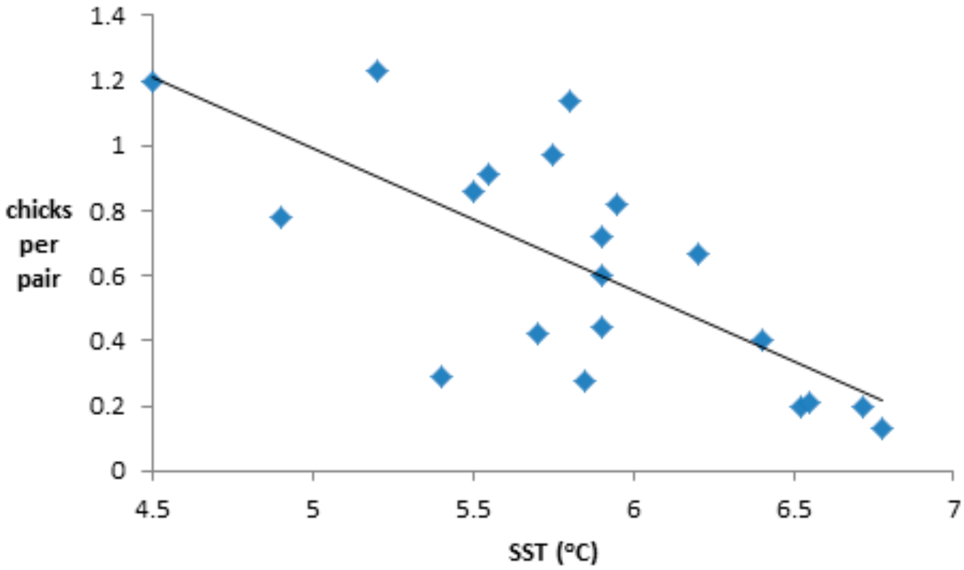

Figure 3.11 *Relationship between annual breeding success of kittiwakes (Isle of May, Scotland) and sea surface temperature (SST) in the previous winter, in years when there was no commercial fishery for sandeels in the region (1983-1990, 2003-2013; redrawn from Frederiksen, 2014). Source: Furness (2020).*

Top-down effects

- Research question:
  - Which climate-related factors (temperature, wind pattern, storm frequency, among other) have an effect (positive or negative) on the prey stocks and availability for seabirds.

- Data sources:
  - Literature research

Bottom-up effects

- Research question:
  - Which climate-related factors have an effect (positive or negative) on prey quality of forage fish and shellfish for seabirds?

- Data sources:
  - Literature research

3.6 Human disturbance

- Research question:
  - Which data sources are available to map human disturbance to the focus species?

- Data sources:
  - Spatial and temporal data commercial fisheries (AIS and VMS).
  - Compilations available from https://www.emodnet-humanactivities.eu/.
  - Data layers describing bathymetry, topography, grain size distribution of the sediment, temperature available from a compilation in van der Reijden et al. (2018). The data sets in this publication can be freely downloaded.
  - Locations of wind farms available from 4COffshore.
  - Literature on behavioral response to human activity, such as Jarret *et al.* (2018).
  - Marine Scotland developed a tool (FeAST) to get an overview of the species-specific vulnerability for human disturbance and (human-related) changes in the environment: http://www.marine.scotland.gov.uk/feast/.

4 Main foraging areas of focal bird species

4.1 Introduction

North Sea wide distribution maps of seabirds at monthly scales are needed for conservation and marine management. These maps are usually distilled from standardized and systematic aerial and vessel surveys, with recorded densities interpolated over larger areas and restricted spatial and temporal coverage. Waggitt *et al.* (2019) have developed an alternative approach consisting of: (a) collating diverse survey data to maximize spatial and temporal coverage, (b) using detection functions to estimate variation in the surface area covered (km^2) among these surveys. standardizing measurements of effort and animal densities, and (c) developing species distribution models (SDM) that overcome issues with heterogeneous and uneven coverage (Figure 4.1). It would be advisable to validate the various distribution models of seabirds at sea.

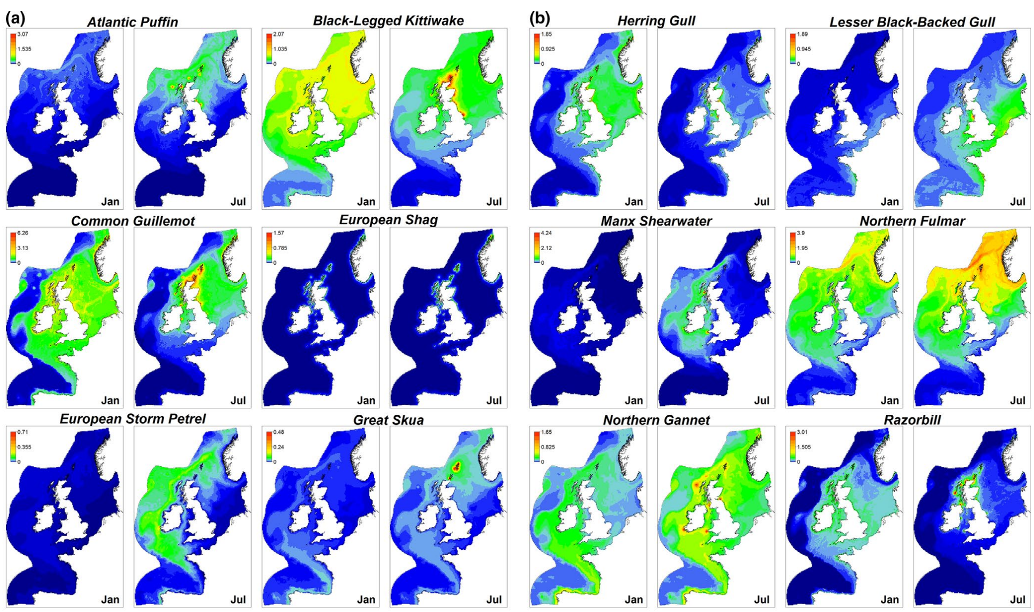

Figure 4.1 Distribution of 12 species of seabirds in the North Sea and NE Atlantic in January and July (Waggitt et al. 2019).

4.2 Distribution of birds

- Research questions:
  - What is the spatial and temporal distribution of the 32 focal seabirds species?
  - Which abiotic and biotic factors can explain and/or predict this distribution.
  - The following explanatory variables likely predict spatial and temporal variation in densities:
    - Annual temperature and temperature variance
    - Breeding colony index
    - Breeding cycle

    - Depth
    - Fronts
    - Distance from land
    - Regional temperature
    - Seabed roughness
    - Other factors: forage fish abundance, discard abundance

- Data sources:
  - MWTL / ESAS – (digital and traditional) aerial and vessel surveys.
  - Waterbird counts of coastal N2000-areas: several seabird species with conservation goals in these areas are included in the monitoring.
  - SOVON trendanalysis of trektellen.nl data.
  - Location and counts of UK colonies: many years of data analyzed by Ian Mitchell.
  - For UK, colony sizes and locations are available from JNCC online Seabird Monitoring Programme database (managed by BTO, contact person at JNCC daisy.burnell@jncc.gov.uk).
  - For terns in the UK, focal follow data (following birds in boats) have been collected for Common, Arctic, Sandwich & Roseate from a number of colonies in the UK (contact person at JNCC julie.black@jncc.gov.uk).
  - GPS tracking data of breeding adult seabirds are held in a number of different online databases such as BirdLife seabird tracking database, SEATRACK, Movebank, RSPB FAME and STAR databases.
  - Geolocator data are available for the non-breeding season as well for various seabird species, in particular kittiwake, gannet, guillemot and razorbill.
  - BTO have GPS tracking data for Black-legged Kittiwake (Aberdeen Bay), Lesser Black-backed Gull (Orfordness, Firth of Forth, Walney, Barrow in Furness, Skokholm, Belfast, Ribble, Bowland Fell), Herring Gull (Firth of Forth, Copeland, Bangor), Great Black-backed Gull (Firth of Forth).
  - BTO & Bureau Waardenburg have been collecting GPS data from Sandwich terns on the North Norfolk Coast.
  - GPS data for gannets has also been collected from Bempton Cliffs (Saskia.wischnewski@rspb.org.uk & Keith Hamer/Jude Lane) and Alderney (Jonathan.green@liverpool.ac.uk). Francis Daunt has collected GPS tracking data for many of the species concerned from the Isle of May (frada@ceh.ac.uk).
  - Distribution during non-breeding as well as breeding season can be modelled using predictive environmental variables. See for example database used in Waggitt *et al.* (2019). The Marine Ecosystems Research Project produced monthly distribution maps for many of the species concerned (james.waggitt@bangor.ac.uk).
  - Geolocator data for birds tagged as breeding adults at selected colonies indicate extent of colony-specific or overlapping distributions. See, for example, Furness & Buckingham (2019) and MacArthur Green (2019) for guillemot and razorbill from colonies in Scotland (Figure 4.2; Figure 4.3).

4.3 Variation between seasons

- Research question:
  - Which factors determine the spatial and temporal distribution of seabirds during the breeding and non-breeding seasons?

- Data sources:
  - Same data sources as mentioned in 4.2, distinguishing between breeding season vs non-breeding season, and colony-bound versus non-colony-bound.
  - Tracking data during the non-breeding season can be directly linked to the various colonies. Some of the BTO Herring & Lesser Black-backed Gull data also cover the non-breeding season, though a significant proportion do not winter in the UK. UKCEH have deployed geolocators on a range of species and have recently published a paper on the results for Guillemot & Razorbill (Lila Buckingham, libuck51@ceh.ac.uk).
  - The Marine Ecosystems Research Project produced monthly distribution maps for many of the species concerned, including the non-breeding season (james.waggitt@bangor.ac.uk).

4.4 Knowledge gaps

- Research question:
  - What are the knowledge gaps in understanding the spatial and temporal distribution of seabirds?

- Data sources:
  - Literature search
  - Contact with experts

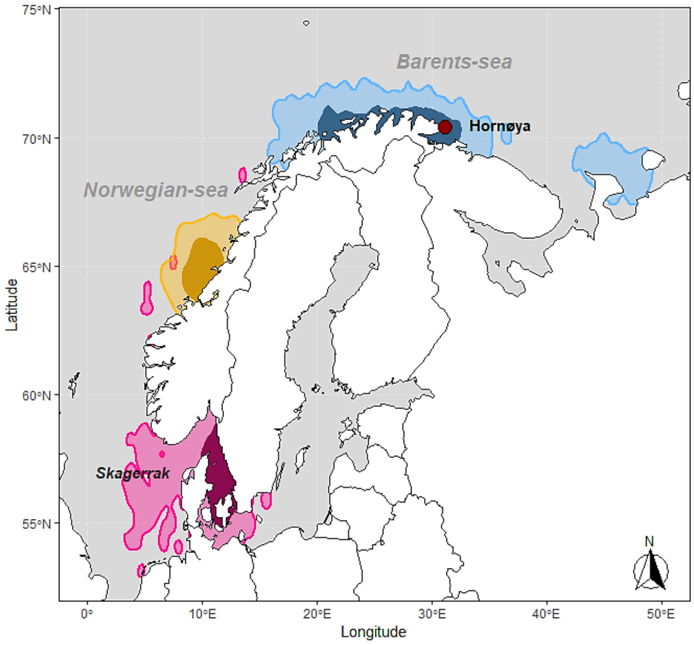

Figure 4.2 *Geographical distributions of Hornøya-Razorbills (breeding coloniy Barents Sea) during the main wintering period (December-January) displayed as 95 and 50 % kernel density contours (main and core home-ranges, respectively). Blue color: Birds wintering in the Barents-sea region (resident). Brown color: Migratory birds wintering in the Norwegian-sea. Red color: Migratory birds wintering in the Skagerrak-region including the southern North Sea (Hestem, 2019.*

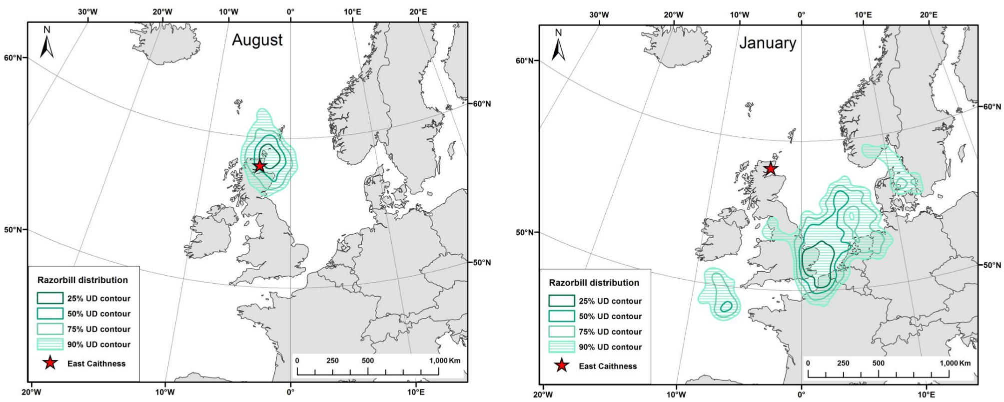

Figure 4.3 *Distribution of razorbills from the breeding colony in Whinnyfold, Scotland in August (left) and December (right) as determined from geolocator data (MacArthur Green, 2019).*

5 Conclusions Plan of Action

5.1 Data availability and quality

In the previous chapters, we described the factors most likely impacting the suitability of an area for foraging. For each of these factors, we also described the data requirements. In this chapter, we give an overall indication of the data quality.

Note that within the Desktop Study, additional factors may be identified which affect the quality of an area for foraging. In addition, additional sources may be found by more thorough literature search and contact with experts.

Type of factor	Indication of spatio-temporal data availability (preliminary)
Abiotic factors	Good
Biotic factors	Moderate to Good
Food supply	Moderate
Forage fish	Insufficient (only fishery related)
Predatory fish (competitors)	Insufficient (only fishery related)
Shellfish	Good
Food demand of seabirds	Moderate to good

5.2 Links with other MONS projects and datasets

As mentioned in the introduction, different MONS-projects should be linked together in order to use data from the MONS programme efficiently and create synergy between projects. For example, the spatio-temporal distribution of forage and predatory fish is being analyzed within a separate MONS project. The results of that particular project is of great interest for this seabirds project. Vice versa, the research questions formulated in this desktop study will improve and increase the scope of other relevant MONS-projects. These research questions have been marked with an asterisk*. The effect chain (Figure 3.3) may help in linking the MONS-projects.

The same can be the case for other types of diet, as well as other projects on birds or factors affecting the quality or accessibility of a foraging area.

5.3 Knowledge gaps

At this stage, we can only provide a preliminary overview of expected knowledge gaps. Additional literature search and contact with experts will give more insight in these knowledge gaps.

- For some species, quantitative information on **diet composition** may be limited
- **GPS data** may not be available for all species. Although distribution can be analyzed from other sources as well (for example aerial and ship-based surveys), GPS data gives more insight into areas used for foraging specifically.

- For birds counted during aerial and ship-based surveys, the **breeding origin** is unknown (unless rings can be read). For several of the study species, we expect that information on breeding colonies will be limited. If GPS data are available, the important foraging areas of birds breeding in that particular colony can be analysed. However, GPS data are not available for all species, particularly for the time outside the breeding season.
- **Monitoring of fish** is generally carried out with fishing net equipment, often with help of commercial fishing vessels, and aimed at the management of commercial fisheries (e.g. ICES 2020a,b,c). This means that the focus is on areas in which commercial fisheries take place. Other areas within and outside the Dutch part of the North Sea are understudied regarding the distribution and availability of fish for seabirds and marine mammals. This is the case for forage fish, as well as for predatory fish.

6 Desk study: research questions, analyses and results

6.1 Overall research questions

The desktop study will need to provide answers to the overall research questions if the derived research questions are accurately formulated, the necessary data with sufficient resolution available, and the proposed analysis methods appropriate.

The general research questions of this part of MONS are:

- What is the **carrying capacity** of the Dutch part of the North Sea for coastal and offshore seabirds?
- How is this carrying capacity influenced by climate change and anthropogenic use (fisheries, offshore wind farms, sand mining and other **pressure factors**) and the interaction therein?

6.2 General overview of analyses

Different types of analyses are foreseen within the desktop study. Here, we give an overview of types of analyses which will most likely be performed within the desktop study:

Prey availability:

- *The analysis of main prey items per species:* this may be available within literature, but may also need further analysis based on diet studies.
- *Distribution maps*: how are prey species, predatory fish and commercial fisheries spatially and temporally distributed?
- *Spatial analysis of food supply:* in addition to densities presented in distribution maps, a caloric map of forage fish gives insight in energetic value as well. For an example of such a caloric map, see Ransijn et al. (2019).
- *The definition of a relation model for each functional group:* which factors influence the suitability of foraging areas
- *Time series analysis*: how do these factors vary over time?
- *GIS-analysis*: what is the spatial variation in each factor?
- *Population trends* of prey species

Location of main foraging areas:

- *Distribution maps birds*: in addition to surveys, GPS tracking data can provide insight in areas specifically important for foraging.
- *Variation in distribution maps between seasons*
- *Origin of birds – where are the breeding colonies?*
- *Trends in number and breeding success in these colonies?*

Pressure factors:

- What is the effect of climate change, fisheries, offshore windfarms, and other factors on the suitability of an area for foraging? How do these factors affect prey density and/or catchability? How do these factors affect the distribution of the bird species of interest?

The exact analyses depend on the final decision on factors influencing the suitability of foraging areas for each functional group.

Expert knowledge

In order to construct a complete relation model, we advise to organize an international workshop with experts in the fields of seabird ecology, fish ecology, benthos ecology and marine ecology. In addition, more insight can be gained from separate interviews with experts.

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