Agenda Item 3.2 | Species Action Plans

Conservation Plan for Harbour Porpoises in the North Sea

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Setting Research Priorities to Guide Management of Harbour Porpoises JMPO

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Crossing boundaries for cetacean conservation: Setting research priorities to guide management of harbour porpoises

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ABSTRACT

Effective management of natural resources involves a multidisciplinary perspective to address complex issues in data poor-environments. With mobile species that do not conform to human-defined borders a cross-boundary approach is essential. There is a continuing concern of ecological sustainability of marine environments, which demands monitoring of ecosystem indicators. Such indicators are increasingly derived from monitoring sentinel species. Harbour porpoises (*Phocoena phocoena*) are included as indicator species in several national and international agreements. Increasing exposure to anthropogenic stressors may impact harbour porpoise populations. To investigate these risks, a better understanding of threats and their effect is required. This study aimed to identify current knowledge gaps, to predict future pressures or threats, and to define useful conservation indicators to facilitate future research on harbour porpoises in the North Sea, through expert elicitation gained in a two-round Delphi approach. The three most important knowledge gaps addressed were bycatch, population dynamics, and the cumulative effects of multiple stressors. Bycatch was predicted as the highest concern for porpoises in the next 20 years, followed by chemical and noise pollution, respectively. A list of essential indicators aiming to increase understanding of harbour porpoises' health status was established and studying causes of death, distribution, abundance, habitat use and diet composition were scored as most relevant. These results should guide research focus and management objectives of harbour porpoise populations and the study design could be translated to serve managers in other geographical areas aiming to identify knowledge gaps and defining research priorities for other wildlife species.

1. Introduction

Human impact has transformed the world's oceans, by direct and indirect means, to such an extent that there is a rising concern on the ecological sustainability of most marine ecosystems [1,10,23]. Increased sea surface temperatures, coastal development, removal of prey species, habitat degradation, and chemical or noise pollution all can result in ecosystem changes, influencing population numbers and species composition [1,18,29]. The management of the marine environment often involves complex decisions at an international scale where managers need to deal with data-poor environments and lack of ecological understanding [16].

Marine mammals are used as sentinels for monitoring of aquatic ecosystems, as they are relatively long-lived, highly mobile species which feed at or near the top of the food chain [1,3,18]. For example, studies on arctic ecosystems revealed that increases in water temperature accompanied by a decline in prey availability resulted in spatial and temporal shifts of sea-ice dependent species [6,26,29] and decreases in abundance and migration changes of mysticetes [18]. The use of marine mammals as ecosystem sentinels, however, goes beyond investigating changes in distribution and abundance. Their overall health status can reflect the health of the ecosystem in which they live, making monitoring of cetacean population health a useful endeavour that can provide crucial information far beyond the individual populations themselves [4]. One key example is the investigation of bioaccumulation of persistent organic pollutants (POPs) and heavy metals in cetacean tissue. From the presence and concentrations of such pollutants one can infer contamination levels in the marine ecosystem, and this may provide an early warning system for potential human health hazards (e.g. [2,7,14,15,27,28]).

Harbour porpoises (*Phocoena phocoena*) are protected and included under several international, European and national conventions.

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International protection is provided by e.g. the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [8,13,24]. On a European scale, the European Union Habitats and Species Directive 1992 recognise the harbour porpoise as a '*species of community interest which is in need of strict protection*' and porpoises are listed under Annex II and IV that aim to establish a network of Special Areas of Conservation (SACs) and requires establishment of distinct conservation and management needs, respectively. In 2008, the Marine Strategy Framework Directive (MSFD) was formally adopted by the EU and the first EU legislative instrument related to the protection of marine biodiversity. It aims '*to achieve or maintain good environmental status within the marine environment by the year 2020 at the latest*' and determined 'good environmental status descriptors', among which several relate to the harbour porpoise [8,13,24]. On regional scales, the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) aims to achieve and maintain a favourable conservation status for small cetaceans within their agreement area. Here, the harbour porpoise is an abundant and widespread species with a population size of around 350,000 individuals [11].

Frequent exposure of harbour porpoises to human activities has raised concerns among conservationists, both in terms of direct impacts as well as nonlethal effects impacting population viability. The available knowledge on pressures affecting this species varies widely, and specific topics, such as climate change, urgently require further attention. Protection measures for harbour porpoises need to be implemented at a scale relevant to their ecosystem. To be effective and as encouraged by existing conventions this requires international co-ordination, yet most current research and management efforts are implemented at a national level [5,13]. To meet the requirements of both the EU Habitats Directive and MSFD, a broad approach identifying current knowledge gaps and predicting future threats is necessary to adequately assess the health status of harbour porpoise populations. This involves a clear understanding of the risks associated with increasing exposure to anthropogenic pressures [12,21,25].

In this study expert opinions were exploited through a two-round Delphi approach that aimed to identify current knowledge gaps, predict future pressures or threats and suggest useful conservation indicators to guide research and monitoring, at an international and interdisciplinary level. The outcomes of this study subsequently identified and ranked research priorities as defined by the panel of marine mammal experts, with the aim that this could inform future conservation management and mitigate threats to harbour porpoises.

2. Materials and methods

2.1. The Delphi method

The Delphi method is a survey-based research approach that enables experts to collectively address complex problems through structured group communication. It comprises two- or more rounds of questionnaires, each followed by a feedback round that enables participants to clarify and revise responses from previous rounds to ensure accurate judgements [19,21]. The Delphi method has been used previously in a range of disciplines, such as nursing, tourism and medicine, and is particularly powerful assessing complex issues in data poor environments. One of its major strengths is the possibility for people to respond anonymously, reducing the influence of social pressure and 'group-thinking', yet allowing collation of both formal and informal knowledge in a transparent and robust way [16,19]. Use of the Delphi method in conservation and ecological management is still uncommon [19].

2.2. Study area and expert panel

The North Sea was used as the study area, due to the increasing anthropogenic activities in this area (e.g. expansion of offshore windfarm industry) and as it borders multiple countries, all with their own national conservation focus. Experts working in different sectors and geographic areas were selected to generate a complete and robust judgement on the issues addressed. Experts were individuals knowledgeable in harbour porpoise conservation, and particularly practitioners and policy-makers working in this field, which was ensured by their affiliation to two conservation bodies:

1. Members of the Advisory Committee (AC) of ASCOBANS, with a sub-selection on those affiliated to North Sea bordering countries. The AC provides advice and information to the Secretariat and the involved Parties on the conservation and management of small cetaceans and on other matters related to the running of the Agreement on an annual base. Each Party is entitled to appoint at least one member and additional advisors to the AC, and therefore consists of experts with different background; both researchers, as well as conservationist and policy-makers. It annually discusses current knowledge (both published and unpublished) and conservation issues. This selection resulted in 81 contacts.
2. Members of the North Sea Group (NSG), which is the steering group for the ASCOBANS conservation plan for harbour porpoises in the North Sea. This overlapped with the AC selection with 72%, however, an additional eleven contacts were identified through the NSG.

Invited experts suggested other colleagues for participation, resulting in 14 additional participants. 106 people were invited to the first round of the survey. All survey participants voluntarily contributed to this study and contribution was kept anonymous among the expert panel and within the research team, except for the facilitator.

2.3. The Delphi design and process

A two-round Delphi exercise was electronically conducted between January and March 2017. The first round of the questionnaire was unstructured, allowing participants to give open answers and comment on the issues raised. The second round summarised responses obtained in the first round, which was provided as feedback to the panel and allowed them to revaluate the topics addressed. The questionnaire of the second round involved evaluation and rating of the answers gained in round one. Both questionnaires can be found in the online Supporting information. Round one was accessible for 17 workdays, during which reminders were sent to encourage the experts to participate. Round two was made available 15 workdays later and was accessible for an additional 24 workdays. During all stages of both surveys, the expert panel was given the opportunity to provide suggestions or additional information, if desired.

Demographic information on the participants, current country of work, main field of expertise (open-question) and main field of work (closed-question with options: research, welfare, advocacy, government, monitoring or other) was requested to assess the spread in sectors of expertise and geographical areas of the panel. Collation and reviewing of responses was done by three members of the research team. The first task in the process was to encourage the panel to think about what 'harbour porpoise health' means and involves. The survey focus was on three major topics: identifying knowledge gaps, predicting future pressures or threats, and defining conservation indicators.

2.3.1. Defining 'health'

At the beginning of the survey, experts were given the summary statement of a previous Delphi study on polar bears (*Ursus maritimus*) [21] on the definition of health: "*Polar bear health is a multidisciplinary concept and is concerned with multiple factors that affect polar bears. Polar bear health can be applied at the individual, species, and ecosystem levels, but its most important defining characteristics are whether a population can respond to factors in its environment and sustain itself long term.*". With the aim of encouraging the panel to think about what assessing 'health status' involves, they were asked whether they found the definition by Patyk et al. [21] sufficient to apply for harbour porpoise health, with a yes/no answering option and, if improvement was necessary, what changes they would suggest. The proposed changes to the definition which were made by two or more participants were presented to the panel in round two and participants were asked to rate whether each change would "improve", "decrease", or "neither" improve or decrease the suitability of the definition according to their opinion. Changes were adopted when > 50% of the expert panel responded that these improved the definition.

2.3.2. Current knowledge gaps

In round one the panel was asked to rate currently available information on harbour porpoises regarding its usefulness for assessing their health status in the North Sea on an integer scale from 1 (no relevant information available) to 10 (all necessary information available). This was followed by an open question asking for their opinion of the most significant knowledge gap that, if addressed, would best improve the ability to assess the health status of harbour porpoises in the North Sea. Responses were collated and sixteen statements composed. These were presented to the panel in round two, accompanied by the request to give their percent agreement to each statement from 0% (I do not agree with this statement/I do not think this improves our ability to assess porpoise health status) to 100% (I fully agree with this statement/I think this highly improves our ability to assess porpoise health status).

2.3.3. Future threats or pressures

With an open question the expert panel was asked to predict the most significant threats and pressures affecting harbour porpoise health in the North Sea over the next 20 years. The research team pooled these responses thematically. In the second round, the expert panel was asked to rate each threat for: 1. Index of concern: on a 10-point scale, where 1 = 'not a concern', 5 = 'somewhat a concern', and 10 = 'a major concern' for harbour porpoise populations in the North Sea; 2. Index of the sufficiency of knowledge: on a 10-point scale, where 1 = 'currently, knowledge is insufficient', 5 = 'currently, an average amount of knowledge is present', and 10 = 'currently, knowledge is complete and sufficient'. Participants could rate a 0 in round 2 if they were unsure about specific threats. Subthemes (e.g. specific noise sources like seismic) were only included in round two when two or more experts specifically had addressed this in round one. Density plots were created (using R version 3.3.1) visualising the distribution of scores obtained from the expert panel, providing an overview of the index of concern and index of sufficient knowledge per identified threat.

2.3.4. Conservation indicators

With an open question, the expert panel was asked to list indicators that would be most useful to understand harbour porpoise health status in the future, while keeping in mind the future threats and pressures mentioned in the previous section. To assess the value of each indicator for specific threats, the nine identified threats from round one were presented and the panel was asked to assess each indicator in connection to the different threats on a three-point scoring system: "little to no value", "significant value" and "essential". Any missing indicators could be provided as 'other' and specified in a text box. For this topic, experts could leave sections blank if the addressed threat did not fit within their field of expertise. For the purposes of this study, the definition of indicators according to MSFD was followed: '*indicators are distinctive technical features, which help make the descriptors more concrete and quantifiable*'.

Each indicator in relation to each threat was evaluated for its use by translating the three-point scoring system into values, with: "little to no value" = 0, "significant value" = 1 and "essential" = 2. Research priorities were identified through the calculation of the average total score for each indicator per threat, corrected for the number of experts that completed each subsection. All indicators that scored an average value of > 1.5 for all threats combined, were appointed as the highest priority.

Table 1
Invited and participated expert numbers in both survey rounds, their country, work field and expertise.

Characteristic		Round one N =	Round two N =
Invited		106	44
Participated		44	32
Country	Belgium	2	2
	Denmark	2	2
	France	3	3
	Ireland	1	0
	Germany	13	8
	Netherlands	7	6
	Norway	1	1
	United Kingdom	15	10
Work field	Advocacy	5	4
	Government	10	5
	Monitoring	4	4
	Research	18	12
	Welfare	2	2
	Other	5	5
Expertise	Anthropogenic interaction/impact		15
	Conservation and management		10
	Population dynamics		9
	Marine policy		7
	Acoustics		5
	Stranding and pathology		5
	Oceanography		1
	Cetacean rescue		1

3. Results

3.1. Composition of the Delphi expert panel

Forty-four experts participated in round one, with 32 completing round two of this Delphi exercise. Experts from all countries surrounding the North Sea were involved, with most participants from the larger North Sea bordering countries: United Kingdom (15 and 10 respectively) and Germany (13 and 8 respectively). Most experts worked in the field of 'research' (18 and 12, respectively), followed by 'government' (10 and 5 respectively) (Table 1). Experts that completed both rounds (n = 32) mainly worked on anthropogenic interactions and impacts (n = 15), conservation and management (n = 10), ecology (including diet studies) (n = 9) and population dynamics (including abundance and distribution) (n = 9) (Table 1).

3.2. Defining 'health'

Participants were asked if they found the definition by Patyk et al. [21] sufficient to apply for harbour porpoise health, or provide improvements to this definition. Most experts (66%) agreed with the sufficiency of the definition, yet several suggestions were made in round one which were integrated as described in the methods for round two for the whole panel to assess (Table 2). This lead to the slightly adapted definition of harbour porpoise health as: "*Harbour porpoise health is a multidisciplinary concept and is concerned with multiple factors that affect harbour porpoises. Harbour porpoise health can be applied at the individual, species, and ecosystem levels, but its most important defining characteristics are whether a population or subpopulation is resilient to factors in its environment and can sustain itself long term.*"

3.3. Knowledge gaps

Experts rated the usefulness of currently available information on

Table 2
Condensed list of proposed changes to the definition of harbour porpoise health and the average percentage judged by the panel in round two (n = 32). The number of experts that identified each change in round one is given in the parentheses.

Proposed change	Increases %	Decrease %	Neither %
Add […] its most important defining characteristics are whether *an individual* or population can […] (7)	45.2	35.5	22.6
Add […] its most important defining characteristics are whether a population *or subpopulation* can […] (3)	**64.5**	9.7	29.0
Change "in its environment *and* sustain itself long term" to "in its environment to sustain itself long term" (4)	48.4	19.4	35.5
Change "a population *can respond* to factors" to "a population is resilient to factors" (9)	**64.5**	19.4	19.4

harbour porpoises slightly above average for assessing health status (rating of 5.6/10, with minimum 3; maximum 9; mode 7). The four most significant knowledge gaps, that, if addressed, would most improve the ability to assess health status of harbour porpoises in the North Sea were population size and structure (n = 12), cumulative impact of stressors (n = 11), reproduction parameters (n = 9) and the impact and effects of contaminants (n = 8). The knowledge gaps identified, as well as the composed statements based on these knowledge gaps with the average percentage agreement of the panel can be found in Table 3.

3.4. Future threats and pressures

The panel was asked to predict future threats and pressures. Bycatch (n = 31), noise pollution (n = 23), decrease in prey quality and quantity (n = 21) and chemical pollution (n = 20) were most frequently mentioned (Table 4). Within the themes noise- and chemical pollution, some experts identified specific threats. For noise pollution, this included (de)construction of energy platforms (n = 11), shipping (n = 6), ordnance detonation (n = 2), sonar (n = 1), wind farm operation (n = 1), seismic (n = 1) and oil extraction (n = 1). For chemical pollution, this included persistent organic pollutants (including polychlorinated biphenyls) (n = 4) and eutrophication (n = 1). Specific threats within the topics noise- and chemical pollution are included in Table 4 when mentioned by two or more experts.

Threats were rated an index of concern and an index of sufficiency of knowledge in round two (Table 4). The concern was rated consistently higher for almost all threats than the available knowledge. The threat with the highest index of concern was bycatch (8.1/10), followed by chemical pollution (7.5/10) and noise pollution (7.1/10). Competition with sympatric species and shipping interactions (e.g. ship collision) were rated the lowest concern (3.3/10 and 4.2/10, respectively). For knowledge, bycatch and chemical pollution scored the highest indexes (5.5/10 and 5.4/10, respectively), whilst the knowledge on climate change and prey quality and quantity rated as currently most insufficient (3.6/10 and 3.9/10, respectively) (Fig. 1).

3.5. Conservation indicators

The participants were asked to define indicators useful for understanding harbour porpoise health and nine indicators were assigned (left column of Table 5). All indicators were evaluated for their use to assess the defined threats so research priorities could be identified through the calculation of the average total score for each indicator per threat. This shows that certain indicators, or research into these topics, can be of use when assessing a particular threat, whilst other indicators are of value in the assessment of a range of threats. As an example, the indicator to ultimately assess the extent and effects of bycatch was unanimously and logically assigned by the panel to be 'assessment of interactions with fisheries'. However, also investigating causes of death and temporal and spatial distribution were rated as essential research topics to be able to assess bycatch. For assessing the extent and effects of chemical pollution, measurements of contaminant levels in tissues and investigation of causes of death, and to a lesser extent also the assessment of nutritional body condition, were assigned by the panel as essential research topics. To increase knowledge on threats assigned the lowest index of the sufficiency of current knowledge (climate change and prey quality and quantity), research on certain indicators was singled out to encourage progress. For climate change, this included research into spatial and temporal distribution and abundance. To gain knowledge on prey quality and quantity, research into prey availability, diet composition and nutritional body condition needs to be intensified.

The overall value of each indicator was also calculated for all threats combined, to establish a shortlist of indicator research areas that will

Table 3
Collated list of knowledge gaps from the first round in response to the question what currently are the most significant knowledge gaps, which, if addressed, would most improve the ability to assess the health status of harbour porpoises in the North Sea, with the number of experts that identified each knowledge gap provided in the parentheses. Sixteen statements were composed based on these knowledge gaps and presented to the expert panel in round 2, requesting percent agreement to each statement.

Knowledge gaps	Statements *It is important to…*	Agreement with statement (%)
Bycatch (7)	quantify bycatch numbers, both lethal and non-lethal	92.3
Population size and structure (13)	understand population size and structure	90.0
Effective reduction of impacts (1)	mitigate threats and pressures instead of only characterizing them	86.9
Cumulative impacts (11)	understand cumulative impact and combined stressors	86.8
Contaminants (8)	understand the influence of contaminants	85.7
Noise (7)	understand the effects of impulsive and continuous noise	84.5
Reproduction parameters (9)	understand the factors affecting reproduction parameters	82.3
Standardisation and research scales (6)	establish more international collaborations to conduct research on appropriate scales	82.0
Feeding ecology and behaviour (3)	understand changes in prey availability and their impacts	80.9
Seasonal and inter-annual movement (6)	understand spatial and temporal aspects of habitat use	77.4
Health of free-ranging individuals (6)	know the health status of free-ranging individuals	73.7
Energetic needs and nutritional status (6)	understand energetic needs and what affects these	71.7
Population boundaries (4)	understand population boundaries, including defining subpopulations	71.5
Representativeness of data from stranded animals (6)	better quantify the biases associated with strandings data	69.7
Climate change (1)	understand the effects of climate change at individual, population and ecosystem levels	65.9
Competition (2)	understand the impact of competition for prey between porpoises and sympatric species	57.9

Table 4
Condensed list of threats and pressures affecting harbour porpoise health in the North Sea in the next 20 years: experts (n = 32) rated each subject an index of concern (left table) and an index of sufficiency of knowledge (right table) on a ten-point scale, with the mean and most rated (mode) indexes presented.

Index of concern	n	mean	mode	Index of sufficiency of knowledge	n	mean	mode
Bycatch (31)	32	8.1	10	Bycatch (31)	32	5.5	6
Chemical pollution (20)	31	7.5	8	Chemical pollution (20)	31	5.4	6
Noise pollution (in general) (23)	32	7.1	8	Construction of energy platforms (11)	30	4.8	7
Construction of energy platforms (11)	31	6.7	8	Ordnance detonation (2)	28	4.8	4
Insufficiency in prey quality or quantity (21)	32	6.2	6	Disease (3)	28	4.7	5
Disease (3)	29	6.2	7	Noise pollution (in general) (23)	32	4.7	5
Ordnance detonation (2)	29	6.1	8	Shipping interactions e.g. ship strikes (6)	30	4.2	4
Climate change (9)	29	5.6	5	Competition with sympatric species (1)	30	4.0	3
Plastics (micro and macro) (2)	29	5.6	4	Plastics (micro and macro) (2)	31	4.0	4
Shipping interactions e.g. ship strikes (6)	32	4.2	5	Insufficiency in prey quality or quantity (21)	30	3.9	5
Competition with sympatric species (1)	30	3.3	2	Climate change (9)	29	3.6	5

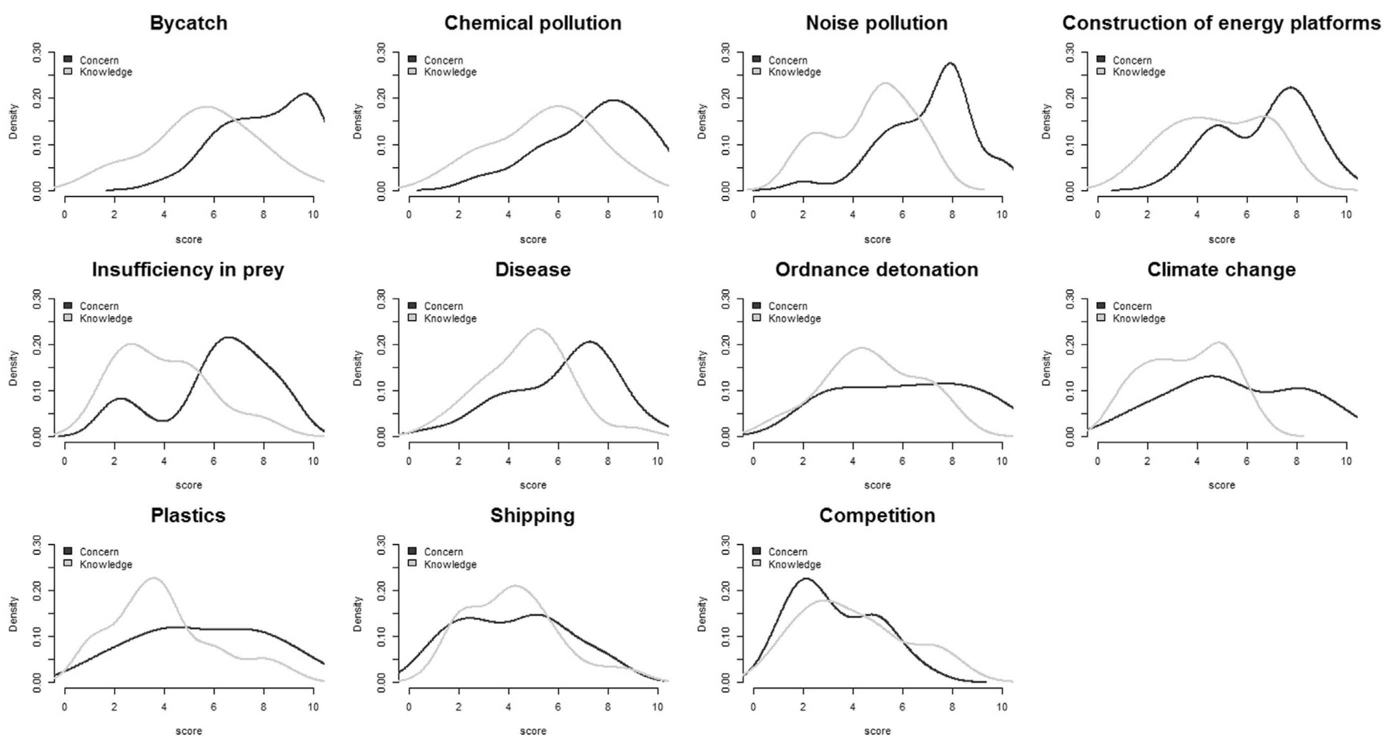

Fig. 1. Density plots showing the distribution of answers obtained by the expert panel, providing an overview of the index of concern and index of sufficiency of knowledge per identified threat. Experts (n = 32) rated each subject an index of concern (dark grey) and an index of sufficiency of knowledge (light grey).

contribute to the assessment of a the full range of threats and could therefore be seen as priority research to assess porpoise health status in the future. The five indicator research areas that were assigned with the highest priority were cause of death, distribution, abundance, habitat use and diet composition (right column Table 5).

4. Discussion

In this study current knowledge gaps, future threats and useful conservation indicators for assessing the health status of harbour porpoises were collectively appointed by an international and interdisciplinary panel of marine mammal conservation experts. The expert panel subsequently identified and ranked research priorities that can inform future conservation management aiming to mitigate threats. Through the combination of the involvement of experts from different geographic locations and expertise, and the Delphi method's strength in efficiently collating formal and informal knowledge in a transparent and robust way, this study appoints research priorities that otherwise may not have been collectively reached.

Assessing the cumulative effects of multiple stressors is stated a top-priority problem in marine ecology [20] and this also stood out in our study as a major knowledge gap. Cumulative risks derive from a combination of anthropogenic threats (such as bycatch, noise and chemical pollution, marine debris etc.), as well as natural stressors, such as increased presence of predators, decreased presence of prey and increases of pathogens and parasites. Stressors can be intrinsic; a result of internal changes (e.g. fasting), or extrinsic; a factor of the external environment (e.g. noise). A way of quantitatively assessing cumulative effects is however yet to be established, but conceptual frameworks have been suggested [20]. Appointing data gaps is key in this process. The usefulness of currently available information on harbour porpoise health status was scored just above average in our study (rating of 5.6/10) and by large the mean consensual opinion among the experts was that currently the most important knowledge gaps for the North Sea area were the extent and effects of bycatch, and population size and structure. The most significant pressures for harbour porpoise populations in the North Sea were attributed to bycatch, chemical pollution and noise pollution, respectively. Interestingly, the concern for almost all

Table 5
List of indicators which would be most necessary to understand harbour porpoise health status in the future, scored for effectiveness in assessing the nine identified main threats on a three-point scoring system: 0 = "little to no value", 1 = "significant value" and 2 = "essential". The numbers in the table represent the calculation of the average total score for each indicator per threat, corrected for the number of experts that completed each subsection and the final column represents the calculation of the average score of each indicator for each threat. Green indicates the 'essential' rated indicators per threat, orange indicates the 'significant' rated indicators per threat.

Indicators	Bycatch	Pollution	Climate	Prey	Disease	Noise	Competition	Plastic	Shipping	Average score	Number of threats for which indicator is essential	Number of threats for which indicator is useful	Index of usefulness
Causes of death	1.84	1.79	0.93	1.54	1.89	1.34	1.08	1.71	1.74	1.54	7	2	9
Abundance incl. repro. and mortality	1.61	1.33	1.52	1.52	1.43	1.28	1.16	0.88	1.23	1.33	3	6	9
Habitat use	1.33	0.81	1.41	1.15	0.73	1.59	1.62	1.12	1.5	1.25	2	6	8
Temporal and spatial distribution	1.61	0.74	1.86	1.54	0.74	1.66	1.58	0.92	1.58	1.36	6	1	7
Health status of free-ranging population	0.7	1.44	1.14	1.46	1.7	0.96	1.13	1.12	0.38	1.12	1	6	7
Body condition	0.41	1.52	1	1.68	1.68	0.58	1.12	1.23	0.58	1.09	3	4	7
Stranding numbers	1.2	1.11	0.93	1	1.33	0.93	0.8	1	1.23	1.06	0	7	7
Diet composition	0.97	1.41	1.39	1.79	0.96	0.36	1.81	1.27	0.22	1.13	2	4	6
Prey availability	1.2	0.78	1.43	1.89	0.74	0.71	1.88	0.69	0.39	1.08	2	3	5
Contaminant levels in tissue	0.37	1.93	0.26	0.85	1.56	0.25	0.2	1.35	0.08	0.76	2	1	3
Physiological char. e.g. stress indicators	0.55	0.93	0.92	0.89	1.19	1.5	0.68	0.72	0.48	0.87	0	2	2
Reproduction parameters	0.79	1.36	0.96	0.96	1.11	0.75	0.64	0.48	0.17	0.8	0	2	2
Disease surveillance	0.33	1.48	0.77	0.78	1.86	0.54	0.29	0.72	0.22	0.78	1	1	2
Interaction with fisheries/fishing effort	2	0.19	0.43	1.15	0.15	0.32	0.6	0.32	0.52	0.63	1	1	2
Water quality	0.24	1.41	0.59	0.59	0.88	0.15	0.2	1.12	0.09	0.58	0	2	2
Shipping activity	0.47	0.07	0.07	0.11	0.15	1.55	0.16	0.2	1.89	0.52	2	0	2
Age structure	0.9	0.96	0.73	0.81	1.32	0.64	0.75	0.56	0.61	0.81	0	1	1
Occurrence of predators	0.33	0.07	0.68	0.44	0.26	0.14	1.08	0.04	0.17	0.36	0	1	1
Noise levels in the environment	0.5	0.15	0.07	0.26	0.41	1.9	0.28	0.16	0.96	0.52	1	0	1
Genetic variability	0.5	0.4	0.75	0.31	0.65	0.26	0.29	0.21	0.09	0.38	0	0	0

pressures was rated consistently higher than the available knowledge for these pressures; indicating that there was consensus among the expert panel on the need to improve our knowledge concerning harbour porpoise populations and their viability.

The top five indicators as appointed by the expert panel as the most essential to assess harbour porpoise population health in the future were the research into causes of death, identifying the spatial and temporal distribution, establishing abundance estimates, and revealing small scale habitat use and diet composition. Prioritising research and investing resources in these indicators, which are of relevance to the assessment of multiple threats, could be seen as essential to help the research community to better evaluate and predict the health status of harbour porpoises in the future. Therefore, these indicator researches can be seen as 'the best value for money' for conservation managers to focus upon. In addition experts agreed that the standardisation and connection of databases from different research fields to conduct studies on appropriate ecological scales is needed. Moving from only characterising knowledge gaps towards the establishment of an effective way to reduce pressure and mitigate will become necessary. Efforts into the development of methodological approaches to address the integration of complexity of relationships between threats, indicators and knowledge gaps should also be further developed.

The Delphi method proves to be adaptable and is widely used, but its scientific merit and outcomes have been reviewed and criticised [22]. Strengths of the methods lie within the ability to bring together a range of knowledge and experience without geographical limitations, making it quick and relatively efficient. This was demonstrated here; experts from all countries surrounding the North Sea were involved and two questionnaires were conducted in a short period of time, without the use of any funds. The Delphi method allows the best use of current available formal and informal information in a transparent and robust matter, though, its reliability is strongly influenced by the complexity of the topic involved and could well be heuristics-driven. Additionally, the number of questions, rounds and participants could strongly influence the outcomes [16,22]. This study aimed to generate a broad yet complete view of harbour porpoise health status, a highly complex issue to address, to assess current knowledge gaps and predict future threats and pressures. This did not allow in-depth focus on specific topics, which could be necessary for certain topics, e.g. when geographical differences occur or threats can be subdivided into more specific sources or topics. One example in this study was noise pollution; when an in-depth evaluation for a specific noise source is required, a Delphi exercise (or other approach) with a more specific focus is needed. An example is the study by McWinnie et al. [17] who investigated marine noise pollution from vessels in Canada and identified priority information needs to inform new research and address policy needs through an iterative Delphi style process and workshop.

The results of any Delphi exercise should be considered as an opinion of the included experts [22]. This study showed that the most significant pressures for harbour porpoise populations in the North Sea were attributed to bycatch, chemical pollution and noise pollution. These threats are all tangible and well established threats which form current priorities within ASCOBANS as well as other EU bodies, making these historically and politically ranked as important. It is likely that these widespread and 'familiar' threats have a higher profile amongst the participants than more emergent or nebulous risks, e.g. climate change, which could have resulted in a higher rank. This might also explain the lack of consensus within the expert panel when rating the concern and available knowledge of those more nebulous threats. A low scoring could however also be based on either a comprehensive awareness of the topic, a balanced appraisal that it is of less significance than other topics, or an ignorance of the topic, and hence falsely attributed as less important. The success of a Delphi exercise is thus strongly dependent upon the experience of the panel with the range of topics addressed. The panel in this study consisted of individuals working in governmental and non-governmental organisations. They had a very differing range in experience with varying backgrounds in conservation management and knowledge on harbour porpoise populations. Feedback rounds within a Delphi exercise therefore seem crucial; aiming to ensure accurate understanding of expert knowledge and their given answers. The selection of experts affiliated to ASCOBANS may have eliminated knowledgeable other experts, e.g. those working in research without participating in conservation bodies. Although participants could be assigned by the invited experts and were subsequently included in this study it is likely that valuable individuals were missed with unknown influence on the study outcomes presented here. Yet, the results of the Delphi exercise may be exploited to become a valuable communication tool to generate debate on the topic addressed [22] and this exercise presents the first attempt to define knowledge gaps and research priorities for studying harbour porpoise health, at an international and interdisciplinary level.

Where relevant ecological knowledge and experience is lacking and management decisions need to be made, the Delphi approach could bridge the gap between science and policy [16,19]. Conservation progress may be increased when communication between researchers and wildlife managers is improved and clear management needs are identified [9,19]. Current research is often directed to a single or similar set of threats, due to isolated funding sources and managers having less funds to support research directly. The study results presented here suggests that the expert panel understands the multifactorial and nonlinear link between individual threats and general ecosystem health. Whilst such specialisations may be useful in gaining details on specific topics, only integrating these research findings in a wider context will significantly increase our understanding of health and a paradigm shift from research into specific threats towards a broader approach seems to be required. The results of our study can be used in conservation management for prioritising research to eventually mitigate threats for harbour porpoises in the North Sea and in order to meet the requirement of several international conventions, aiming for a more favourable conservation status of this species. Additionally, this study presents a study design that could be adapted to function as a technique usable in other geographic areas where managers are in need of defining knowledge gaps and research priorities for other (wildlife) species.

5. Conclusion

Harbour porpoises are protected and included under several international, European and national conventions aiming for a favourable conservation status of this species. To meet the requirements of such conventions this study used an international and interdisciplinary approach aiming to identify current knowledge gaps and predict future threats to harbour porpoise populations in the North Sea. The three most important knowledge gaps addressed were bycatch, population dynamics, and the cumulative effects of multiple stressors. Bycatch was predicted as the highest concern for porpoises in the next 20 years followed by chemical and noise pollution respectively. In order to affectively assess harbour porpoise populations and to guide research focus and management objectives in the future, a list of essential indicators was established. Studying causes of death, distribution, abundance, habitat use and diet composition were scored as most relevant to assess and understand the health status of harbour porpoises in the future.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2018.07.006.

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