Interim Report of the ASCOBANS Resource Depletion Working Group

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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, Kinze et al. 2003, Reid et al. 2003, Camphuysen & Peet 2006, Hammond et al. 2013, Goetz et al. 2015, Hammond et al. 2017, 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.

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). Links with HELCOM, OSPAR, ICES and IWC were proposed. A list of members is provided as an Annex to the present document.

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.

The present interim report covers ToRs A, C, D, F and H.

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

Authors: Taylor, Pinn, Evans

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.* 2007; Leopold et al. 2015; Andreasen et al. 2017; Booth 2020). While high dietary variability is often interpreted as indicating an opportunistic foraging strategy, cetaceans are also known to select prey according to prey quality rather than quantity.

A reduction in the availability of prey or a change in the quality of the prey available, collectively defined as 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). In theory, prey depletion is likely to have a negative impact on small cetaceans, given the fundamental need for sufficient good-quality prey to survive. In practice, there are many influencing factors that must be considered in understanding the drivers of prey depletion to ensure that the most appropriate management and mitigation measures can be identified and implemented.

Causes of prey depletion

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 the availability as a result of fishing extraction, either spatially or in terms of biomass or quality (e.g. size; nutritional value) of targeted species has the potential to negatively impact the cetaceans in competition for that same food source (Lassalle *et al*, 2012). This form of prey depletion is likely to be localised and may not always be associated with overfishing (DeMaster et al. 2001).

Reduced prey intake may result from alterations in behaviour due to disturbance or displacement due to physical changes in habitat. Behavioural changes have consequences for an individual's health through time lost foraging (Brandt et al. 2011), socialising or resting (Lusseau 2003). This impacts life functions such as survival and reproduction which can in turn affect population dynamics. Strictly speaking this is not an example of the effect of prey depletion if the prey field is not altered, but its effects on the cetaceans may be similar.

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. 2018a&b).

Aggregate extraction can also cause disturbance to cetaceans, leading to changes in behaviour which may affect foraging (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 removal 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 could indirectly lead to prey depletion through influences on distribution and abundance (Macleod et al. 2005, Learmonth et al. 2006. Evans & Waggitt 2020). These indirect impacts influence location and volume of prey species, which, in turn, impacts the ability of cetaceans to locate adequate energy and nutrition to underpin health and biological needs such as growth and reproduction (Booth 2020).

Impacts

The impacts of insufficient prey, its displacement, or changes in prey availability will be manifested in small cetaceans in a variety of ways, depending on the species characteristics and 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 Bressem et al. 2009).

There may be short- and long-term impacts which relate to changes in the nutritional quality of the available prey. If a prevalence of nutritionally-rich species such as herring, sprat and sandeel, is replaced by 'lower value' prey such as whiting, saithe or cod (Evans 1990, Hislop et al. 1991, MacLeod et al. 2007a, 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).

Population status could also be impacted through changes in prey availability directly through increased mortality and, indirectly, through a reduction in reproductive rates and survival (Macleod et al. 2007a, Leopold et al., 2015, Booth 2020).

Adaptability

There is a growing body of evidence regarding diet of some small cetacean species, which suggests some species, or populations within a species, may be more 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), may be less capable of adapting to prey depletions, given a persistent preference for a single or small group of prey species. Even where a diet is varied, some species (e.g. bottlenose dolphins) develop foraging techniques and behaviour that can lead to site-specific specialisations (Bailey & Thompson 2010, Dunshea et al. 2013). Generalists, such as harbour porpoise (Santos & Pierce 2003), may be less affected by depletion of a particular prey as their diet can consist of a range of moderate to high energy-density prey combined with ultra-high foraging rates and high capture success (Wisniewska et al. 2016, 2018a). However, there is also evidence to suggest that if the higher-energy prey is depleted, the generalist diet may not provide adequate nutrition to sustain a healthy animal over time (MacLeod *et al.*, 2007a). Therefore, there is a need to focus mitigation of prey depletion on those prey species which are identified as having the highest potential impact on small cetaceans following that depletion.

Monitoring and surveillance

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

- Strandings analysis programmes which Parties to ASCOBANS are required to implement. These record information on cause of death, although alongside the ultimate cause of death, there is a need to understand the other factors that may be 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 provide short-term dietary information (Pierce & Boyle 1991, De Pierrepont et al. 2005, Spitz et al. 2018), whilst fatty acid and stable isotope analyses from live or dead animals can identify longer-term information on recent diet (fatty acids) or trophic level feeding (stable isotopes) which 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). Provided that other health issues can be accounted for, body condition may be indicative of the availability of sufficient prey.

Modelling of trade-offs between fisheries and marine mammal consumption has also shown capacity to demonstrate the impact of biomass removal on sustainability and recovery of some cetacean species, which could be a useful tool to develop in support of understanding the impacts of prey removal through extraction (Williams et al. 2011, Smith et al. 2015, Spitz et al. 2018).

Additional research needs

- Stable isotope analysis as a comprehensive measure of diet over time: correlations between prey and health; indicator of key prey species and how this has changed over time.
- Stomach content analysis as an integral part of the post-mortem analyses within strandings monitoring programmes as a tool for identifying recent dietary information: potential for evidence of regional feeding preferences, and possible links with key prey resources.
- Body condition assessment of stranded carcasses as standard within strandings programmes; consider potential for increased monitoring of body condition in live animals as a real-time indicator of health (e.g. integrate into existing monitoring schemes, analysing stills and video imagery through mark, recapture programmes; development of aerial drone studies).

- Appropriate frequency of abundance and distribution data collection of predator and prey: 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 best use of available evidence across the Agreement Area, and in collaboration with neighbouring regions.

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.

Authors: Brownlow, IJsseldijk, Ridoux

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 prey depletion at a population level, could potentially be conducted 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 approach could include:

- Cetacean population ecology factors, such as species, season and age, including the likelihood 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. This 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 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 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.

Besides emaciation (poor nutritional body conditions), animals may be more susceptible to infectious disease or (interlinked) changes in reproductive success. The latter has been shown in larger cetacean species, where 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 has been linked to reductions in killer whale fecundity (Ward et al. 2009). Changes in reproductive output could, in the long term, affect population numbers and may therefore have serious complications for population growth.

A starting point could therefore be the assessment of (changes in) life history parameters, including age at sexual maturity and pregnancy rates using information gained from necropsied animals. Animals which died due to physical trauma (e.g. bycatch, collisions or predatory attacks) offer a relatively unbiased sample (i.e. at least not biased towards sick animals) which could be used to assess natural variation in body condition in a living population. 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.

Regarding liaising with other conventions or working groups: Jan Haelters confirmed that within the MSFD Framework, there has been discussion regarding health indicators; however, currently no indicator has been established. Ursula Siebert confirmed that 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.

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.

Authors: Kessler, Evans

Morphology, energetics 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 has also been linked to suction feeding (Werth 2000, 2006). This foraging technique, although with 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 small cetacean species will be specialized to take relatively small prey.

In spite of the evidence that suggests these species forage on the same type of prey, their dietary niches appear to be well segregated. For example, Sowerby's beaked whales only

consume very small prey (<10 g body mass), whilst Cuvier's beaked whales and long-finned pilot whales mostly consume small to medium 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 Fernández et al. 2012). Furthermore, the 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).

Delphinids (common dolphins, striped dolphins, bottlenose dolphins, Atlantic white-sided dolphins, white-beaked dolphins and killer whales) display small, cone-shaped teeth, and phocoenids (harbour porpoises) 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 (Goetz et al. 2015). This suggests they feed on mesopelagic fish, as well as more coastal species (Massé 1996, Silva 1999, Abaunza et al. 2003, Carrera and Porteiro 2003, Pusineri et al. 2007, Méndez Fernández 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). Hence there should be prey selection towards high-quality prey such as small pelagic fish (see species cited above) (Poulard and Blanchard 2005, Meynier et al. 2008, Spitz et al. 2010, 2012, 2014, 2018). Indeed, it has been found that, as their energy content increased, the prey was increasingly selected, suggesting a quality-based prey selection for the common dolphin (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, whilst 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).

Like the common dolphin, these species have high energy requirements, suggesting positive selectivity towards high caloric density prey, such as small pelagic fish (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 demonstrates an occasional presence in neritic habitats, and should hence feed on oceanic prey, such as deep-water cephalopods and fish (Spitz et al. 2006, 2011, Méndez Fernández et al. 2012, Goetz et al. 2015).

Bottlenose dolphins are present in both shallow coastal water 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 (Santos et al. 2001, 2007, Wilson 2008).

Together with striped dolphins they have medium to high energy requirements, suggesting a low selectivity in terms of prey energetic quality (Spitz et al. 2012).

Methodology to study diet

Stomach contents analysis is the most commonly used methodology for assessing small cetacean diet. Although it only gives an insight on the diet in the preceding 6 to 48 hours and not on a longer time-scale, it is still a highly informative method and the only one that consistently allows identifying prey life-stages (Pierce & Boyle 1991, Hayden et al. 2014, Nielsen et al. 2018). Being based on the identification of fish otoliths and bones, and

cephalopod beaks, this method presents some limitations. Firstly, several guides exist but access to a reference collection is necessary (Pierce & Boyle 1991). Secondly, the identification of prey remains can be quite difficult, and sometimes limited to relatively high taxonomic levels, since the material is 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 do not possess otoliths, which emphasises the need to identify bones 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). 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 hence persistent in the stomach, such as cephalopod beaks (Santos et al. 2001a, Fernández et al. 2009, Glaser et al. 2015).

The molecular approaches allow higher taxonomic resolution of prey than in stomach contents analysis. This methodology requires reference databases, which, in spite of being laborious to acquire, are rapidly expanding (Pompanon et al. 2012, Nielsen et al. 2018). As with stomach contents analysis, it is also subject to sample contamination due to secondary predation, which is even harder to detect, although secondary prey may still contribute to the predator's nutritional intake (Bowser et al. 2013, Nielsen et al. 2018). A more concerning issue is environmental contamination, as DNA in the water can be swallowed by the predator (Kelly et al. 2014).

A third approach is to analyse fatty acids using blubber samples. This is based on the fact that each prey possesses a unique fatty acid profile, allowing their identification (Dalsgaard et al. 2003). 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, therefore calibration coefficients are necessary to avoid biases when estimating prey proportions (Iverson et al. 2004, Happel et al. 2016). Another issue, specific to fish, is that differences in fatty acid signatures in the oil of different species are more quantitative than they are qualitative. Adding to the fact that fish-based diets often present many different components and many different prey species, this can make it somewhat difficult to differentiate between them by this method (Pierce & Boyle 1991).

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). Both bulk or compound-specific stable isotopes can be used, even though the compound-specific isotopes provide more dietary tracers than bulk stable isotopes, therefore allowing the differentiation between more prey items. This method presents an advantage compared to other diet analysis methods, which is the possibility of assessing diet broadly over a long-time scale (weeks, months or even years), because the latter is dependent upon the half-life of the stable isotopes and the tissue's turnover rate (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 also, as 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 is the difficulty of interpretation because of the resemblance of certain stable isotope signatures. This can particularly be an issue if the ecosystems' baseline values are unknown, because different ecosystems with the same baseline values can result in indistinguishable stable isotope signatures resulting nevertheless from different diets (Ramos & González-Solís 2012, Louis 2014). The fact that this method is spared the problem related to different digestion rates makes it useful as a supplement to stomach contents and fatty acid analysis (Monteiro et al. 2015), bearing in mind that the information it provides is relatively coarse (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, Hume & Mackie 1980, Laird et al. 1982 – all cited in Pierce & Boyle

1991). Arguably, the most convincing method is to identify target proteins and raise antisera to detect the presence of these proteins in the samples in order to identify prey species. This method presents nonetheless a drawback: even though the protein compositions are species-specific, there may be antigenic sites in common, and, as that is what the antisera react with, this may lead to error (Pierce & Boyle 1991).

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 for illustrating this methodology. 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). The drawbacks of using interference with contaminants is the improbability of identifying prey with a low taxonomic rank, and the absence of a general methodology that can be used for any contaminant.

Distribution and diet of each species

Distribution maps of the commoner cetacean species in the eastern North Atlantic and North Sea are displayed in Figure 1.
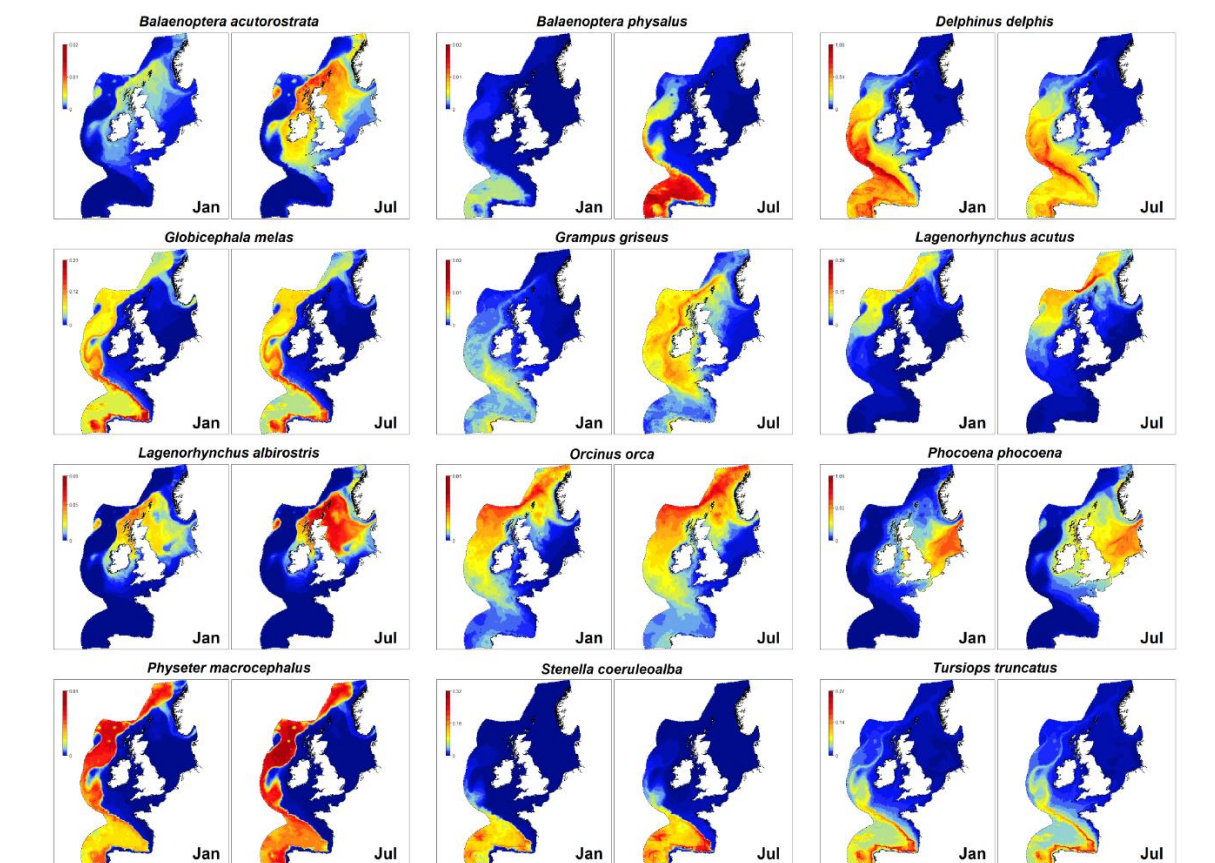

Figure 1. Summer and winter modelled density distributions for the 12 most common cetacean species in the eastern North Atlantic and North Sea (source: Waggitt et al. 2020)

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 both by 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 (*Micromesistius poutassou*), *Trisopterus* sp. 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 schmidti, and *Taonius pavo*, *Histioteuthis reversa*, and *Gonatus* sp. (Santos et al. 2001). Other prey included *Histioteuthis bonelli*, *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).

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.

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 and O'Shea 2009, Spitz et al. 2011, Santos et al. 2014), although fish may also be taken (Overholtz and 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 (*Trachurus trachurus*) (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 (*Eledone cirrhosa*), 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).

The most important fish prey for killer whales in the Northeast Atlantic appears to be herring (*Clupea harengus*) with the species following its migrations between Norway and Iceland (Foote et al. 2012, Nøttestad et al. 2014, Vongraven & Bisther 2014). It frequently associates with trawlers fishing for herring or mackerel (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 (*Micromesistius poutassou*) to be the most important prey, both by number and by weight, followed by whiting (*Merlangius merlangus*). Other prey species included Atlantic mackerel (*Scomber scombrus*), silvery pout (*Gadiculus argenteus*) and myctophids (Hernandez-Milian et al. 2015). Elsewhere in the north-west Atlantic, in the Gulf of Maine stomach contents analysis of 62 individuals (Craddock et al. 2009) found at least 26 fish species and three cephalopod species. The predominant prey were silver hake (*Merluccius bilinearis*), spoonarm octopus (*Bathypolypus bairdii*), and haddock (*Melanogrammus aeglefinus*). The stomach from a net-caught animal on the continental slope contained 7,750 otoliths of the Madeira lanternfish (*Ceratoscopelus maderensis*). Sandeels (*Ammodytes* spp.) were the most abundant species in the stomachs of stranded animals. Seasonal variation in diet was indicated; pelagic Atlantic herring (*Clupea harengus*) was the most important prey in summer, but was rare in winter.

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.

Studies in the North-east Atlantic have identified whiting (*Merlangius merlangus*) and Atlantic cod (*Gadus morhua*) 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 (*Merluccius merluccius*) were additional prey (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 neither to 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. 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 flying squid (*Todarodes sagittatus*), the veined squid (*Loligo forbesi*), and the curled octopus (*Eledona cirrhosa*), but in different proportions. In April, one dolphin also consumed a fourth species, the demersal lesser flying squid (*Todaropsis eblanae*). Stomachs of three dolphins which had remains of *Eledona* also contained one other benthic invertebrate, although these may have been prey items of the squid. The diet includes both mid-water (*Todarodes* and *Loligo*) and bottom dwelling (*Eledona*, *Todaropsis*) species.

In the English Channel, the stomach contents of three Risso's dolphins included European common cuttlefish (*Sepia officinalis*), curled octopus (*Eledone cirrhosa*) and lesser flying squid (*Todaropsis eblanae*) (Gonzropsis eal. 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. 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 (*Merluccius merluccius*) and blue whiting (*Micromesistius poutassou*), followed by horse mackerel (*Trachurus trachurus*), 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 (*Merluccius merluccius*), horse mackerel (*Trachurus trachurus*), common ling (*Molva molva*), conger eel (*Conger conger*), whiting (*Merlangius merlangius*), blue whiting (*Micromesistius poutassou*), and pollack (*Pollachius pollachius*).

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,

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 (Marouring pal. 2018).

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 horse mackerel (*Trachurus trachurus*) 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.

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 kroeyeri*), 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 steentrupi*), 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 gadids, gobiids, clupeids, engraulids and carangids (Pusineri et al. 2007). In the Bay of Biscay, these families are represented by sardine (*Sardina pilchardus*), followed by sprat (*Sprattus sprattus*), European anchovy (*Engraulis encrasicolus*), scads (*Trachurus* spp.), and horse mackerel

(*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 (*Micromesistius poutassou*) and European hake (*Merluccius merluccius*) (Silva 1999, Cabral and Murta 2002, Mar Murta 2002, cci). Cephalopods identified in the diet have included *Loligo* sp., *Alloteuthis* sp. and *Sepiola* sp. (Desportes 1985).

Seasonal variation in 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 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, 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).

Another intra-specific difference to be noted is that, 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.

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, loligid, 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 (>10 % by weight or mass). The most important were sand smelt (*Atherina presbyter*) and blue whiting (*Micromesistius poutassou*), followed by gobies, *Trisopterus* spp., Atlantic gonate squid (*Gonatus steenstrupi*), 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 and 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 (*Gadus morhua*), sandeel (*Ammodytidae*), sprat (*Sprattus sprattus*), whiting (*Merlangius merlangus*), and herring (*Clupea harengus*) (Santos & Pierce 2003, Víkingsson 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 (*Sprattus sprattus*). They also feed on whiting and sandeel, and in shallow coastal areas such the southernmost North Sea and Belt seas, particularly gobies (Koschinski 2001, Börjesson et al. 2003, Lockyer and Kinze 2003, Santos

and 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 important, followed by haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), pollack (*Pollachius pollachius*) 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 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 numbers (Evans & Borges 1995, Borges & Evans 1997, Evans et al. 1997). This fits with the concept of prey switching as revealed in the tempioral differences in stomach contents analysed from Scotland.

In the Bay of Biscay, whiting has been documented as main prey along with horse mackerel (*Trachurus trachurus*), sardine (*Sardina pilchardus*), and blue whiting (*Micromesistius poutassou*) (Spitz et al. 2006).

Prey species importance appears to vary seasonally. In the Baltic Sea, for example, 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 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 more gobids than 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).

Table 1 summarises the main prey species recorded in the diet of each cetacean species in the ASCOBANS Agreement Area.

Species	Foraging Method	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

Species	Foraging Method	Prey species commonly taken
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 *Gonatus*); also herring, redfish
Sowerby's beaked whale	Mesopelagic	Squids, cod, hake, sandeeel
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

ToR F: Review relevant information from *emerging technologies*

Author: Spitz

Emerging technologies 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 and in three dimensions observe the foraging behaviour of cetaceans and the anti-predator behaviour of their prey (Nøttestad and Axelsen, 1999; Benoit-Bird and 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 stimulate the implementation of multidisciplinary surveys. These surveys collect *in-situ* data from environmental characteristics to top predator abundance, distribution and behaviour, providing an integrated monitoring of marine ecosystems (Doray et al. 2018). Such projects simultaneously record spatial data both for cetaceans and their prey. These data are crucial to understand 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).

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 (Valentini et al. 2016), and especially where and when cetaceans are actively feeding. DNA metabarcoding provides also a valuable tool for assessing some aspects of marine predator diets (McInnes et al. 2017). Some traditional analyses as prey proximate composition and energy density, 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 was the domain of science fiction, suggest the progress that could be made in the coming decades.

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

Author: Kaminska, Pinn

Within the ASCOBANS area, fisheries management is applied through the EU Common Fisheries Policy (CFP, EU Regulation 1380/2013), which strives towards management based on 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, small cetaceans can benefit from both of these types of measures in terms of availability of prey.

In the context of the CFP, the International Council for the Exploration of the Sea (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 the 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 or 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 will no longer be 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, a variety of measures are used to ensure that fish resources are exploited sustainably, the most important of which are the EU multiannual management plans[1]. 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 also include specific conservation rules, such as reducing the bycatch of non-target species, with the aim of increasing stability and long-term predictability for fishermen.

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. The technical measures provide a broad set of rules which govern how, where and when fishermen may fish. These technical measures cover both the conservation of fishery resources and the protection of marine ecosystems.

Technical measures in fisheries are a broad set of rules which govern how, where and when fishermen 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
- 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)

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

- 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, 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 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 more permanently identified fisheries closure areas described above, Real time closures (RTCs[2]) can also be implemented. These RTCs are defined areas of the sea 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 skippers declarations). 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 vessels 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 whiting[3].

As a result, fisheries closure 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). 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, so as to minimise 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 may cause a mismatch making the closure ineffective, especially when closed areas are very small. This mitigation measure is mostly considered to reduce bycatch of non-targeted species such as marine mammals e.g. small cetaceans.

Real-time closures for fisheries can be targeted at specific areas, for example to protect areas of high abundance, areas where juveniles comprise higher than average proportion of the catch, or areas where catch composition is likely to result in high levels of discards. Real-time closures 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 measure[4].

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,

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[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

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

including to support the reaching of environmental objectives (Halpern 2003, Halpern et al. 2010, Fenberg et al. 2012). 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 of adult fish, pelagic eggs and larvae to adjacent areas and systems (Abesamis and Russ 2005, Halpern et al. 2010), and positive effects on other parts of the food-web besides the targeted fish populations (Thrush and Dayton 2010, Baskett and 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 an "ecosystem-based approach to 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, fish stock assessment 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.

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