

Agenda Item 2.2

Review of New Information on Threats and
Other Issues Relevant to Small Cetaceans

Resource Depletion

Document 2.2

**Report of the ASCOBANS Resource
Depletion Working Group (August 2022)**

Action Requested

Take note

Submitted by

Resource Depletion Working Group



Report of the ASCOBANS Resource Depletion Working Group*

August 2022

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Table of contents

Background and Terms of Reference	3
ToR A: Review/summarise recent information on resource depletion and its impacts on small cetaceans and identify additional research needed.	5
<i>Introduction</i>	5
<i>Causes of prey depletion</i>	5
<i>Impacts</i>	6
<i>Adaptability</i>	6
<i>Monitoring and surveillance</i>	7
<i>Filling data and knowledge gaps</i>	7
TOR B. Review sources of information on prey distribution and abundance (e.g., fishery landings and effort data, stock assessments, fish surveys (which potentially offer information with a higher spatial resolution), habitat models for fish and cephalopods) and, if appropriate, propose a mechanism to collate relevant data, focused on species already identified as of importance in the diet of small cetaceans.	9
TOR E. Review spatio-temporal trends in sightings data on distribution and abundance of small cetaceans, in relation to possible relationships with trends in distribution and abundance of their known prey.	9
ToR C. Liaise with other ASCOBANS initiatives to develop health/condition indicators for small cetaceans, based on information from live animals and/or necropsies, with the ultimate aim to improve the resolution of these indicators for identifying impacts of prey depletion and other cumulative stressors. Establish collaboration with HELCOM in relation to their development of a health indicator for porpoises. The indicators are likely to be multi-faceted, including information on pathology, physiological status (e.g. pregnancy, stress), body condition (e.g. blubber thickness), considering that simple indicators such as blubber thickness are influenced by multiple factors and do not necessarily reflect resource abundance.	12
<i>Assessing cetacean health and condition</i>	12
<i>Filling data and knowledge gaps</i>	13
ToR D. Review and collate information on diet of small cetaceans in the ASCOBANS area (including long-term dietary variation) and foraging behaviour, to improve understanding of likely responses to changes in prey availability; identify knowledge gaps and encourage new research and monitoring of diet, considering that ongoing monitoring of diet and spatio-temporal trends is an essential part of surveillance of cetacean conservation status.	14
<i>Morphology, energetics, distribution and diet</i>	14
<i>Methodologies to study diet</i>	15
<i>Distribution and diet of different cetacean species</i>	17
<i>Filling data and knowledge gaps</i>	24
ToR F. Review relevant information from <i>emerging technologies</i>	25
ToR G. Explore prospects for integrating information from multiple data sources to provide inter/multidisciplinary insights into the resource depletion issue	26
ToR H. Mitigation of pressures affecting cetacean prey availability - fisheries	28
References	31
Annex 1. Members of the ASCOBANS Resource Depletion Working Group	49

Background and Terms of Reference

The ASCOBANS area hosts a high diversity of small cetaceans (36 species – Evans, 2020). This includes a large number of delphinids, the most common of which are common dolphin (*Delphinus delphis*), striped dolphin (*Stenella coeruleoalba*), bottlenose dolphin (*Tursiops truncatus*), white-beaked dolphin (*Lagenorhynchus albirostris*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), Risso's dolphin (*Grampus griseus*), long-finned pilot whale (*Globicephala melas*), and killer whale (*Orcinus orca*). Other small odontocetes present include several beaked-whales: northern bottlenose whale (*Hyperoodon ampullatus*); Sowerby's beaked whale (*Mesoplodon bidens*); and Cuvier's beaked whale (*Ziphius cavirostris*). Within the family Phocoenidae, only one member is present: the harbour porpoise (*Phocoena phocoena*) (see, for example, Weir et al 2001, Hammond et al 2002, 2013, 2021, Kinze et al 2003, Reid et al 2003, Camphuysen & Peet 2006, Goetz et al 2015, Rogan et al 2017, Crawley et al 2020, Evans, 2020, Evans & Waggitt, 2020, Waggitt et al 2020).

Resource depletion is one of many potentially important threats to cetacean populations in the ASCOBANS area, an issue that has to date received relatively little attention.

The 24th Meeting of the ASCOBANS Advisory Committee requested the establishment of a Working Group on resource depletion to (i) review new information on resource depletion and its impacts on small cetacean populations and (ii) make recommendations to Parties and other relevant authorities for further action. The Resource Depletion Working Group (RDWG) is to report to Meetings of the Advisory Committee, as necessary. Its work is intersessional, by e-mail and video conference.

The RDWG was envisaged as including veterinary and fishery science expertise as well as cetacean biology, ecology and conservation expertise (e.g. collection and analysis of samples from stranded animals and determination of causes of death, dietary and feeding ecology studies, management and governance). A list of members is provided as an Annex to the present document. Links with the International Council for the Exploration of the Sea (ICES), the International Whaling Commission (IWC) and the Commissions associated with the Helsinki Convention (HELCOM) and the Oslo and Paris Conventions (OSPAR) were proposed.

The Terms of Reference are as follows:

- A. Review/summarise recent information on resource depletion and its impacts on small cetaceans and identify additional research needed.
- B. Review sources of information on *prey distribution and abundance* (e.g., fishery landings and effort data, stock assessments, fish surveys (which potentially offer information with a higher spatial resolution), habitat models for fish and cephalopods) and, if appropriate, propose a mechanism to collate relevant data, focused on species already identified as of importance in the diet of small cetaceans.
- C. Liaise with other ASCOBANS initiatives to develop *health/condition indicators* for small cetaceans, based on information from live animals and/or necropsies, with the ultimate aim to improve the resolution of these indicators for identifying impacts of prey depletion and other cumulative stressors. Establish collaboration with HELCOM in relation to their development of a health indicator for porpoises. The indicators are likely to be multi-faceted, including information on pathology, physiological status (e.g. pregnancy, stress), body condition (e.g. blubber thickness), considering that simple indicators such as blubber thickness are influenced by multiple factors and do not necessarily reflect resource abundance.
- D. Review and collate information on *diet of small cetaceans* in the ASCOBANS area (including long-term dietary variation) and foraging behaviour, to improve understanding of likely responses to changes in prey availability; identify knowledge gaps and encourage new research and monitoring of diet, considering that ongoing monitoring of diet and spatio-temporal trends is an essential part of surveillance of cetacean conservation status.

- E. Review spatio-temporal trends in *sightings data on distribution and abundance* of small cetaceans, in relation to possible relationships with trends in distribution and abundance of their known prey.
- F. Review relevant information from *emerging technologies* (e.g. drones to determine condition; eDNA to estimate fish presence in association with actively feeding cetaceans) and multidisciplinary research cruises
- G. Explore prospects for *integrating information from multiple data sources* to provide inter/multidisciplinary insights into the resource depletion issue.
- H. Recommend possible mitigation measures; explore options for better integrating cetacean conservation measures (e.g. MPAs, time-area closures) with fishery management procedures to help reduce risk of prey depletion.

ToR A: Review/summarise recent information on resource depletion and its impacts on small cetaceans and identify additional research needed.*Introduction*

For any species, there is a balance between the energy expended in acquiring food, the energy provided by that food and its subsequent expenditure to maintain body processes, such as thermoregulation, growth, and reproduction. Most cetacean species commonly occurring in the Agreement Area feed on a variety of fish and cephalopod species. The diet of a particular species can vary with season and age in terms of prey size and selection, with the prey type differing in terms of quality and the energy provided (Evans 1990, MacLeod et al 2007a, Leopold et al 2015, Andreassen et al 2017, Booth 2020). While high dietary variability is often interpreted as indicating an opportunistic foraging strategy, some cetacean species are also known to select prey according to prey quality rather than simply availability.

The term prey depletion is widely used without being explicitly defined. It is generally understood to refer to a reduction in the number of prey available. In marine ecosystems the term is usually used in the context of removal by fisheries, although in ecology generally it can refer to the removal of prey by predators (e.g. Whitehead et al 1999). Prey depletion can be viewed as a form of habitat degradation. Such changes are often linked to human activities, including fishing, aggregate extraction, marine construction and climate change (Evans 2017). There is also usually an implication that the availability of prey to predators is reduced, at least locally or temporarily. However, the relationship between availability and abundance is not necessarily linear or even positive: prey availability may increase or decrease due to changes in prey distribution, independently of abundance, while removal of part of a population by fishing may have a disproportionate effect on predators if the most accessible portion of the population has been removed. It also seems reasonable to extend the concept to refer to prey biomass and not only numerical abundance. Finally, considering prey as a source of energy (as in the context of optimal foraging theory, e.g. Pyke 1984) and/or essential nutrients for predators, the concept of prey depletion could also include declines in prey quality. A reduction in the energy content of individual prey may of course also lead to a reduction in the total biomass of the prey population. All the above changes to the prey field (another term widely used without being explicitly defined) are likely to negatively impact predators, in this case small cetaceans, by impacting their ability to locate and eat sufficient good quality prey (in terms of energy and nutrition) to survive, remain healthy, grow, mature and breed (Booth 2020; Stockin et al 2022).

Reduced prey intake may also result from alterations in predator behaviour due to disturbance by human activities (including fishing) or longer-term displacement due to physical changes in habitat. Such behavioural changes can have consequences for an individual's health through time lost foraging (Brandt et al 2011), socialising or resting (Lusseau 2003), hence impacting life functions such as survival and reproduction and ultimately affecting population dynamics (Pirota et al 2018, Booth et al 2022). Strictly speaking, if the prey field is not altered or the response of the predators is independent of changes in the prey field, this is not an example of the effect of prey depletion, although the consequences for the cetaceans may be similar.

Causes of prey depletion

While the role of fisheries as a driver of prey depletion for cetaceans will almost inevitably be the major focus, in practice, there are many factors influencing prey abundance, which should be considered to ensure that the most appropriate management and mitigation measures can be identified and implemented.

Many species of fish and shellfish preyed upon by small cetaceans are also exploited by commercial and recreational fisheries (DeMaster et al 2001, Bearzi et al 2006, Lassalle et al 2012, Smith et al 2015). Any significant change in fish availability as a result of fishing extraction, through effects on distribution, numerical abundance, biomass or quality (e.g. size, nutritional value) of targeted species has the potential to negatively impact the cetaceans that

are in competition for that same food source (Lassalle et al 2012). However, such prey depletion (if we allow that the term applies to all these changes) may be localised and not necessarily be associated with overfishing (DeMaster et al 2001).

Disturbance and associated changes in behaviour can occur as a result of marine surveys or infrastructure installation (Dahne et al 2013, Tyack et al 2011, New et al 2013, Dyndo et al 2015; Haelters et al 2015; Brandt et al 2018, Booth 2020). When disturbed, individuals may stop vocalising and cease foraging (Wisniewska et al 2018 a,b).

Aggregate extraction can also cause disturbance to cetaceans, leading to changes in behaviour, which may affect foraging success (Tillin et al 2011, Todd et al 2015). In addition, aggregate extraction can affect the distribution of prey species as a result of disturbance or destruction of spawning grounds, leading to a reduction in prey availability (Groot 1996, Stelzenmüller et al 2010, Tillin et al 2011, Todd et al 2015).

Climate change and other forms of both anthropogenic and natural environmental change could indirectly lead to prey depletion through influences on prey and/or predator distribution and abundance (Macleod et al 2005, Learmonth et al 2006, Simmonds & Isaac 2007, Simmonds & Elliott 2009, Evans & Waggitt 2020, Peters et al 2022).

Impacts

The impacts of insufficient prey, their displacement, and/or changes in prey availability will be manifested in small cetaceans in a variety of ways, depending on the characteristics of the species including its capacity to adapt. If prey depletion leads to reduced calorific intake, body condition will likely deteriorate leading to subsequent health issues and a potential increase in instances of emaciation and starvation. There may also be a higher likelihood of disease or susceptibility to other pressures in nutritionally compromised animals, which could become a contributing or primary factor in the decline and/or ultimate cause of death of an animal (Learmonth et al 2006, Van Bressemer et al 2009).

There may be short- and long-term impacts related to changes in the nutritional quality of the available prey. If energy-rich species such as Atlantic herring (*Clupea harengus*), European sprat (*Sprattus sprattus*) and sandeels (Ammodytidae), are replaced in the diet by 'lower value' prey such as whiting (*Merlangius merlangus*), saithe (*Pollachius virens*), or Atlantic cod (*Gadus morhua*) (Evans 1990, Hislop et al 1991, MacLeod et al 2007b, Leopold et al 2015), the short-term and/or long-term health of the predator may be negatively affected (Spitz et al 2018, Booth 2020). Changes in prey availability may ultimately result in reductions in survival and reproductive rates hence resulting in population level effects. (MacLeod et al 2007b, Leopold et al 2015, Booth 2020).

It is important to note that, perhaps counterintuitively, the adverse health effects of eating fewer energy-rich fish are not necessarily a consequence of the lower energy content of the species that replace them in the diet. Thompson et al. (1997) found that years of low clupeid availability were associated with changes in haematological parameters of harbour seals that included macrocytic anaemia. These changes were not related to body condition, suggesting that they were not due to reduced energy intake. It was proposed that such effects of dietary changes could explain some pinniped population declines.

Adaptability

There is a growing body of evidence that some species or populations of small cetaceans may be more or less capable of adapting to prey depletion than others, given their feeding behaviours. Specialist feeders such as Risso's dolphin (*Grampus griseus*), which show a preference for cephalopods (Blanco et al 2006, Öztürk et al 2007, Bearzi et al 2011, Macleod et al 2014), may be less capable of adapting to prey depletion, given a persistent preference for a single or small group of prey species. It may also be noted that the status of most commercially important cephalopod stocks in European waters is less well known than is the case for commercially important fish, given the general lack of routine stock assessment for

cephalopods. Even where the diet of a species is varied, there may be localised development of foraging techniques and behaviour that can lead to site-specific specialisations, as in bottlenose dolphins (Bailey & Thompson 2010, Dunshea et al 2013), which could in turn result in site-specific vulnerability to prey depletion. Generalists, such as harbour porpoise (Santos & Pierce 2003), may be less affected by depletion of a particular prey species as their diet can consist of a range of different moderate to high energy-density prey species. On the other hand, porpoises also display ultra-high foraging rates and high capture success reflecting their high metabolic rate (Wisniewska et al 2016, 2018a), which in turn probably makes them vulnerable to a general reduction in prey availability. There is also evidence to suggest that if the prey species with higher energy density are depleted, a generalist diet may not provide adequate nutrition to sustain a healthy animal over time (MacLeod et al 2007b). Therefore, there is a need to focus mitigation of prey depletion on those prey species the decline of which would have the highest potential impact on small cetaceans.

Monitoring and surveillance

Monitoring of the effects of resource depletion on small cetaceans is achieved through a variety of methods. These include:

- Strandings monitoring programmes, which Parties to ASCOBANS are required to implement. These programmes record information on cause of death also it is also important to know about the general health status, and about other factors that may have been significant in contributing to the mortality of the animal (Baker et al 1998, Ten Doeschate et al 2017) and affect the health status of an individual.
- Stomach contents analyses, normally based on stranded animals, provide short-term dietary information (Pierce & Boyle 1991, De Pierrepont et al 2005, Spitz et al 2018), whilst fatty acid and stable isotope analyses of body tissues from live or dead animals can identify longer-term information on recent diet (fatty acids) or trophic level (stable isotopes). The more recently developed compound-specific stable isotope analysis (CS-SIA), typically based on amino acids, can potentially provide information on diet. Results of dietary can also indicate niche apportioning between sympatric species (Iverson et al 2004, Thiemann et al 2008, Jansen et al 2013, Kanaji et al 2017, Young et al 2017).
- Body condition can also be assessed in live animals using remote sampling methods such as photogrammetry, e.g. using photos taken using drones (Joblon et al 2014; Raudino et al 2019) or, more traditionally, biosampling (Nykänen et al 2018) or sampling from stranded animals (Joblon et al 2014). If other health issues affecting energy balance can be accounted for, body condition may be indicative of the availability of sufficient prey.

Modelling of management trade-offs between fisheries and marine mammal conservation, specifically in relation to the amount of fish removed by both fisheries and marine mammals, can reveal the impact of biomass removal on fishery sustainability and on recovery of some cetacean species, representing a useful tool to support our understanding of the impacts of prey removal through extraction (Williams et al 2011, Smith et al 2015, Spitz et al 2018).

Filling data and knowledge gaps

A multi-method approach is needed to assessing cetacean diet, its variation over time, and its relationships with health and reproductive success. Diet should be routinely determined based on stranded animals and using a suite of methodologies: bulk and compound-specific stable isotope analysis, fatty acid analysis and stomach contents analysis (both the traditional approach using hard remains and the application of molecular prey identification which, while still less quantitative, can help fill gaps in our knowledge of diet choice). The suite of methods will provide insights into both recent diet and average diet over a longer time-scale.

Body condition assessment of stranded carcasses should be completed routinely within all strandings programmes; the potential for increased monitoring of body condition in live animals as a real-time indicator of health should be investigated (e.g. by integration into existing monitoring schemes, analysing still and video imagery from capture, mark, recapture

programmes and development of aerial drone studies). Development of proteomic and metabolomic assays of blubber could further assist in characterising physiological status and energy balance from live biopsy and stranded cases.

Studies on health status are also essential to help interpret information of diet and condition, e.g. to determine whether apparent starvation has a pathological cause.

An appropriate frequency of abundance and distribution data collection of predator and prey will enable identification of correlation with prey and cetacean distributions to inform management priorities.

All relevant strandings programme data, including an overview of the physical samples archive, should be made available through the ASCOBANS strandings database, to enable the best use of available evidence across the Agreement Area, and in collaboration with neighbouring regions.

TOR B. Review sources of information on prey distribution and abundance (e.g., fishery landings and effort data, stock assessments, fish surveys (which potentially offer information with a higher spatial resolution), habitat models for fish and cephalopods) and, if appropriate, propose a mechanism to collate relevant data, focused on species already identified as of importance in the diet of small cetaceans.

TOR E. Review spatio-temporal trends in sightings data on distribution and abundance of small cetaceans, in relation to possible relationships with trends in distribution and abundance of their known prey.

TORs B and E are closely related and therefore have been covered together. This is a developing and complex area of work.

The distribution of many small cetaceans is closely linked to the distribution of their prey, but our understanding of prey availability is often very limited. Where the prey species are also fished commercially, there is may a variety of information available. Whilst fishing effort data and landings data could contribute useful information for assessments of prey depletion, publically available data are often difficult to link to a specific location at sea (at best they can be associated with an ICES rectangle). The data from fish and stock assessment surveys will be more valuable, providing information specific to the distribution, abundance and biomass of prey species that are also of commercial importance.

For harbour porpoises, efficient foraging (maximising intake whilst minimising expenditure) is an essential element for survival and reproduction. Therefore, understanding the energy available in an ecosystem is critical to understand the ecology of the species, identify important areas and to understand the potential drivers of change for populations. The UK Joint Nature Conservation Committee (JNCC) commissioned work to assess the spatiotemporal distribution the energy available in prey species of harbour porpoises in the North Sea, with a particular focus on the Southern North Sea Special Area of Conservation (SAC), which was created based on predictions of persistent high-density areas of harbour porpoise. The diet of harbour porpoises consists of a wide variety of fish and cephalopod species and varies regionally, although a few prey types dominate the diet in any one area. Important prey species include gobies, whiting, Atlantic herring, sandeels, European sprat and Atlantic cod (Santos, 1998; Santos & Pierce, 2003; Santos et al 2004; Leopold et al 2011; Jansen, 2013; Leopold, 2015; Ross et al 2016); see Table 1 (based on Ransijn et al 2019).

Ransijn et al (2019) used data from the International Bottom Trawl Survey (NS-IBTS) to create density surface models for Atlantic cod, whiting, European sprat, Atlantic herring and sandeels. Data from 2003-2017 were used to make predictions for the years 2005 (SCANS II) and 2016 (SCANS III) for which estimates of harbour porpoise abundance and distribution in the North Sea were available (Hammond *et al* 2013, 2021). Because bottom trawl gear does not catch all fish in the path of the net, survey catches do not generally represent true amounts of fish in the area. Ransijn et al (2019) compared the NS-IBTS estimates of abundance with the stock assessments in order to account for these differences. Estimates of biomass for each prey species were then converted to energetic content in order to provide an assessment of energy available for harbour porpoise. Seasonal variation seen in energy density of fish, which is especially notable mature herring (Pedersen and Hislop, 2001) was taken into account for herring and whiting although not for other species. Energy density of the largest size classes of lesser sandeel in August is around double the value in April (Hislop et al 1991). It should also be noted that some of the energy values used were from northwest Atlantic rather than European stocks and that the, does not appear to have been taken into account. An example of the mapped output from Ransijn et al (2019) is shown in Figure 1 for the summer period (July to September).

Table 1. The main prey in the diet of harbour porpoises in the North Sea: percentage of reconstructed biomass from several studies. For each study, the range of years covered and the sample size are indicated. Adapted from Ransijn et al (2019) and based on results in (1) Santos (1998), (2) Jansen (2013), (3) Leopold et al (2011), (4) Leopold (2015) and (5) Santos et al (2004).

Prey species / family	Timeframe for study (number of porpoise stomachs)					
	Dutch waters				Scottish waters	
	1989-1995 n=62 ¹	2003-2010 n=76 ²	2003-2010 n=229 ³	2006-2014 n=826 ⁴	1992-1996 n=72 ¹	1992-2003 n=188 ⁵
Gobiidae	6.4%	36.6%	22.1%	20.5%		
Gadidae	85.9%			36.5%	54.2%	
whiting	78.7%	25.4%	42.3%		43.6%	53.0%
Haddock, saithe, pollack						5.6%
Atlantic cod	3.3%	5.2%	4.4%			3.8%
Clupeidae	1.9%			10.9%		
Atlantic herring		5.9%	4.6%		3.0%	1.3%
European sprat		4.1%	5.8%			
Ammodytidae	2.8%		11.1%	18.1%	41.1%	25.6%
Lesser sandeel		13.2%				

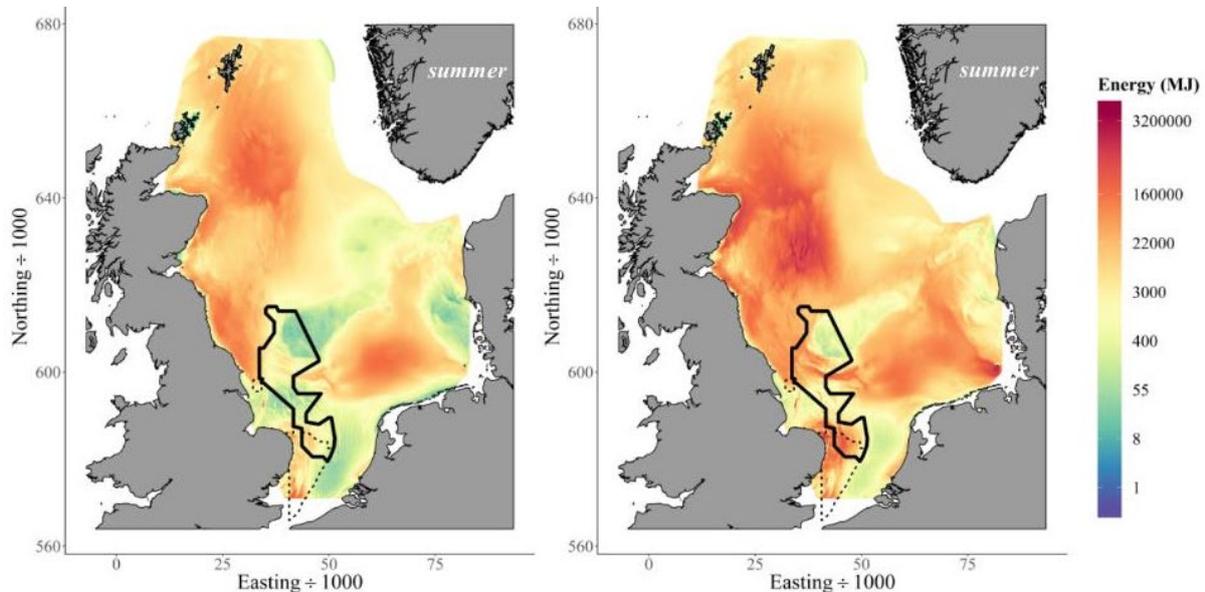


Figure 1: Spatiotemporal summer (July-September) distribution of porpoise prey species energy per km² for the North Sea, illustrated for 2005 on the left and 2016 on the right. Bold outlines represent the corresponding seasonal part of the Southern North Sea SAC and the dotted lines represent the remainder of the site. Lower figure illustrates porpoise distribution. (From Ransijn et al 2019).

Ransijn et al (2019) concluded that there are extremely high levels of energy available relative to the population density of harbour porpoises and daily energy requirements for the species in the North Sea, while noting that this does not take into account the amounts removed by fisheries and other predators. In addition, the authors comment that, the SAC region does not seem to cover the very highest energy areas identified by the spatial models in the North Sea, but nonetheless comprises a significant energy resource. This work was extended to incorporate estimates of foraging range based on telemetry tracking and stranding data by Ransijn et al (2021), allowing investigation of multivariate functional responses. Model results confirmed that the importance of all the main prey species in the diet increased as a function of their availability and was higher when the availability of alternative prey was lower. However, there was also evidence of a preference for sandeel, consumption of which was consistently

higher than predicted by the model, and remained high even when the availability of other prey was high.

Similarly, harbour porpoise habitat models for the North Sea have shown an increasing porpoise density with decreasing distance to sandeel grounds, at least within the range 0-50 km (Gilles et al 2016). Such studies clearly demonstrate the value of integrating data from multiple sources. Inclusion of information on prey consumption from strandings, predator foraging distribution using telemetry, and prey availability from fish surveys, into statistical modelling approaches provides a useful framework for considering the potential for prey depletion at the regional seas scale.

It is important to understand the historical ranges and distributions of cetaceans, and how they may have adapted to past climatic events and shifts in prey distribution. For example, common dolphin abundance in the North Sea has been highly variable in recent decades and there have been movements into the northern sector, related to the main driver of climate variability in the region, the North Atlantic Oscillation (NAO) (Camphuysen & Peet 2006, Evans et al 2003, Evans & Scanlan 1989, Murphy 2004, Murphy et al 2013) and the spread into the North Sea of warm-water prey species such as sardine (*Sardina pilchardus*) and European anchovy (*Engraulis encrasicolus*) (Beare et al 2004, Evans & Bjørge, 2013). The NAO is driven by latitudinal variations in atmospheric pressure, which determine the strength and direction of warm westerly winds and associated currents and may thus affect both sea temperature and the distribution of fish species upon which the dolphins feed. In recent years, it has become more difficult to disentangle the effects of natural large-scale ocean climatic variation recent anthropogenic global warming (Alheit et al 2007, 2012, Montero-Serra et al 2015), thus making it more difficult to predict future shifts in the distribution of common dolphins in the NE Atlantic. There is evidence of recent weakening of the Gulf Stream (Caesar et al 2018, Praetorius, 2018, Thornally et al 2018) which will reduce inflow of warm and nutrient-rich Atlantic waters, leading to cooling and loss of productivity in the seas off Europe's Atlantic coasts (see Murphy et al 2021).

ToR C. Liaise with other ASCOBANS initiatives to develop health/condition indicators for small cetaceans, based on information from live animals and/or necropsies, with the ultimate aim to improve the resolution of these indicators for identifying impacts of prey depletion and other cumulative stressors. Establish collaboration with HELCOM in relation to their development of a health indicator for porpoises. The indicators are likely to be multi-faceted, including information on pathology, physiological status (e.g. pregnancy, stress), body condition (e.g. blubber thickness), considering that simple indicators such as blubber thickness are influenced by multiple factors and do not necessarily reflect resource abundance.

Assessing cetacean health and condition

Effective assessment of the role of resource depletion on cetacean health is complex and requires integration of data from a range of sources. Assessment of starvation or emaciation as a cause of death requires a multifactorial approach, has no single pathognomonic indicator, and attribution based on necropsy data is often a diagnosis of exclusion. At an individual level, identification of a fitness cost attributable to a lack of prey or nutrient deficiency requires consideration of observed body condition in an ecological context and, in the context of stranded animals, assessment of a range of potentially causal factors.

Effective assessment of the impact of prey depletion at a population level could potentially be achieved by aggregating data from stranded individuals and subsequent diet analyses, sightings data and prey stock assessments, again with careful consideration to the ecological context and expected variability in parameters. A framework for the approach could include:

- Cetacean population ecology factors, such as species, season and age, including the possibility that animals are in an extralimital, dynamic or otherwise unsuitable habitat. Assessment could consider data derived from necropsied animals such as life history parameters, (including age at sexual maturity and pregnancy rates) combined with abundance, distribution and trend information from live animal sightings.
- Individual health factors such as infectious disease, trauma, ingestion of marine litter, effects of pollution and contaminant burden, including physiological status (e.g. pregnancy, reproductive stress), body condition (e.g. blubber thickness, accounting for allometric relationships of blubber thickness with body size), and diet composition. Much of this will be derived from necropsy data of stranded animals but assessment of body condition of at-sea or live-stranded and refloated/released animals is also possible.
- Prey abundance, distribution and trends from stock assessment data, as well as prey 3D aggregation, proximal composition and nutritional value. These may differ depending upon cetacean species, age and season.

It is normal for some (especially larger) cetacean species to experience periods where energy intake is below expenditure, and certain species are physiologically adapted to fasting. Crucially, fasting animals are doing so under a degree of hormone-mediated control, whereas starved animals have lost homeostatic regulation and their physiological function is compromised, usually in response to an unexpected decrease in food supply. However, some smaller species, notably harbour porpoises, are considered particularly vulnerable to even short periods of fasting, due to their small size and high metabolic rate necessary to maintain thermoregulatory homeostasis (Wisniewska et al 2016).

In theory, acute and severe resource depletion could result in acute starvation, distinguished from fasting by potentially identifiable pathophysiological effects, such as dehydration, hepatic lipidosis and changes in the adipocytokine milieu. More prolonged periods of prey insufficiency and associated negative energy balance may be identifiable by wider and more chronic impacts on health and welfare status, such as increased stress, higher disease prevalence and

lower fecundity. Identification and standardization of these metrics requires significant further work, but, alone or in combination, could eventually be of use as indicators of impact.

If many animals are stranding in poor nutritional condition (especially for a species or population where this did not occur before) this could be indicative of prey depletion, and that the situation may well be worse than seeing some marginal changes in body condition in bycaught animals. Animals in a poor nutritional condition may be more susceptible to infectious disease as well as the consequences of mobilisation of lipophilic persistent organic pollutants (POPs) stored in the blubber. In turn, these effects may reduce the chances of reproductive success (e.g. Aguilar & Borrell 1994).

At the same time, knowledge on distribution and abundance of favoured prey species (which may differ depending upon cetacean species, age and season) is highly necessary to estimate risk/exposure to resource depletion.

In larger cetacean species, maternal body condition affected foetus growth in minke whales (Christiansen et al 2014) and pregnancy rates in fin whales (Williams et al 2013), whilst declines in (preferred) prey abundance of killer whales have been linked to reduction in their fecundity (Ward et al 2009). Changes in reproductive output could, in the long term, affect population numbers and may therefore have serious consequences for population growth.

A starting point to amass evidence for population level effects could be the assessment of (changes in) life history parameters, including age at sexual maturity and pregnancy rates using information gained from necropsied animals. Typically, it is noted that pregnancy rates may be underestimated if there is a large proportion of sick animals in the sample. One solution is to base calculations only on animals that died due to physical trauma (e.g. bycatch, collisions or predatory attacks). However, in the context of estimating effects of prey depletion on population dynamics, it makes no sense to exclude sick and emaciated animals which are precisely those most likely to have reduced pregnancy rates.

Filling data and knowledge gaps

There is scope for ASCOBANS to liaise /collaborate with other conventions and working groups on the topic of prey depletion: within the MSFD Framework, there has been discussion regarding health indicators, however, no indicator has yet been established. Within HELCOM, blubber thickness was deemed unacceptable as a reliable indicator of health due to the many physiological changes that may affect blubber thickness. Long-term studies using full pathological investigations and a control group of 'healthy' animals are necessary to select and subsequently propose important organ systems that could be indicative of the health status for individuals or species.

Further work on assessing body condition indices for the common dolphin, work that may aid in developing an OSPAR's biodiversity indicator for monitoring ecosystem state, is being undertaken by a PhD at the Atlantic Technological University (see ToR D for further information).

ToR D. Review and collate information on diet of small cetaceans in the ASCOBANS area (including long-term dietary variation) and foraging behaviour, to improve understanding of likely responses to changes in prey availability; identify knowledge gaps and encourage new research and monitoring of diet, considering that ongoing monitoring of diet and spatio-temporal trends is an essential part of surveillance of cetacean conservation status.

Morphology, energetics, distribution and diet

The skull characteristics and dentition of different cetacean species and populations are good clues to their dietary preferences. For most deep-diving beaked whale species, dentition is much reduced or adapted for purposes other than foraging (MacLeod 1998, MacLeod et al 2006), a characteristic of cephalopod eaters since the rubbery flesh is not easily handled with small conical teeth, and it has therefore been hypothesized that these predators use suction feeding.

The blunt, rounded jaws and rostra of pilot whales and Risso's dolphin have also been linked to suction feeding (Werth 2000, 2006). This foraging technique, although involving low energy investment, limits the maximum size of prey that can be ingested as they are swallowed whole (Werth 2000, 2006, MacLeod et al 2006, MacLeod et al 2007b). Hence, it is expected that these cetacean species will be specialized in feeding on relatively small prey.

Despite the indirect evidence suggesting that these species would forage on the same type of prey, their dietary niches appear to be well segregated. For example, Sowerby's beaked whales consume only very small prey (<10 g body mass), while Cuvier's beaked whales and long-finned pilot whales mostly eat small to medium-sized prey (10–100 g body mass). Risso's dolphins and Sowerby's beaked whales forage largely on the seabed beyond the continental shelf edge, whereas long-finned pilot whales exploit both oceanic and neritic habitats (Kiszka et al 2007, Spitz et al 2011, Méndez Fernandez et al 2012). Furthermore, energy requirements vary between these species. Beaked whales and Risso's dolphins may have low energy requirements, hence feeding almost exclusively on cephalopods, which represent energy-poor prey, whilst long-finned pilot whales need richer food in terms of energy density, in order to meet somewhat higher energy requirements, hence feeding on both cephalopods and fish (Spitz et al 2011, 2012, 2018). In the Azores, studies combining biologging with eDNA analysis found that Risso's dolphin and Cuvier's beaked whale showed strong overlap in prey spectra between foraging zones, selectively targeting epi/meso- and bathypelagic foraging zones for their cephalopod prey, with fewer, more calorie-rich, mature cephalopods taken in deeper waters. However, there was interspecific niche segregation in that Risso's dolphins foraged closer to the surface and nearer to the shore than Cuvier's beaked whales (Visser et al 2021).

Delphinids (common dolphins, striped dolphins, bottlenose dolphins, Atlantic white-sided dolphins, white-beaked dolphins and killer whales) display small, cone-shaped teeth, whereas phocoenids (harbour porpoises) have short, spoon-shaped teeth, capable of gripping and handling prey. They mostly capture prey using a pincer movement of the jaws, and some species may occasionally use suction feeding. Mastering both techniques enables them to have access to a wider range of prey sizes (MacLeod et al 2006).

The common dolphin is an oceanic species mainly encountered in intermediate to deep waters, mostly over the continental shelf, but is also found in coastal waters (Reid et al 2003; Goetz et al 2015, Waggitt et al 2020). This is consistent with dietary studies showing that they feed on mesopelagic fish such as blue whiting (*Micromesistius poutassou*), as well as more coastal species, such as horse mackerel (scad, *Trachurus trachurus*), sardine and anchovy (Massé 1996, Silva 1999, Abaunza et al 2003, Carrera and Porteiro 2003, Pusineri et al 2007, Méndez Fernandez et al 2012, Santos et al 2013a, b, Spitz et al 2018).

This species has high energy requirements (Meynier et al 2008, Spitz et al 2012) and would thus be expected to show a preference for energy-rich prey such as small pelagic fish (see species cited above) (Poulard & Blanchard 2005, Meynier et al 2008, Spitz et al 2010, 2012,

2014, 2018). Indeed, there is evidence of quality-based prey selection in common dolphin, with more energy-rich species being more preferred (Spitz et al 2010).

The distributions of white-beaked dolphin and harbour porpoise in North-west Europe are concentrated over the continental shelf, suggesting they feed on more coastal species, whereas the Atlantic white-sided dolphin and striped dolphin are oceanic species, occurring mostly in deep waters off the continental shelf edge, and the killer whale is present in both neritic and oceanic habitats (Weir et al 2001, Reid et al 2003, Evans 2020). The broad skulls and short beaks of harbour porpoise and white-beaked dolphin are adapted for feeding off the seabed (Evans 1987).

These species have high (e.g. porpoise or medium to high (e.g. striped dolphin and bottlenose dolphin) energy requirements, with the former most likely to prefer high caloric density prey, such as small pelagic fish and the latter likely to be somewhat less selective (Koopman 1998, Lockyer and Kinze 2003, Lockyer 2007, Pierce et al 2007, Spitz et al 2012, 2018).

The striped dolphin is an oceanic species that occasionally enters neritic habitats, hence feeding mainly upon oceanic prey, such as deep-water cephalopods and fish (Spitz et al 2006, 2011, Méndez Fernandez et al 2012, Goetz et al 2015).

Bottlenose dolphins are present in both shallow coastal waters and in deeper waters, over the shelf edge (Reid et al 2003, Goetz et al 2015, Evans 2020). Resident coastal populations tend to feed on a wide range of shelf or estuarine species, including cod, whiting, salmonids, sea bass, eels and various flatfish (Santos et al 2001, 2007, Wilson 2008).

Small cetaceans may show narrow or broad diets, displaying more or less selectivity for certain types of prey, not always the most energy-rich species. It is common to refer to species with a broad diet as “opportunistic”, implying an absence of preferences based on anything other than availability, and frequently eaten prey species may be described as “preferred”. However, both terms imply an understanding of foraging behaviour, which is often lacking. Given information on prey and predator distribution, predator foraging movements, predator diet and caloric content of prey it is possible to derive multivariate functional responses (e.g. Ransijn et al 2021) and thus demonstrating the degree of preference for different prey species. From an optimal foraging theory perspective, diet choice can be predicted if the availability and energy density of different prey types are known, along with the capture and handling costs of eating each prey type.

Methodologies to study diet

As has known since at least 17th century (Tyson, 1680), cetacean stomachs, like those of ruminants (to which they are closely related), have four chambers. Stomach contents analysis is the most commonly used methodology for assessing small cetacean diet. It usually gives an insight into the diet in the preceding 6 to 48 hours, although certain prey remains such as cephalopod beaks, which are both resistant to digestion and may become lodged in the stomach lining may remain in the stomach for longer periods. It is still a highly informative method and the only one that consistently allows determination of prey life-stages in addition to prey identity (Pierce & Boyle 1991, Hayden et al 2014, Nielsen et al 2018). Being based on the identification of fish otoliths and bones, cephalopod mandibles (beaks) and crustacean exoskeletons, this method presents some limitations. Although many guides exist, especially for fish otolith identification), access to a reference collection is necessary (Pierce & Boyle 1991). Secondly, the identification of hard remains of prey can be quite difficult, and sometimes limited to relatively high taxonomic levels, since bones are often damaged during capture and ingestion, and the material is often partially digested and sometimes eroded (Nielsen et al 2018). This can also lead to an underestimation of prey size when determined based on eroded otoliths or bones (Pierce & Boyle 1991, Silva 1999, Santos et al 2013a). In addition, some fish lack otoliths (non-teleost fish) or have fragile easily digested otoliths, which emphasises the need to identify other hard parts in parallel (Pierce & Boyle 1991). Thirdly, an inevitable issue is sample contamination due to secondary predation, also known as the “Russian doll” effect (presence of prey remains that were ingested not by the predator itself but by its prey) (Pierce

& Boyle 1991, Pierce et al 2007). Note, however, that secondary prey may still contribute to the predator's nutritional intake (Bowser et al 2013, Nielsen et al 2018). Lastly, different prey can exhibit different digestion rates, which can lead to overestimation of the prey species for which hard parts are difficult to digest and persistent in the stomach, such as cephalopod beaks (Santos et al 2001a, Fernández et al 2009, Glaser et al 2015).

Molecular approaches to identification of prey remains in stomach contents can increase the taxonomic resolution of diet composition and detect species that leave behind no recognizable hard parts, although the approach is not fully quantitative (the amount of DNA amplified is not necessarily a good indicator of the biomass or number of each prey type that was ingested). This is an approach that is becoming increasingly accessible as the methodology has evolved and costs have fallen (Pompanon et al 2012, Nielsen et al 2018). As with analysis of hard parts is also subject to sample contamination due to secondary predation, which is even harder to detect, A possible further concern is environmental contamination, as DNA in the water can be swallowed by the predator (Kelly et al 2014) but, equally, eDNA analysis at known foraging locations of cetaceans can be used to identify prey species (e.g. Visser et al 2011).

A third approach is to analyse fatty acids using blubber samples. This is based on the fact that each prey species possesses a unique fatty acid profile, allowing their identification (Dalsgaard et al 2003). Note however that the fatty acid profile of a prey species reflects its diet and may therefore not be permanently fixed. Although it is widely used for diet tracing, identifying all the items present in the predator's diet is rarely feasible (Dalsgaard et al 2003, Traugott et al 2013). Despite that, quantitative prey proportions in a predator's diet can be estimated using quantitative fatty acid signature analysis (QFASA) (Iverson et al 2009). One limitation is that fatty acid profiles are modified in consumers, so that calibration coefficients are necessary to avoid biases when estimating prey proportions (Iverson et al 2004, Happel et al 2016) – and calibration coefficients not only vary between predator species, they may also depend on the prey species eaten (Rosen & Tollit 2012). However, Bromaghin et al (2017) developed an approach of determine diet composition and calibration coefficients simultaneously.

The use of stable isotopes is based on the fact that a predator's stable isotope ratios reflect that of its prey (Michener et al 2007, Nielsen et al 2018). Bulk or compound-specific stable isotope analysis can be used. The compound-specific analysis provide more dietary tracers than bulk stable isotopes, therefore allowing the differentiation between more types of prey. This method presents an advantage compared to other diet analysis methods, which is the possibility of assessing the broad diet (or at least trophic level) over a long-time scale (weeks, months or even years), dependent upon the half-life of the stable isotopes and the turnover rate in the studied tissue (Abend & Smith 1995, Monteiro et al 2015, Nielsen et al 2018). However, being dependent on tissue turnover rates also implies that the stable isotopes are integrated over different time scales both in different tissues of the same animal and (since metabolic rates are species-specific), in the tissue of different species (Tieszen et al 1983, Hobson & Clark 1992, MacAvoy et al 2006). Another drawback of this methodology, at least for bulk analysis is that several prey species may have similar isotopic profiles. Interpretation can also be problematic if baseline values for some ecosystems are unknown or similar to each other (Ramos & González-Solís 2012, Louis 2014). Since stable isotope ratios are measured in body tissues, differences in the rate of digestion of different prey species are irrelevant and results from this approach can be complementary to those from stomach contents and fatty acid analysis (Monteiro et al 2015), bearing in mind that the information provided on diet is relatively coarse (generally at the trophic level rather than species level).

Proteins can also be used as dietary tracers, as fish muscle protein composition is species-specific (Mackie 1969, 1972, 1980, Hume & Mackie 1980, Laird et al 1982). Protein profiles can be revealed by electrophoresis or by raising and applying specific antisera. As with all such methods it is important validate the results to ensure that similar species are not confounded (Pierce & Boyle 1991) and these approaches have largely been abandoned in favour of molecular methods of prey identification.

Marine mammals bioaccumulate contaminants in their bodies during their lifetime. As most of these contaminants originate from their prey, it is possible to use the interaction with these contaminants as a dietary tracer (Aguilar et al 1999, Lahaye et al 2005). The use of cadmium

as a metallic tracer is a good example. Cephalopods are a major source of cadmium due to their mode of feeding, and thus will be revealed in the diet of those cetacean species feeding largely upon them (Hamanaka et al 1982, Bustamante et al 1998, 2002, Lahaye et al 2005). However, it would be difficult to identify the prey to species level based on such data. Concentrations Persistent Organic Pollutant concentrations, e.g. those of polychlorinated biphenyls (PCBs) might prove more informative since the concentrations of a large number of different PCB congeners can be measured which might provide enough discrimination to distinguish different prey species.

Distribution and diet of different cetacean species

Distribution maps of some of the commoner cetacean species in the eastern North Atlantic and North Sea are displayed in Figure 2 and Table 2 summarises the main prey species recorded in the diet of each cetacean species in the ASCOBANS Agreement Area.

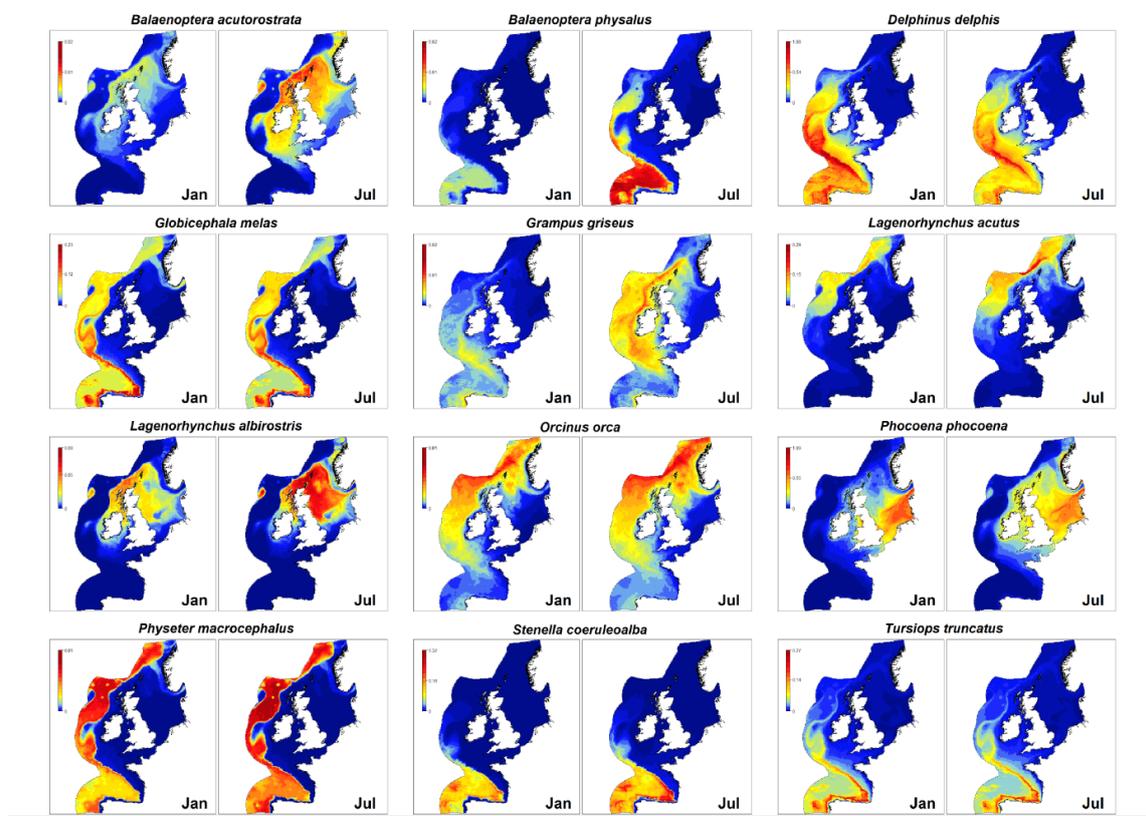


Figure 2. Summer and winter modelled density distributions for the 12 most common cetacean species in the eastern North Atlantic and North Sea (source: Waggitt et al 2020)

Table 2. The main prey species recorded in the diet of each cetacean species in the ASCOBANS Agreement Area. See the main text for further details.

Species	Foraging habitat	Prey species commonly taken
Harbour porpoise	Mainly benthic	Whiting, sandeel, sprat, herring, cod, gobies, pouts
Bottlenose dolphin	Meso- and benthopelagic	Sea bass, salmon, whiting, cod, herring, sandeel, sprat, saithe, haddock, pouts, hake, scad, mullets
Common dolphin	Pelagic	Mackerel, pouts, sardine, anchovy, whiting, scad, sprat, sandeel, blue whiting
Risso's dolphin	Mainly benthic	Octopus, cuttlefish, various small squids
Striped dolphin	Meso- and benthopelagic	Sprat, blue whiting, whiting, silvery pout, pouts, hake, scad, anchovy, bogue, garfish, haddock, saithe, myctophids, gobies, squids
Atlantic white-sided dolphin	Pelagic	Herring, mackerel, silvery pout, blue whiting, scad, argentine, myctophids, squids
White-beaked dolphin	Pelagic	Cod, whiting, herring, mackerel, hake, scad, sprat, pouts, sandeel, haddock, sole, gobies, octopus
Killer whale	Pelagic	Mackerel, herring, salmon, cod, halibut, other marine mammals
Long-finned pilot whale	Benthic and pelagic	Mainly squids; also mackerel, cod, whiting, pollack, scad, sea bass, hake, sole, pouts, eels
Northern bottlenose whale	Benthic and pelagic	Mainly squids (particularly <i>Gonatus</i>); also herring, redfish
Sowerby's beaked whale	Mesopelagic	Squids, cod, hake, sandeel
Blainville's beaked whale	Meso- and benthopelagic	Mainly squids; also gadoids and myctophids
Cuvier's beaked whale	Mainly benthic	Mainly squids; also blue whiting and gadoids
Sperm whale	Mesopelagic	Mainly squids; also saithe, monkfish, halibut, other fish, and crustaceans
Minke whale	Meso- and benthopelagic	Sandeel, sprat, herring, cod, haddock, saithe, whiting, mackerel, pouts, gobies
Fin whale	Pelagic	Mainly euphausiids, also copepods; herring, mackerel, sandeel, blue whiting, squids
Sei whale	Pelagic	Mainly copepods; also euphausiids, small schooling fishes and squids
Humpback whale	Pelagic	Mainly euphausiids; also herring, sprat, sandeel

Northern bottlenose whale: In the central and eastern North Atlantic, the northern bottlenose whale occurs in deep waters (usually >500m depth) from Svalbard south to the southern tip of the Iberian Peninsula, with concentrations around Iceland, northern Norway, west of Svalbard, and the Faroe Islands.

This species mainly feeds on deep-water gonatid squids, particularly *Gonatus fabricii* in northern waters and *G. steenstrupi* further south (Bloch et al 1996, Lick & Piatkowski 1998, Hooker et al 2001, Santos et al 2001b, Fernández et al 2014). Stomach contents of nine whales stranded in the Faroe Islands contained at least 13 different squid species (Bloch et al 1996), while the stomach contents of whales stranded from the North Sea contained at least 16 different species in one study (Santos et al 2001) and 21 different species in another (Fernández et al 2014). Apart from *Gonatus*, other common taxa found are *Teuthowenia* spp., *Taonius pavo* and *Histioteuthis reversa* (Hooker et al 2001). For ten whales stranded from the

North Sea, *Gonatus* spp., *Teuthowenia* spp. and *Taonius pavo* together made up more than 90% of the total diet by both weight and number (Fernández et al 2014).

Sowerby's beaked whale: A largely deep water temperate species, the distribution of Sowerby's beaked whale appears to be mainly from around the Faroe Islands and west of Norway south to the Bay of Biscay and out into the central Atlantic (including the Azores); it only rarely enters the North Sea and Baltic (Evans 2020). An analysis of stomach contents from three individuals in the Bay of Biscay and ten from the Azores revealed that this species, unlike most of the other beaked whales, primarily feeds on fish (Pereira et al 2011, Spitz et al 2011). In the Bay of Biscay sample, the most common prey were gadids: blue whiting, *Trisopterus* spp. and European hake (*Merluccius merluccius*) (Spitz et al 2011). In the Azores, the diet consisted mainly of small mid-water fish, the most numerous being *Diaphus* sp., *Lampanyctus* sp. and Melamphaidae species. Myctophids were present in all stranded individuals, followed by Diretmidae, Melamphaidae and *Opisthoproctus soleatus*, while the remaining fish species were scarce or single occurrences.

Cuvier's beaked whale: Also a deep water species, the Cuvier's beaked whale appears to be the most common beaked whale in Southern Europe, around the Iberian Peninsula and in the Bay of Biscay, although its distribution at least in recent years extends northward west of Ireland towards the Faroe Islands.

Stomach contents analyses from one animal stranded in Scotland and two from Galicia indicate a diet dominated by oceanic cephalopods, mainly squid: *Teuthowenia megalops*, *Mastigotuthis schmidtii*, and *Taonius pavo*, *Histioteuthis reversa*, and *Gonatus* sp. (Santos et al 2001). Other prey included *Histioteuthis bonellii*, *Histioteuthis arcturii* and *Todarodes sagittatus*, as well as *Vampiroteuthis infernalis*, *Stauroteuthis syrtensis*, and *Japotella diaphana*. Ten samples from the Bay of Biscay comprised small to medium-sized cephalopods, a third of which by biomass were Cranchiid squids, including mainly *Teuthowenia megalops* and *Galiteuthis armata*, and a third Histioteuthid squids, mainly *Histioteuthis reversa* and *Histioteuthis bonnellii* (Spitz et al 2011).

As a note of caution, recent improvements in cephalopod beak identification and taxonomy have resulted in some past identifications of Southern Ocean cephalopods being revised (Cherel 2020) and a similarly critical review of past identifications from the northeast Atlantic may be needed, especially for oceanic cephalopod species.

Long-finned pilot whale: Within the ASCOBANS Agreement Area, the species is found mainly along the edge of the continental shelf from the Faroes south to the Iberian Peninsula, although it will enter the northern North Sea and western English Channel. Pilot whales are scarce in the Irish Sea, Skagerrak, Kattegat, Belt Seas and Baltic (Evans 2020).

Cephalopods are the main component in the diet of this species (Gannon et al 1997, Dos Santos and Haimovici 2001, De Pierrepont et al 2005, Beatson et al 2007, Beatson & O'Shea 2009, Spitz et al 2011, Santos et al 2014), although fish may also be taken (Overholtz & Waring 1991, Spitz et al 2011). In Scotland, the Bay of Biscay and northwest Iberia, stomach contents mainly comprised octopods such as curled octopus (*Eledone cirrhosa*), and squid such as European flying squid (*Todarodes sagittatus*), reverse jewel squid (*Histioteuthis reversa*), umbrella squid (*Histioteuthis bonnellii*), and armed cranch squid (*Galiteuthis armata*), but also included conger eel (*Conger conger*) and scad (Spitz et al 2011, Monteiro et al 2015). In Scotland, prey from the pelagic squid family Ommastrephidae were the most important whereas off Northwest Spain, neritic octopod species, such as curled octopus, were recorded at highest frequency (Santos et al 2014).

Killer whale: Although the species has a global distribution, it is most abundant in polar and subpolar regions. Within the ASCOBANS area, it occurs primarily in deep waters between Norway and Iceland including the Faroes south to west Scotland and western Ireland. It is rare in inner Danish waters, the Baltic Sea, Irish Sea, central and southern North Sea, English Channel, Bay of Biscay and around the Iberian Peninsula (although a small population feeding upon bluefin tuna occurs in the Strait of Gibraltar) (Evans 2020).

Individual killer whale populations tend to specialise in feeding on particular kinds of prey (Felleman et al 1991), including those which specialise in feeding on other marine mammals. Such specialisation may make these populations vulnerable to depletion of preferred prey species. However at least some killer whale groups appear to be capable of switching between different prey types (Vongraven & Bisther 2013). The most important fish prey for killer whales in the Northeast Atlantic appears to be Atlantic herring with the whales following the herring migrations between Norway and Iceland (Foote et al 2012, Nøttestad et al 2014, Vongraven & Bisther 2014). It frequently associates with trawlers fishing for Atlantic herring or Atlantic mackerel (*Scomber scombrus*) (Couperus 1993, 1994, Luque et al 2006) and animals in Scottish waters will predate seals (Bolt et al 2009).

Atlantic white-sided dolphin: This species occurs in the northern part of the ASCOBANS Agreement area mainly along the shelf edge although it will seasonally enter coastal waters such as around the Faroe Islands, Shetland and Orkney and Hebrides. It is rare south of Ireland, and its range seems to be shifting north in response to climate change (Evans & Waggitt 2020).

A study of a mass stranding in western Ireland found *Trisopterus* spp. and blue whiting to be the most important prey, both by number and by weight, followed by whiting. Other prey species included Atlantic mackerel, silvery pout (*Gadiculus argenteus*) and myctophids (Hernandez-Milian et al 2015).

White-beaked dolphin: In the ASCOBANS Agreement Area, the white-beaked dolphin is primarily a cold temperate shelf species occurring from Norway south to the British Isles and Ireland. It is common in the North Sea and the west of Scotland, rarer off the west of Ireland and only occasionally enters the Irish Sea or further south in the Bay of Biscay (Evans 2020).

Studies in the North-east Atlantic have identified whiting and Atlantic cod as important prey for white-beaked dolphins (De Pierrepont et al 2005, Canning et al 2008, Jansen et al 2010). Some slight variation in the preferred prey species can be observed between areas. In Dutch and German waters, poor cod (*Trisopterus minutus*) was found in addition to whiting and cod in white-beaked dolphin stomachs (Lick 1994). In French waters, pollack (*Pollachius pollachius*) and *Trisopterus* sp. were also found (De Pierrepont et al 2005). In British waters, haddock (*Melanogrammus aeglefinus*) and European hake were also eaten (Canning et al 2008). In other regions, distribution and abundance of these dolphins were related to preferred prey (Brodie 1996, Trippel et al 1999, MacLeod et al 2004).

Diet was found to be correlated to neither size nor sex, at least in the southern North Sea and around Scotland. No seasonal variation was found, nor was any long term variation detected (Jansen et al 2010). However, sample sizes remain limited.

Risso's dolphin: The species is found particularly along the continental shelf slope of Atlantic Europe from the Iberian Peninsula north to the Faroe Islands and west Norway. It is only occasional in the western Baltic and is uncommon in the North Sea except for the northern sector where it is regular in Shetland and Orkney (Evans 2020). Although never common, greatest numbers occur around the Hebrides, west of Scotland and Ireland, in the Irish Sea, in the western English Channel, Bay of Biscay and Iberian Peninsula.

Stomach contents analysis of 14 Risso's dolphins from two separate schools in the Faroe Islands (Bloch et al 2012) found they had consumed the same three species: the European flying squid, the veined squid (*Loligo forbesii*), and the curled octopus (*Eledone cirrhosa*), but in different proportions. In April, one dolphin also consumed a fourth species, the demersal lesser flying squid (*Todaropsis eblanae*). The diet includes both mid-water (*Todarodes* and *Loligo*) and bottom dwelling (*Eledone*, *Todaropsis*) species.

In Scottish waters, stomach contents of 11 Risso's dolphins contained curled octopus 74% of the diet numerically and almost 90% in terms of biomass, as well as smaller amounts of as loliginid (*Loligo* sp.) and ommastrephid squids (*Todarodes sagittatus* and *Illex coindetii* or *Todaropsis eblanae*), cuttlefish (*Sepia* spp.) and sepiolids. At least three species of gadid fish were also eaten (1.3% and 1.5% of the diet by numbers and weight respectively).

In Northwest Spain, the stomach contents of three Risso's dolphins included specimens of European (longfin) squid (*Loligo vulgaris*), common octopus (*Octopus vulgaris*), curled octopus and broadtail shortfin squid (*Illex coindetii*) (González et al 1994).

Bottlenose dolphin: The species is locally fairly common near-shore off the coasts of Scotland, Wales, South-west England, western Ireland, France, Spain and Portugal (Evans 2020). Much larger numbers range up and down the continental shelf edge anywhere between the Faroe Islands and the Iberian Peninsula. Although still to be fully established, it is quite possible that these form distinct coastal and offshore ecotypes, as found in other parts of the world.

In neritic waters, bottlenose dolphins tend to feed mostly on large demersal and epibenthic fish (Barros et al 2000, Santos et al 2001a), whereas in oceanic waters they take mainly small very mobile mesopelagic prey (Pusineri et al 2007). In the Bay of Biscay, the main prey found in stomach contents were European hake and blue whiting, followed by scad, mullets (Mugilidae), and, to a lesser extent, squid of the genera *Loligo* and *Sepia* (Desportes, 1985, Spitz et al 2006, Santos et al 2007). In western Ireland, analysis of the stomach contents of 12 bottlenose dolphins revealed 37 prey taxa, with the main species being European hake, scad, common ling (*Molva molva*), conger eel, whiting, blue whiting, and pollack.

Common dolphin: The common dolphin is an abundant and widely distributed species, occurring in the ASCOBANS area particularly along the continental shelf break from the Iberian Peninsula north to northern Scotland, with greatest numbers in the Bay of Biscay. The species also ranges over the shelf, particularly in the western English Channel, Irish Sea, western Ireland and Scottish Hebrides. Common dolphins are rare in the central and southern North Sea, Skagerrak, Kattegat, Belt Seas and Baltic (Evans 2020),

Like the bottlenose dolphin, the common dolphin inhabits both inshore and offshore waters. There is some evidence to suggest that these may form different ecotypes, one being neritic and the other oceanic (Lahaye et al 2005).

Common dolphins generally prey on small, pelagic shoaling fish and, in some cases, cephalopods (Desportes 1985, Silva 1999, De Pierrepont et al 2005, Spitz et al 2006, Pusineri et al 2007, Garrido and Murta 2011, Garrido et al 2015, Santos et al 2013a). They show a great diversity of prey (Young and Cockcroft 1994, Silva 1999, Brophy et al 2009, Santos et al 2013a), although there is some evidence for selective behaviour (Spitz et al 2010, Meynier et al 2008), favouring particular prey when available but also displaying opportunistic foraging.

Stomach contents of 76 common dolphins stranded along the coast of Ireland were compared with those from 58 animals bycaught in the offshore tuna driftnet fishery southwest of Ireland (Brophy et al 2009). The diet of common dolphin stranded along the coast was dominated by gadids, particularly *Trisopterus* spp, whereas the offshore bycaught animals had mainly myctophids (particularly *Myctophum punctatum* and *Notoscopelus kroyeri*) in their stomachs, although scad was also important. The offshore sample comprised largely juvenile dolphins so there may also be an age effect, as well as a bias towards night feeding since that was when most of the dolphins were bycaught. Brophy et al (2009) reported that a preference for prey with higher lipid content might be responsible for seasonal movements of common dolphins within the North-east Atlantic, due to the energetic demands of pregnant and lactating females. The authors suggested that the offshore movement of some mature females (and calves) during the spring and summer was to take advantage of lipid rich prey at times when neritic prey had reduced caloric content or had dispersed to/from spawning groups.

A study in the Bay of Biscay also compared common dolphin diet in oceanic and neritic habitats. In the oceanic habitat, its diet was largely dominated by the lancet fish (*Notoscopelus kroyeri*), but other important prey included Mueller's pearlside (*Maurolicus muelleri*), glacier lantern fish (*Benthosema glaciale*), spotted lanternfish (*Myctophum punctatum*), Atlantic saury (*Scomberesox saurus*), angel clubhook squid (*Ancistroteuthis lichtensteini*), Atlantic gonate squid (*Gonatus steenstrupi*), common arm squid (*Brachioteuthis riisei*) and Atlantic cranch squid (*Teuthowenia megalops*) (Pusineri et al 2007). In neritic habitats, its diet included far fewer cephalopods (10 times less) (Pierce et al 2004) and mostly comprised of gadids, gobiids, clupeids, engraulids and carangids (Pusineri et al 2007). In the Bay of Biscay, these families are represented by sardine, followed by sprat, European anchovy, and scads (*Trachurus* spp.,

including *Trachurus trachurus*) (Meynier 2004, Meynier et al 2008, Spitz et al 2018). Sardine was also found to be the main prey in western Iberian waters, followed by chub mackerel (*Scomber japonicus*) and scads (*Trachurus* spp.). Other important prey in this area included blue whiting and European hake (Silva 1999, Cabral and Murta 2002). Cephalopods identified in the diet have included *Loligo* sp., *Alloteuthis* sp. and *Sepioloa* sp. (Desportes 1985).

Seasonal variation in the prey species taken has also been reported. In the Bay of Biscay, sardine was most important in autumn and winter, whilst sprat was absent, as were gobies in autumn. During summer, it was horse mackerel that were comparatively absent from the diet. These seasonal variations in diet were attributed to changes in prey availability (Meynier et al 2008). Variation over the years has also been observed in the Bay of Biscay. The contribution of sardine and anchovy in the diet has generally increased from the early 1980s to the early 2000s, whilst that of hake, sand smelt (*Atherina presbyter*), and *Trisopterus* spp., which were important prey in the past, has decreased, again reflecting adaptation of diet to prey availability in the area (Meynier et al 2008).

On the French coast, juvenile dolphins seem to prefer more pelagic prey compared with semi-benthic prey that adult dolphins mostly consume (Desportes 1985).

Striped dolphin: The striped dolphin is generally found further offshore than the common dolphin, mainly occurring beyond the shelf edge from the Iberian Peninsula north to the British Isles, with greatest numbers in the southern Bay of Biscay and west of the Iberian Peninsula (Evans 2020).

The striped dolphin feeds on both neritic and oceanic species of both fish and cephalopods (López et al 2003, Ringelstein et al 2006, Spitz et al 2006, Santos et al 2008), but displays a preference for small migrating mesopelagic fauna (Ringelstein et al 2006). According to Clarke (1996), its preferred prey are ommastrephid, loliginid, enoploteuthid and lycoteuthid squid. This species' dietary plasticity, and its capacity to switch between neritic and oceanic habitats to forage, have been well documented in the Bay of Biscay where both oceanic species and neritic prey species have been identified in stomach contents, although only neritic species were of high importance. The most important were sand smelt and blue whiting, followed by gobies, *Trisopterus* spp., Atlantic gonate squid, ommastrephid squid, and *Loligo* spp. (Spitz et al 2006). Off Scotland, however, where the species has occasionally stranded, the main species in stomach contents was whiting (*Merlangius merlangus*) along with *Trisopterus* spp. (Santos et al 2008). A larger study focusing on the oceanic sector of the outer Bay of Biscay identified lancet fish (*Notoscopelus kroyeri*), Cocco's lantern fish (*Lobianchia gemellarii*), Atlantic cranch squid (*Teuthowenia megalops*) and *Histioteuthis* spp. as the main prey of striped dolphins (Ringelstein et al 2006).

Santos et al (2008) found a higher number of *Trisopterus* spp. in female dolphins than in males in Scottish stranded animals. Spitz et al (2006), on the other hand, found no differences related to either sex, age, or season in the Bay of Biscay.

Harbour porpoise: Widely distributed over the North-west European shelf, harbour porpoises are common throughout much of the ASCOBANS area, although they are rare in the Baltic Proper, and relatively uncommon around the Iberian Peninsula.

Porpoises prey on small, schooling fish, mostly clupeids and gadids in the North Atlantic (Rae 1973, Smith and Gaskin 1974, Recchia & Read 1989, Fontaine et al 1994, Santos & Pierce 2003). Their diet is very broad, although the following species have most commonly been recorded across its North-west European range: Atlantic cod, sandeels, sprat, whiting, and herring (Santos & Pierce 2003, Vikingsson et al 2003, Heide-Jørgensen et al 2011, Hammond et al 2013). The relative importance of prey species varies both spatially and temporally. Across the northern North Sea and western Baltic, the harbour porpoise's main prey are cod and herring, followed by sprat. They also feed on whiting and sandeel, and in shallow coastal areas such as the southernmost North Sea and Belt seas, particularly gobies (Koschinski 2001, Börjesson et al 2003, Lockyer & Kinze 2003, Santos & Pierce 2003, Sveegaard et al 2012, Jansen et al 2013, Leopold 2015, Andreasen et al 2017).

Off Scotland, stomach contents analysis indicated both whiting and sandeel as being important, followed by haddock, saithe, pollack and *Trisopterus* spp, with more sandeel being eaten on the east mainland coast and more gadids eaten around the Northern Isles (Santos et al 2004). Previously, Rae (1973) had documented that during the 1960s, the main prey in stomach contents analyses of harbour porpoise were herring and sprat in addition to whiting. Herring stocks then crashed and many marine predators that had previously taken herring are thought to have switched to sandeel and/or sprat (Evans 1990). In the Northern Isles, sandeel stocks declined sharply during the 1990s, leading to widespread seabird breeding failure and a decline in harbour porpoise numbers (Evans & Borges 1995, Borges & Evans 1997, Evans et al 1997). This fits with the concept of prey switching as revealed in the temporal differences in stomach contents analysed from Scotland.

Analysis of 73 stomachs revealed that although a broad range of fish taxa were consumed by harbour porpoises in Irish waters, whiting, and *Trisopterus* sp. (poor cod and Norway pout *Trisopterus esmarkii*) were identified as important in terms of percentage by number, whereas in terms of percentage occurrence herring was also important (Brown 1999, Rogan 2009). Analysis of a sub-set of individuals (n=34, sampled between 1993 and 1999) showed that the prey remains obtained from stranded and by-caught animals were largely similar; though fewer clupeids and more poor cod were observed in the stomachs of by-caught individuals. Overall, fish consumed were predominately < 30 cm in length, with a modal size class of 11-20 cm (Brown 1999).

In waters off the south-west UK, whiting, Gobiidae sp, herring, sprat and scad were the most important fish species by weight in the stomachs of stranded and by-caught harbour porpoises (n= 67 stomachs). The three most important fish taxa by weight for by-caught individuals were whiting, Gobiidae sp., and herring. For animals that died from other causes of death, whiting, sandeel and Gobiidae sp. were important. Animals from off the south-west coast of the UK consumed smaller sized prey than did porpoises in the North Sea and Outer Hebrides. Whiting increased in importance in stomach contents during 1995-2002 in UK waters, from 63% to 94% (n=123), while herring decreased in importance, from 33% to 7% (Tierney 2002).

In the Bay of Biscay, whiting has been documented as the main prey along with scad, sardine and blue whiting (Spitz et al 2006).

Prey species importance appears to vary seasonally. In the Baltic Sea, cod is most commonly consumed in autumn and winter, whereas gobies are of lesser importance in the autumn (Sveegaard et al 2012, Andreasen et al 2017). Herring is most important in the winter and spring, but is of lesser importance in the summer, which is related to the seasonal variation of abundance of this species, hence related to its availability. Cod, gobies and herring are nonetheless the most frequently occurring species over the twelve months, whereas in this region, sprat, whiting, haddock and sandeel occur mainly during the summer (Nielsen et al 2001, Guse et al 2009, Sveegaard et al 2012, Andreasen et al 2017). Off Scotland, whiting were mostly consumed in winter, whereas sandeel were most important in the summer, which coincides with their availability (whiting being more abundant in winter, and sandeel moving out of the substrate in summer) (Santos et al 2004).

In the Baltic Sea, Sveegaard et al (2012) found no correlation between the length of the porpoise and the mean length of its prey. However, off Scotland, it was found that medium-sized individuals consumed more clupeids than did large individuals, and that the importance in terms of number of haddock, saithe, and pollack in the diet was positively correlated with porpoise length (Santos et al 2004). In both areas, juvenile harbour porpoises (less than one year old) consumed many more gobiids than did adults, even to the point of them becoming their most common prey (Santos et al 2004, Andreasen et al 2017), whilst adults were found to consume more hagfish than juveniles. There were also gender differences, with females consuming more hagfish and sandeel than males, the latter taking more herring, whiting and gobies. These differences may be due to the different needs of pregnant or lactating females (Börjesson et al 2003, Andreasen et al 2017).

Filling data and knowledge gaps

A substantial amount of past work on diet of cetaceans in the ASCOBANS area, facilitated by collaborations with strandings monitoring networks, remains unpublished. Much of this work has taken place as part of undergraduate and masters projects with no specific funding. Revising prey identification and working the material up for publication takes time and is often not high priority if unfunded. Given dedicated funding (e.g. for a PhD) this material could be worked up and published.

An Irish Research Council funded PhD study by Ms Sofia Albrecht entitled 'Impacts of anthropogenic activities and environmental change on the foraging ecology and nutritional status of common dolphin and its implications towards sustainable resource management' commenced at the Atlantic Technological University in 2021. The context is the increasing number of stranded dolphins along the Irish coastline that show evidence of starvation/emaciation. The study will have access to samples and data collected by Irish stranding and observer bycatch programmes over a 25-year period and will investigate temporal changes and spatial patterns in diet and nutritional status and identify drivers of change (e.g. changes in prey availability). The work will include both conventional stomach contents analysis and novel molecular approaches for detecting prey DNA, to assess occurrence of dietary shifts (e.g. replacement of high-energy prey by low energy prey).

ToR F. Review relevant information from *emerging technologies*

Emerging technologies can contribute novel information on available prey quantity and quality, on predator-prey interactions, and on the nutritional status of small cetaceans.

Firstly, technological innovations implemented on research vessels during scientific cruises continuously improve the quality and the quantity of data obtained on prey distribution and abundance. Beyond a rough assessment of prey biomass, acoustic tools such as multibeam sonars provide, for instance, information on the structure and behaviour of prey schools, and thus offer a three-dimensional view of what cetaceans encounter in the oceans (Gerlotto et al 1999). These developments in sonar techniques can be used to simultaneously observe the foraging behaviour of cetaceans and the anti-predator behaviour of their prey in three dimensions (Nøttestad & Axelsen, 1999; Benoit-Bird & Au, 2009). Developments in both active and passive acoustics now make it possible to observe the oceans with a high spatiotemporal resolution from oceanographic features to marine mammals as never before (Howe et al 2019). The application of new technologies on research vessels has stimulated the implementation of multidisciplinary surveys. These surveys collect *in-situ* data on everything from environmental characteristics to top predator abundance, distribution and behaviour, providing integrated monitoring of marine ecosystems (Doray et al 2018). Such projects simultaneously record spatial data both for cetaceans and their prey, which are crucial to understanding predator-prey interactions at small and meso-scales (Lambert et al 2019).

Where traditional monitoring by scientific vessels is difficult, such as in rocky coastal areas, the polar zones or the deep sea, remote monitoring is opening a window on these ecosystems. Satellites, remote underwater stereo-video stations, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), unmanned aerial vehicles (UAVs), gliders, submarine drones etc. are leading to a technological revolution in the way we observe and quantify marine life (e.g., Suberg et al 2014, Danovaro et al 2016, Verfuss et al 2019). These recent technological advances are in particular thanks to the miniaturization of sensors and the increase in battery performance which benefit also developments in biologging. Biologgers are extensively deployed on pinnipeds and large whales but rarely used on small cetaceans (reflecting welfare considerations and challenges for deployment). Advances in electronics, packaging and attachment methods will enable researchers to more extensively obtain data from tagged dolphins and porpoises (Pearson et al 2017, Visser et al 2021).

Methodological progress in biological sample analysis represent another area of technological innovation benefiting the study of prey quantity and quality, as well as small cetacean health. Continued advances in the use of environmental DNA (eDNA) could complement the monitoring of available prey, especially where and when cetaceans are actively feeding (Valentini et al 2016, Visser et al 2021). DNA metabarcoding provides a valuable tool for assessing some aspects of marine predator diets (McInnes et al 2017).

Some traditional analyses such as the proximate composition and energy density of prey, as well as stress hormone or gene expression assays from cetacean biopsies, require a time-consuming process of sample preparation and assaying. Biomedical research accelerates the development of techniques and tools that can eventually be applied to wild species (Smith and Madden 2016), and then allow us to significantly extend both monitoring of the quality of cetacean prey resources and their health. Some microarrays have already proved their effectiveness on delphinids (Mancia et al 2015).

Finally, different emerging technologies can be combined to provide innovative tools to monitor the health of cetaceans. Drone videos coupled with photogrammetry analysis can monitor the body condition of cetaceans (Lemos et al 2020). Drones can also capture exhaled breath from cetaceans, and provide non-invasive samples to examine the associated microbiome and inform for instance on pulmonary infections (Apprill et al 2017). Such advances in the monitoring of cetaceans, which until about ten years ago were the domain of science fiction, suggest the progress that could be made in the coming decades.

ToR G. Explore prospects for integrating information from multiple data sources to provide inter/multidisciplinary insights into the resource depletion issue

It is difficult to obtain direct evidence of adverse impacts of resource depletion on cetacean populations. However, indirect evidence might derive from a range of sources including those based on current or proposed/recommended routine monitoring. Integrating other data sources may also reveal additive or synergistic consequences of multiple stressors (e.g. impacts of prey depletion could be exacerbated by impacts of pathogens and contaminants). Such integration of information is discussed under several of the other ToRs (above). Relevant types of information could include:

- Unusual mortality events involving multiple individuals in poor condition, as detected from strandings data and associated necropsies;
- Health and condition, e.g. from necropsy of stranded animals, as well as from biopsies and photogrammetry in free-living animals. The reliable attribution of death or poor condition to starvation requires context – there are multiple reasons why an animal may not be feeding normally and prey depletion is just one of them;
- Cetacean population growth parameters (mortality and birth rates), based on analysis of samples and data obtained from stranded animals - and in some cases from living animals, e.g. observations of mother-calf pairs in bottlenose dolphins (Robinson et al 2017);
- Diet composition, foraging behaviour and selectivity, based on (traditional and molecular) stomach contents analysis, as well as stable isotope and fatty acid analysis of cetacean tissues, usually from stranded animals; potentially also e-DNA, satellite tag telemetry and visual observations of feeding behaviour;
- Cetacean abundance and distribution based on dedicated surveys, surveys using platforms of opportunity and citizen science sightings data;
- Fish abundance and distribution, based on catch statistics, annual stock assessments, research surveys and other sources (e.g. citizen science data on observations by divers). Conversion of data on biomass to energy (based on known prey energy density, accounting for variation with size and season, may give the most useful index of prey availability);
- The wider ecosystem impacts of fishing, e.g. seabed damage by trawling which could result in the decline of benthic prey species;
- Evidence of changes in ecosystem structure and function, including that derived from ecosystem models, related to the decline of commercially exploited and impacted species.

Some species of cetacean will be more susceptible than others to prey depletion. In particular, harbour porpoises are likely to be susceptible because of their high metabolic demands (Wisniewska et al 2016), possibly exacerbated by selective pressure for lean body shapes which permit better manoeuvrability (MacLeod et al 2007c). In addition, species with specialised diets (e.g. Risso's dolphin) and those whose diet contains a high proportion of commercially important or impacted fish species (e.g. most small cetaceans) will be vulnerable to depletion of important prey species.

Linking such information to prey depletion, even when multiple sources of information are available, is usually speculative. At best, the evidence tends to be circumstantial. MacLeod et al (2007) proposed that an increase in „starvation” deaths of porpoises in Scotland was linked to a decline in sandeel abundance. Similarly, the southwards shift of porpoise distribution in the North Sea between 1994 and 2005 as revealed by the SCANS surveys may have been linked to shifts in prey distribution resulting in reduced resource availability in the northern North Sea. Interestingly however, Ransijn et al (2019) concluded that harbour porpoises were not found at highest densities where prey energy density was highest, possibly because prey availability was not limiting.

Some of the above-mentioned information is already reported to ASCOBANS and much of the remainder could be provided in national reports on strandings and associated research. Gaps or deficiencies may however be expected in the data due to limited funding to carry out necropsies and carry out subsequent sample analysis, as well as the extended time-gaps between large-scale surveys. It would be helpful to emphasise the importance of providing such information in national reports and to flag the importance of providing information on the

status of key prey populations, either in national reports or as part of a separate annual exercise, given that much of the necessary information (raw data, assessment reports, fisheries advice) is already available in one place (i.e. ICES). It should be noted that the raw data (landings, survey abundance data) may be available from national sources earlier than they would become available via ICES and if such data are to have a sentinel role this may be important.

ToR H. Mitigation of pressures affecting cetacean prey availability - fisheries

Within the ASCOBANS area, fisheries management is applied through the EU Common Fisheries Policy (CFP, EU Regulation 1380/2013), which strives towards management based upon Maximum Sustainable Yield (MSY). There are also commitments to ensure that fishing activities are environmentally sustainable in the long-term and are managed in a way that is consistent with the objectives of achieving economic, social and employment benefits and to implement an ecosystem-based approach to fisheries management to ensure that negative impacts of fishing activities on the marine ecosystem are minimised. If implemented properly, both of these types of measures could help ensure the availability of prey for small cetaceans.

In the context of the CFP, ICES provides annual advice on the status of fish stocks in waters of the Northeast Atlantic European Exclusive Economic Zone (EEZ). Outside the European EEZ, ICES also provides advice to Coastal States such as Iceland and the Faroe Islands, for stocks mostly confined to their EEZs as well as the 'Straddling Stocks', i.e. those which migrate across the waters of different nations and the high seas.

One of the basic measures to ensure that fish resources are utilised in a sustainable way is the application of a Total Allowable Catch (TAC) as determined by Maximum Sustainable Yield (MSY) and associated reference points for appropriate levels of stock size and fishing mortality. These are catch limits (expressed in tonnes or number of individuals) that are set annually for most commercial fish stocks, and every two years for deep-sea stocks by the EU Council of fisheries ministers. TACs are shared between EU countries in the form of national quotas using a system known as 'relative stability'. EU countries have to use transparent and objective criteria when they distribute the national quota among their fishing fleets and are responsible for ensuring that the quotas are not overfished. Although widely used, TACs can be subject to socio-economic pressures meaning the TAC set can exceed that recommended in the ICES scientific advice and, subsequently, are difficult to enforce. Collection of relevant, high quality data every year for assessments of the status of fish stocks is essential.

The management of fisheries within the ASCOBANS area is currently in a state of flux. As of 1st February 2020, the UK left the EU, becoming a separate Coastal State, and entered into a transition period in which fisheries management was maintained through the CFP. From 1st January 2021, this was no longer the case, with the UK taking responsibility for fisheries management within its EEZ. Negotiations on future fisheries management within the ASCOBANS area are currently ongoing.

As part of the CFP, various measures are used to ensure that fish resources are exploited sustainably, the most important of which are the EU multiannual management plans¹. Each plan covers a particular basin or sea area (e.g. North Sea, Western waters). These plans set goals for fish stock management and may include specific conservation rules, such as reducing the bycatch of non-target species, with the aim of increasing stability and long-term predictability for fishers.

The multiannual plans are used to determine the annual TAC to ensure that fish stocks are not overexploited and can achieve MSY. Management plans are complemented by simplified technical measures, which provide a better regional context for fisheries management. These technical measures cover both the conservation of fishery resources and the protection of marine ecosystems, and provide a broad set of rules which govern how, where, and when fishers may fish. They are established for all European sea basins, but they differ considerably from one basin to another, in accordance with the regional conditions. These measures may include:

- minimum landing sizes and minimum conservation sizes

¹ https://ec.europa.eu/fisheries/cfp/fishing_rules/multi_annual_plans_en;

- specifications for design and use of gears
- minimum mesh sizes for nets
- requirement of selective gears to reduce unwanted catches;
- limitations on by-catches (catches of unwanted or non-target species including protected species such as cetaceans)
- limitations on discarding of unwanted catches (e.g. the Landing Obligation)
- measures to minimise the impact of fishing on the marine ecosystem and environment.

Technical measures in fisheries can also include area closures (temporary or permanent) designated in order to protect commercial species. Such closures can have conservation benefits. These area-based measures may restrict certain types of gear or protect a particular commercial species. For example, in Scotland, the Rosemary Bank closure area prevents fishing for blue ling during the spawning season and the East Coast Scotland closed area bans sandeel fishing year-round. Fisheries closure areas may also be designated to protect vulnerable habitats, e.g. the West Rockall Mound closure area prohibits vessels from bottom trawling and fishing with static gear, including bottom set gillnets and longlines, for the protection of vulnerable deep-sea habitats.

In addition to the permanently closed areas as described above, Real Time Closures (RTCs²) can also be implemented. RTCs specify closure of defined areas to fisheries for a limited period defined which are closed to fishing for a limited period, triggered by information gained in "real time", often in cooperation with the fishing industry (e.g. through on-board sampling of catch composition, Vessel Monitoring System (VMS) data, analysis of catch rates and declarations by skippers). RTC schemes are designed to achieve specific objectives, such as a reduction in bycatch, discards or fishing mortality of targeted species. Compliance with RTCs can be monitored through VMS data, and transgressions dealt with through administrative penalties (e.g. the deduction of 5 days effort from the vessel's entitlement). Within the ASCOBANS Area, examples include the RTC for Northern prawn fisheries in the Skagerrak (EU Regulation 2019/2201) and the RTC agreed between Norway and the EU for certain fisheries in the North Sea and Skagerrak covering juvenile cod, haddock, saithe and whiting³.

As a result, closed areas can contribute to a reduction in prey depletion in certain locations. Notably though, such fisheries closure areas are different from Marine Protected Areas (MPAs) designated for conservation purposes (e.g. Special Areas of Conservation (SACs) designated to protect harbour porpoise and bottlenose dolphin). However, on the basis of scientific advice, if the conservation status of the protected feature within an MPA could be improved through fisheries measures, there is the expectation that such management will be introduced. To date, no MPAs have introduced fisheries measures specifically to reduce prey depletion for small cetaceans.

Temporal closures may focus on reducing the degree of spatial or temporal overlap between fisheries and occurrence of the relevant fish species, thus minimising fishing pressure on them at certain periods of the year. Closures can produce simple and enforceable regulations. However, interannual variation in the occurrence of, for example, depleted fish species in specific areas may cause a mismatch, making the closure ineffective, especially when closed areas are very small. This mitigation measure is mostly considered as a way to reduce bycatch of non-targeted species such as marine mammals, e.g. small cetaceans.

Real-time closures for fisheries can be targeted areas of high abundance, areas where juveniles comprise a higher than average proportion of the catch, or areas where catch composition is likely to result in high levels of discards. Compared to Closed Areas, RTCs

² <https://op.europa.eu/pl/publication-detail/-/publication/d3ca3b56-ea99-11e5-a2a7-01aa75ed71a1>

³ <https://www.pelagic-ac.org/media/pdf/2019%20EU%20Norway%20Agreed%20Records.pdf>

enjoy greater confidence from the fishing industry as they are seen to be more responsive to conditions “on the ground”; however, their effectiveness is difficult to measure⁴.

No-take marine reserves or zones (NTZs) are a very particular type of conservation MPA, where no extractive activities are allowed. Very few have been designated and those that do exist are very small (e.g. Lamlash Bay, Scotland, and Lundy Island, England). NTZs have been recommended as a general tool for an ecosystem approach to fisheries management, including to support the achievement of environmental objectives (Halpern 2003, Halpern et al 2010, Fenberg et al 2012, Stewart et al 2020). NTZs are expected to result in a more balanced size structure of the fish community and higher prevalence of larger individuals and larger species, and enable exploited populations to recover. The effects within the areas can usually be seen within a few years, showing that the response is fast. NTZs may also have spill-over effects, exporting adult fish, pelagic eggs and larvae to adjacent areas and systems (Abesamis and Russ 2005, Halpern et al 2010), as well as positive effects on other parts of the food-web besides the targeted fish populations (Thrush & Dayton 2010, Baskett & Barnett 2015), e.g. increase prey resource for small cetaceans. However, these subsequent effects might be slower to take effect and they depend on a long-term and sufficiently scaled protection (e.g. Gårdmark et al 2006). Closures can produce simple and enforceable regulations. However, the beneficial outcomes of MPAs for conservation purposes and fisheries closure areas are considered to be strongly influenced by their objectives (Rice et al 2012). In order to ensure that fisheries management measures are properly implemented, relevant monitoring and assessment of fish stocks is needed, as well as effective control of fishing activity.

In principle, the EU is moving towards “Ecosystem-Based Fishery Management” (EBFM), i.e. a holistic management approach that recognizes all the interactions within an ecosystem rather than considering a single species or issue in isolation. EBFM aims to account for effects of fishing on non-target stocks and ecosystem health, as well as its social and economic consequences. In principle, adverse effects of prey depletion on protected top predators such as cetaceans should be avoided under EBFM, provided of course that an effective means can be found to implement the management approach. It should be noted that the UK has left the EU and the consequences for fisheries remain to be determined.

As a final note, despite the stated objective of moving towards EBFM, it remains the case that fish stock assessment and fisheries management are largely focused on fish abundance. However, size and condition are key determinants of both survival and reproductive success in fish populations - and prey depletion experienced by cetaceans can result from declines in fish quality as well as declines in abundance.

⁴ <https://op.europa.eu/pl/publication-detail/-/publication/d3ca3b56-ea99-11e5-a2a7-01aa75ed71a1>

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