Cumulative Effects Assessment: Proof of Concept Marine mammals

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Authors: Gerjan Piet[1], Arjen Boon[2], Ruud Jongbloed[1], Myra van der Meulen[2], Jacqueline Tamis[1], Lorna Teal[1], Jan Tjalling van der Wal[1]

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Contents

Summary

This development of the framework and approach for a Cumulative Effects Assessment (CEA) is based on a literature review. From this we adopted several definitions that guided this development.

- A CEA is understood as "a systematic procedure for identifying and evaluating the significance of effects from multiple sources/activities and for providing an estimate on the overall expected impact to inform management measures. The analysis of the causes (source of pressures and effects), pathways and consequences of these effects on receptors is an essential and integral part of the process".
- Cumulative effects are "the incremental impact of the action when added to the other past, present and reasonably foreseeable actions". In this approach we only consider a (cumulative) effect significant if it has an impact on a relevant ecosystem component.

Therefore our framework and approach for a CEA is based on all human activities that may have a potential impact on any relevant (from a policy perspective) ecosystem component at an appropriate spatio-temporal scale.

The literature also identified some key challenges that need to be addressed for CEA to evolve into a consistent, appropriate tool to assist decision-making. These challenges included

- A clear distinction of the receptor-led CEA from the dominating stressor-led Environmental Impact Assessment (EIA) approaches and
- Enabling CEA to provide ecosystem-relevant information at an appropriate regional scale.

Therefore this CEA is explicitly developed to be a receptor-led and fully integrated framework, i.e. involving multiple occurrences of multiple pressures (from single and/or different sources) on multiple receptors, as opposed to other existing approaches dealing with only a subset of those pressures or receptors, hence our use of the phrase iCEA for integrated CEA. As a proof of concept for this iCEA we selected one receptor, the ecosystem component marine mammals.

From the literature review we adopted (and slightly modified) a risk-based framework for defining and undertaking cumulative effects assessments which is aligned to the work in the OSPAR Intersessional Correspondence Group on Cumulative (ICG-C) Effects and the ICES Working Group on Integrated Assessments of the North Sea (WGINOSE), thereby ascertaining this framework and approach is well-placed within ongoing international North Sea initiatives. Furthermore, the CEA framework in this study should contribute to national North Sea policymaking, with a specific focus on the Marine Strategy framework Directive (MSFD). This literature review is presented in Chapter 1.

Our iCEA framework consists of four phases each corresponding to a chapter in this report:

1. Conception. This is where purpose and scope are defined (see Chapter 2).
2. Execution (presence). Identification of potential effects of human activities and their pressures on the ecosystem. This results in a so-called "linkage framework" consisting of all the relevant impact chains, i.e. a chain linking driver-pressure-state (= sector-pressure-ecosystem component (see Chapter 3)).
3. Execution (importance). Here we establish the relative importance of each impact chain using a risk-based approach that calculates "Impact Risk", i.e. the contribution of that impact chain to the risk a specific ecosystem component is impacted. Impact Risk is the key concept around which this iCEA evolves. The quality of the underlying information and hence our level of confidence is assessed (see Chapter 4).
4. Evaluation: This is where the significance of the results, including the level of confidence, is considered. This both to inform further work to improve the knowledge base as well as provide guidance on the application of the iCEA as identified in the conception phase (see Chapter 5).

As such we consider this framework an iterative process where each cycle's evaluation phase can feed into (each of the phases of) the next iteration. Each phase of what can be considered the first iteration is presented below.

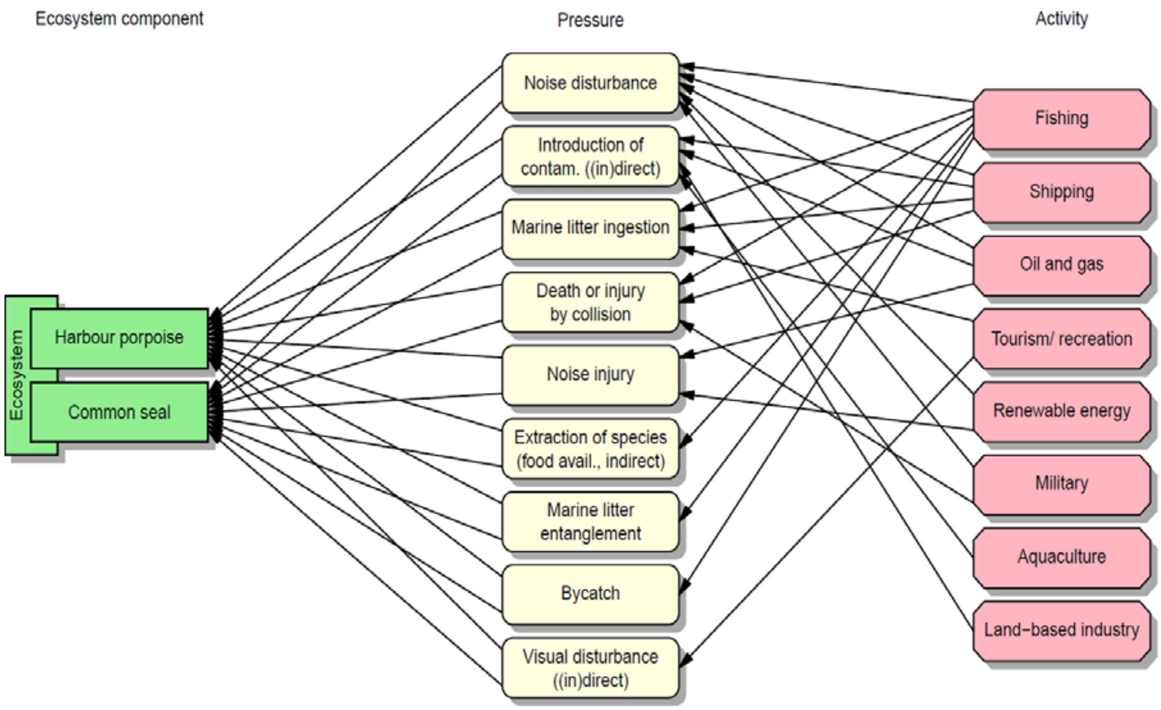
In the conception phase we defined the purpose and scope of the iCEA. In this case the iCEA is intended as a comprehensive integrated CEA (iCEA) which is not only based on expert judgement but, whenever possible, includes the best sources of (preferably quantitative) information available. As this is going to be a piecemeal process the iCEA should explicitly incorporate the level of confidence associated with that information such that each iteration cycle results in a more accurate outcome of the assessment as reflected in increased confidence scores. Ultimately the aim is to apply this iCEA in a policy context, specifically for:

- the identification of the main impact chains contributing to the risk that a specific ecosystem component (here marine mammals) is impacted thereby compromising the achievement of policy goals (e.g. GES) and
- an evaluation of the performance of possible management strategies (as part of the MSFD "Programme of measures") in terms of their contribution to reduce those impacts thereby contributing to the achievement of those policy goals.

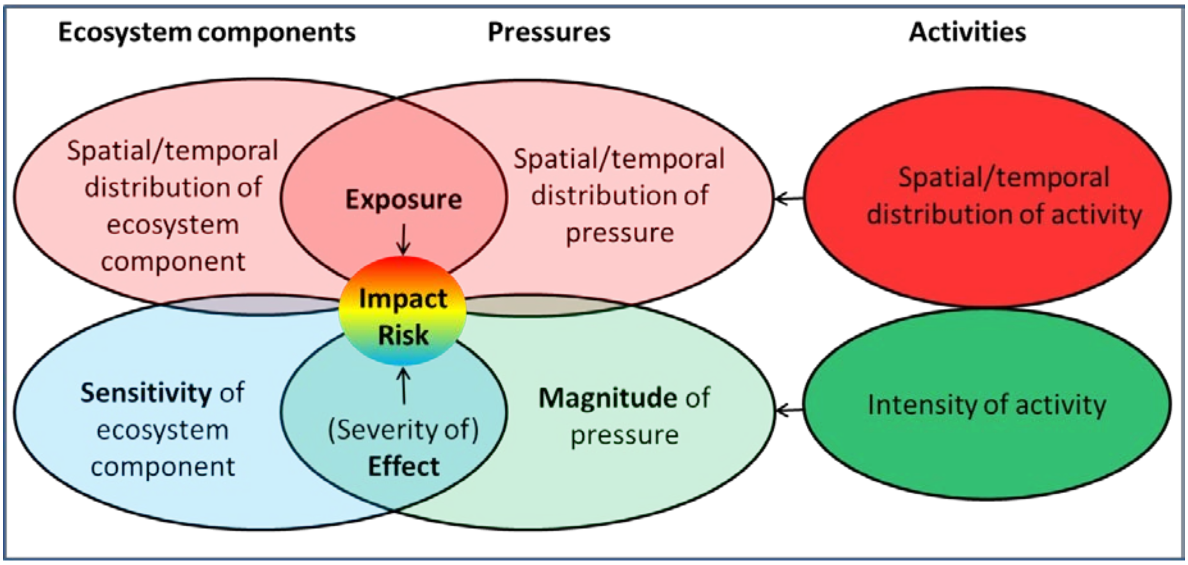
However as this is the first iteration focussing only on a single receptor, i.e. marine mammals, this report will only present a framework that allows an assessment of the relevant information available and identify the knowledge gaps and how these determine uncertainty and a corresponding confidence level. This then leads to a general discussion on the feasibility of (further) developing this iCEA based on the best possible information available, or what can be obtained in the short to medium term. The application of this iCEA in a policy context is not within the remit of this exercise.

The scope of this iCEA was determined by the decision the approach should be receptor-led which comes with requirements for the spatial and temporal scales different than those typically considered for EIAs. This iCEA is intended for the Greater North Sea as defined in the Marine Strategy Framework Directive (MSFD) and the appropriate temporal scale is determined by the persistence of the pressures and the recovery capacity of the ecosystem components.

The 1st execution (presence) phase was based on an existing risk assessment framework and database (from the EU FP7 ODEMM project) selecting marine mammals in the North-East Atlantic region but expanded with impact chains deemed relevant. This resulted in the Marine Mammals Linkages Framework (MMLF) as the basis for the next execution phase.



The 2nd execution (importance) phase consists of the main body of work where we attempted to collate the available information required to estimate Impact Risk and thus determine the relative importance of each impact chain. This iCEA, and its key concept Impact Risk, is based around the principles of environmental risk assessment where risk is based on Exposure and Effect. Exposure is determined by the spatio-temporal overlap between the anthropogenic pressure and the ecosystem component and the severity of the effect is determined by the magnitude of the pressure and the sensitivity of the ecosystem component.



The distinction of impact chains and different aspects of risk each with their own information requirements resulted in a modular approach for the development of this iCEA where the so-called information modules each provide part of the information required for the assessment. This modular approach allows great flexibility in introducing new sources of information (e.g. data, maps, models as well as various forms of expert judgement) if they are considered to be an improvement. For each information module the available information is therefore presented together with our estimated level of confidence based on formal evaluation criteria ranging from the highest confidence score=1 if complete fully detailed quantitative information available, to varying degrees of limited quantitative information available, to expert judgement-based, to a lowest score=0 if nothing is known. Due to time constraints this inventory of information availability may not have been comprehensive but is considered sufficient for the purpose of this exercise and as a relevant result for the following evaluation phase of this first iteration of the iCEA.

The evaluation phase was intended to provide useful guidance for the next iteration cycle of this iCEA framework. To that end we developed a formal evaluation framework where for each information module we combined :

- the level of confidence reflecting the availability and quality of the information according to specific criteria. The result is shown in an example table below where information availability is indicated by the colour of the cell, i.e. Quantitative Full (Dark Green), Quantitative Partial (Light Green), Qualitative (Orange) or No (Red); with
- the scope for improvement based on our expectation of the effort required to achieve higher confidence levels; and
- an assessment of the importance of each information module in terms of its contribution to Impact Risk.

Those information modules which have a low level of confidence, but which can be increased with relatively little effort, and are among the most important contributors to Impact Risk, are considered the preferred candidates for future work.

Pressure	**Effect**	**Exposure**	**Magnitude**	**Sensitivity**
Noise	Injury			
	Disturbance (change in behaviour, displacement)			
Introduction of contaminants	Increase of internal concentration (directly from environment)			
	Increase of internal concentration (indirectly through food)			
Marine litter	Entanglement			
	Ingestion			
Selective extraction	Bycatch			
	Reduced food uptake through decrease food availability			
Death or injury by collision	Death or injury			
Visual disturbance	Change in behaviour, displacement			

The main conclusions of this exercise (see Chapter 6) are that the iCEA framework and approach presented in this study appear suitable to fulfil its main purpose and ultimately inform the policy process as described in the conception phase. However it should be acknowledged this is only the very first step in a process where through many iterations new information can be introduced and assessed (relative to existing information) based on the criteria provided resulting in an improved iCEA with increasing confidence levels. As more information becomes available the relative importance of impact chains and its corresponding information modules may change giving direction to new areas for research.

For further development of this iCEA towards its intended applications we can distinguish between the first purpose, i.e. identification of the main impact chains contributing to the risk that a specific ecosystem component is impacted, which can be achieved with the approach presented here focussing on one specific ecosystem component and the second purpose, i.e. an evaluation of the performance of possible management strategies, which would require all ecosystem components to be included as would be required for ecosystem-based management. Thus to further the development and application of this iCEA towards its (two) purpose(s) the recommendation is to:

- Include the available information presented in this report into the iCEA and develop the Bayesian Belief Network such that it can process this information and its associated confidence into an assessment that identifies the main impact chains for the marine mammals.
- Extend the framework and approach to (all) the other ecosystem components so that a truly integrated CEA is possible. Note that this is likely to affect the identification of what should be considered the main pressures to guide management.
- Improve the information modules that emerged from the evaluation as the most promising to increase the confidence in the outcome of the iCEA. Note that the previous two steps may result in a different prioritisation of the information modules as the importance of pressures and hence impact chains changes.

Glossary of terms

Word / Phrase	Definition
Cumulative effect	the incremental impact of the action when added to the other past, present and reasonably foreseeable actions
Cumulative Effects Assessment (CEA)	A systematic procedure for identifying and evaluating the significance of effects from multiple sources/activities and for providing an estimate on the overall expected impact to inform management measures. The analysis of the causes (source of pressures and effects), pathways and consequences of these effects on receptors is an essential and integral part of the process. In this approach we only consider an effect significant if it has an impact on a relevant ecosystem component.
Driver	According to DPSIR driver or 'driving force' is a need. Examples of primary driving forces for an individual are the need for shelter, food and water, while examples of secondary driving forces are the need for mobility, entertainment and culture. Here the driver is defined by the sector and activity.
	IMPRESS (2003): "An anthropogenic activity that may have an environmental effect (e.g. agriculture, industry), also driving force".
	MA (2005): "Any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.
Ecosystem component	Ecologically coherent elements of an ecosystem, that group together more disparate taxonomic groups into the minimum number of elements, based on the view that the lower the number of elements, the easier it is to gain a coherent and integrated assessment across the ecosystem. Is identical to receptor if intended as the ecological entity, see receptor.
Effect	Human activities exert pressures which have effects which may lead to impacts on receptors. So pressure and effect are always coupled so that every activity and its pressure has an effect, but not every pressure necessarily leads to an impact, e.g. dredging of seafloor sediments has the effect of temporarily mobilizing sediment into suspension in the water column but this may not have a discernible impact on water quality or biota. Slightly modified from Judd et al. (2015)
	Thus ''Effects'' can be managed to reduce or prevent ''impacts''. This embodies the consideration of environmental risk in that whilst human activities exert pressures they do not always impact the environment. For example, various human activities exert pressures on the marine environment through increased nutrient loading resulting in effects of oxygen depletion/hypoxic zones, such effects can be magnified into impacts (e.g. reproductive problems in fish).

Word / Phrase	Definition
Exposure	Exposure science addresses the contact of humans and other organisms with chemical, physical, or biologic (CBP) stressors[1] (EPA 2003; EPA 2011b) over space and time and the fate of these stressors within the ecosystem and organisms—including humans.[1]
Hazard	"A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Comment: The hazards of concern to disaster risk reduction as stated in footnote 3 of the Hyogo Framework are "… hazards of natural origin and related environmental and technological hazards and risks." Such hazards arise from a variety of geological, meteorological, hydrological, oceanic, biological, and technological sources, sometimes acting in combination. In technical settings, hazards are described quantitatively by the likely frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis." [UNISDR, 2009]
Impact chain	Chain linking driver-pressure-state (= sector-pressure-ecosystem component) that causes the specific impact
Impact	The adverse consequence(s) of pressures on any part of the ecosystem where the change is beyond that expected under natural variation given prevailing conditions. According to DPSIR, impact is the changes in the physical, chemical or biological state of the environment which may have environmental or economic consequences affecting the functioning of ecosystems, their life-supporting abilities, and ultimately human health as well as the economic and social performance of society.
	A measurable, detrimental, change to a species or habitat attributable to a human activity. Thus ''Effects'' can be managed through the mitigation of human activities to reduce or prevent ''impacts''. This embodies the consideration of environmental risk in that whilst human activities exert pressures they do not always impact the environment. For example, various human activities exert pressures on the marine environment through increased nutrient loading resulting in effects of oxygen depletion/hypoxic zones, such effects can be magnified into impacts (e.g. reproductive problems in fish). Judd et al. (2015)
Linkage framework	The combination of all the possible linkages through which the Stressor may have an effect on the Receptor. Each linkage is called an impact chain.
Magnitude	The (measurable) level or concentration of the pressure or stressor which is quantitatively and casually linked to the direct or indirect effects on the receptor.
Persistence	- "The continued or prolonged existence of ecological effects or stressors" (Michiel Daam)
	- OECD (2007): " Persistence is the length of time that a compound is able to remain in the environment after being introduced into it. Some compounds may persist indefinitely."

[1] Exposure Science in the 21st Century: A Vision and a Strategy (2012), National Academy of Sciences

Word / Phrase	Definition
Pressure	ODEMM. The mechanism through which an activity has an effect on any part of the ecosystem. Pressures can be physical (e.g. abrasion), chemical (e.g. introduction of synthetic components) or biological (e.g. introduction of microbial pathogens). See MSFD Annex III
	IMPRESS (2003): "The direct effect of the driver (for example, an effect that causes a change in flow or a change in the water chemistry of surface and groundwater bodies."
	an event or agent (biological, chemical or physical) exerted by the source to elicit an effect (that may lead to harm or cause adverse impacts). Judd et al. (2015)
Receptor	Physical (beaches, sandbanks, mudflats) or ecological (ecosystem components, e.g. fish, birds, mammals, plants) or economic (tourism, business) or social/cultural (public enjoyment of open space) entities which are sensitive to the hazards under investigation. In other words, entities which would be affected if exposed to the combined pressures. Judd et al. (2015). An impact is a change in state of the receptor.
Recovery	Ecologically the "return towards undisturbed system state as pressure is relaxed; as a component of resilience, the capability of a system to recover." Tett et al. (2013) In a socio-economic context "The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors"[UNISDR, 2009]
Resilience	"Ecological: ability to recover from perturbation" (Michiel Daam)
	- EEA, 2009: "The ability of an ecosystem to return to its original state after being disturbed."
	- "The ability of a system to absorb impacts before a threshold is reached where the system changes into a different state (CBD Secretariat, 2009)
	- UNEP-WCMC (2013): "The capacity of a natural system to recover from disturbance. OECD 2007 [19]
	- MA (2005): "The level of disturbance that an ecosystem can undergo without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics as well as the organizational and institutional capacity to understand, manage, and respond to these dynamics." /
	- AQUACROSS: "ability to cope with alterations induced by the presence of multiple stressors or with unpredictable or non-directional environmental change. A system is resilient when it retains or returns to its essential features and functions after its elements, processes and structures are submitted to pressure. (Rockström, J. et al., 2014. Water Resilience for Human Prosperity. Cambridge University Press.)
	- "The capacity of an ecosystem to maintain functionality when subject to stressor shock." (Dasgupta, 2013)
Resistance	"Ecosystem ability to withstand perturbation" (Michiel Daam)
	"The capacity of an ecosystem to withstand the impacts of drivers without displacement from its present state. [MA, 2005]

Word / Phrase	Definition
Response	According to DPSIR a 'response' by society or policy makers is the result of an undesired impact and can affect any part of the impact chain
Risk	A function of likelihood and consequence, where highest risk is assumed when a severe consequence is likely.
	A function of exposure and effect which is more appropriate when an assessment of on-going (current) pressure is needed (Smith *et al.*, 2007).
	"The combination of the probability of an event and its negative consequences. Comment: This definition closely follows the definition of the ISO/IEC Guide 73. The word "risk" has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings the emphasis is usually placed on the consequences, in terms of "potential losses" for some particular cause, place and period. It can be noted that people do not necessarily share the same perceptions of the significance and underlying causes of different risks." [UNISDR (2009)]
Risk Assessment	- UNISDR (2009) "A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend. Comment: Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process."
Scale	"Scale is the spatial, temporal, quantitative or analytic dimension used by scientists to measure and study objects and processes". Accordingly, scale is dependent on the extent (magnitude of dimension) and grain/resolution (precision in measurement). (Gibson, 2000)
Sector	A business that exploits the same or related product or service provided by the marine ecosystem (e.g. shipping; coastal infrastructure)
Sensitivity	The level of impact on a receptor caused by a pressure/stressor, mostly used in comparison to other pressures or stressors.
Source	The causal factor for pressure(s) and effects. In simple terms the source (e.g. pile driving, dredging) is derived from an activity (e.g. installation of an offshore wind farm, port operation). Unambiguous identification of the source(s) of the pressures included in the CEA is essential if effects are to be appropriately managed. Judd et al. (2015). Instead of Source we preferred Human Activity.
Spatial Extent	The extent and distribution of the pressure from a human activity (or sector) with the aim to determine its overlap (in time and space) with a particular ecosystem component (for which its spatial extent is also identified).
State	According to DPSIR the 'state' of the environment is the quality of the various environmental compartments (air, water, soil, biota etc.) in relation to the functions that these compartments fulfill. The 'state of the environment' is thus the combination of the physical, chemical and biological characteristics (see MSFD Annex III)

Word / Phrase	Definition
	IMPRESS (2003): "The condition of the water body resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics)."
Stressor	"Stressor refers to abiotic or biotic (e.g. introduction of an alien species) variables that exceeds their range of normal variation, and adversely affect individual physiology or population performance in a statistically significant way. Stressors can be natural and anthropogenic (Vinebrooke, 2004). Instead we use the combination of human activity and pressure.
Sustainable Development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. To be successful, it requires environmental protection, economic growth and social development.

1 Introduction

1.1 Cumulative Effects Assessment

Assessing the cumulative effects of multiple stressors is a top priority problem in marine Ecology (National Academies of Sciences, 2016). Cumulative effects are defined by the U.S. Council on Environmental Quality as “the incremental impact of the action when added to the other past, present and reasonably foreseeable actions” that might interact with a proposed action. This definition of cumulative effects focuses on the incremental effect of a proposed human action when added to those of other human actions. A critical point is that while policy-makers, marine managers and researchers have converged on cumulative effects as a key issue to resolve, the varied aims, contexts and expectations of CEAs leads to outputs that are not necessarily fit for purpose for marine management ambitions (Judd et al., 2015). For example the usage of the term ‘‘cumulative effects (impacts)’’ in practical applications (e.g. Environmental Impact Assessments) is frequently ambiguous, e.g. it is rarely stated whether the cumulative effect assessment is related to:

- multiple occurrences of a single pressure (from single and/or different sources) on a single receptor type (e.g. underwater noise effects on harbour porpoise from a combination of pile driving vessel movements and seismic surveys); or
- multiple occurrences of multiple pressures (from single and/or different sources) on multiple receptors (e.g. underwater noise; contaminants; smothering jointly effects on biogenic reef; herring spawning grounds; marine mammal feeding grounds); or
- multiple occurrences of multiple pressures on single receptors (e.g. underwater noise; contaminants; smothering effects on herring spawning grounds).

Another example involves the difference between stressor-led versus receptor-led CEA (Willsteed et al., 2017). A key criticism of EIA-led CEA is the stressor-led approach, which assesses how single stressors arising from a proposed development together with the same stressor arising from proximal developments or activities impact a valued receptor (Squires & Dubé, 2013; Dubé et al., 2013; Duinker et al., 2012). Recognising that receptors experience multiple stressors and accumulate effects over broad temporal and spatial scales, EIAs thus struggle to assess how receptors respond to cumulative effects (Therivel & Ross, 2007; Duinker et al., 2012). To appraise how additional or novel stressors from one or many activities will impact a receptor requires sufficiently broad horizons that include consideration of the array of stresses that human activities impose on the receptor (Duinker & Greig, 2006; Duinker et al., 2012). Receptors, rather than stressors, therefore, should be the focal point of CEA and guide the identification of the various stressors to include in an assessment of how an activity or activities will impact receptors (Willsteed et al., 2017). In chapter 2 we describe the scope and purpose of the CEA presented in this report and how this relates to some of the issues mentioned above.

Two recent reviews provide a good basis for further development of CEA. The first review identified an effective set of principles for practical implementation of marine CEA (Judd et al., 2015). The second review by (Willsteed et al., 2017) aimed to establish why such a variety of CEA approaches (e.g. in terms of the level of detail, stressor- versus receptor lead, see above) exists today and how this is problematic for the global ambition to implement ecosystem approach management of marine waters. The review includes examination of the key considerations of CEA and why these continue to pose a challenge for marine managers and decision-makers given the current lack of consistency between CEA methods. To name a few:

- The key consideration on “Temporal accumulation” and “Spatial accumulation” is relevant because cumulative effects are known to accumulate over broad temporal and spatial scales (Harriman & Noble, 2008). Time is one of the less examined attributes of cumulative environmental change and is less considered in CEA in large part due to the shortfall of historical data that can be correlated with spatial data (Halpern and Fujita, 2013). Temporal accumulation refers to change brought about by disturbances or perturbations accumulating as the period between perturbations is shorter than the period of ecological recovery (Spaling & Smit, 1993). Spatial accumulation, where the effects of perturbations overlap in space (Spaling & Smit, 1993), can result in cumulative change, as the space between perturbations is less than that required to disperse the disturbance (Cooper, 2004; Spaling & Smit, 1993). Spatial accumulation, as with temporal accumulation, can occur over variable scales, from local to regional to global (Spaling & Smit, 1993).

- The key consideration on “Ecological Connectivity” leads to the potential for indirect effects of stressors to arise, such as food web effects caused by changes in prey abundance (e.g. Perrow et al., 2011).
- The key consideration on “Endogenic and exogenic sources of pressure” relates to the two categories of pressures that according to (Elliott, 2011) contribute to change in the system being studied: endogenic and exogenic. Endogenic pressures are those that are created within the system that can be managed; exogenic pressures, such as climate change, are those that emanate from outside the system or operate at scales beyond the system.

1.2 Environmental Risk Assessment

Environmental risk assessment concepts have often been used to provide a clear structure for CEA (Judd et al., 2015). Ecological (or environmental) risk assessment (ERA) is an approach that provides a flexible, problem-solving solution capable of linking the relationship between human activities and the environment, thereby supporting the decision-making needs of environmental managers (Hope, 2006). In general terms, ERA describes the likelihood and consequences of an event and can be used to evaluate the degree to which human activities interfere with the achievement of management objectives (Samhouri & Levin, 2012). Risk can be assessed using quantitative (e.g. (Francis & Shotton, 1997); Samhouri & Levin, 2012) or qualitative approaches (e.g. (Fletcher, 2005); (Breen et al., 2012); (Fletcher et al., 2010). Ecological risk assessments (e.g. (Astles et al., 2006; Campbell & Gallagher, 2007); (Fletcher, 2005)) have traditionally been based on a likelihood-consequence approach for estimating the risk of a rare or unpredictable event (Williams *et al.*, 2011). However, when an assessment of on-going (current) pressure is needed, then an exposure-effect analysis is more suitable (Smith *et al.*, 2007) (see Figure 1). Examples of this are the use of qualitative descriptors to assess the vulnerability of habitats (Bax and Williams, 2001) or assess the potential for ecosystem-based management (EBM) at sub-regional (Samhouri & Levin, 2012) or regional scales (Knights *et al.*, 2015; Piet et. al., 2015). Risk assessment is therefore playing an increasingly important role in integrating science, policy and management (CENR, 1999).

Risk assessment per se covers a broad array of approaches for a wide set of applications (see reviews by (Holdgate, 1979; Evans, 2004; Fryer, 2006) here we focus on the approaches most suited to ecological risk assessments (e.g. (Astles et al., 2006; Campbell & Gallagher, 2007); (Fletcher, 2005)).

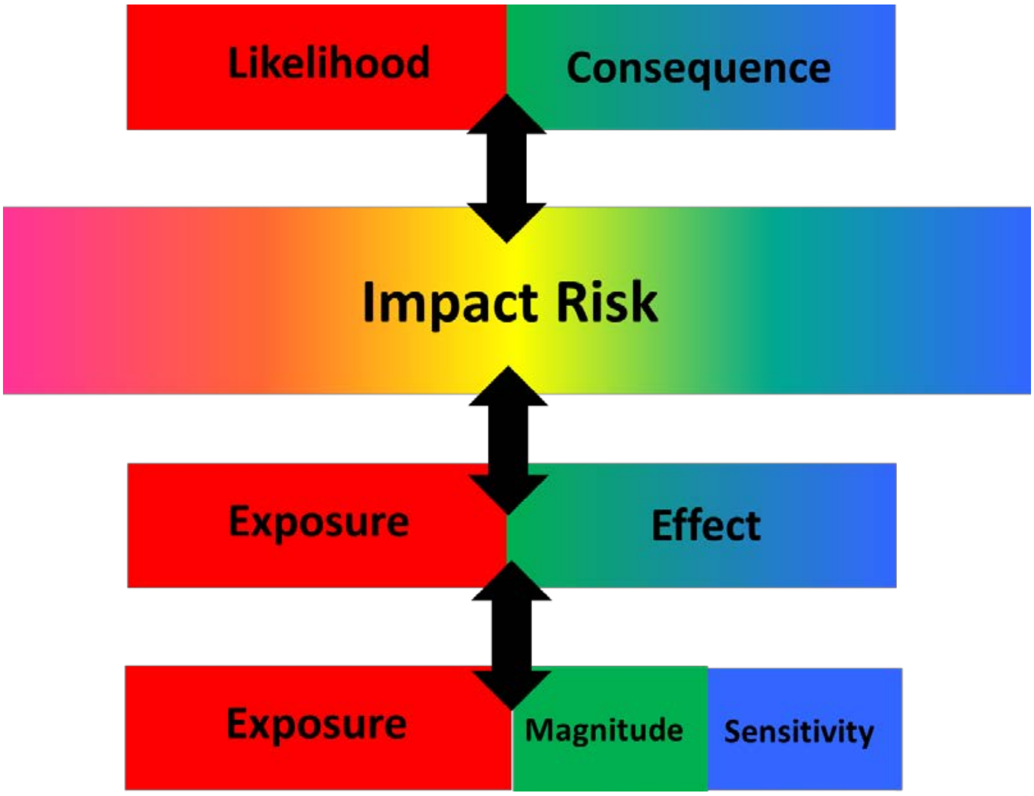


Figure 1 *Impact Risk and how this is relates to the various aspects of risk, i.e. likelihood-consequence approach, exposure-effect approach, and showing how the severity of the effect is based on the magnitude of the pressure and the sensitivity of the ecosystem component.*

Any assessment of risk caused by human activities on an ecosystem will be dependent on (1) a correct description of the functioning ecosystem and how this is impacted by those activities, together with (2) an appropriate methodology to translate the impact into risk. Significant progress has been made toward linking human activities to ecosystem impact with the definition and evaluation of the array of sector-pressure-state combinations or "impact chains", although the resulting network of interactions can be complex (Knights et al., 2013); Tamis et al., 2016; see illustration of impact chains in Figure 2).

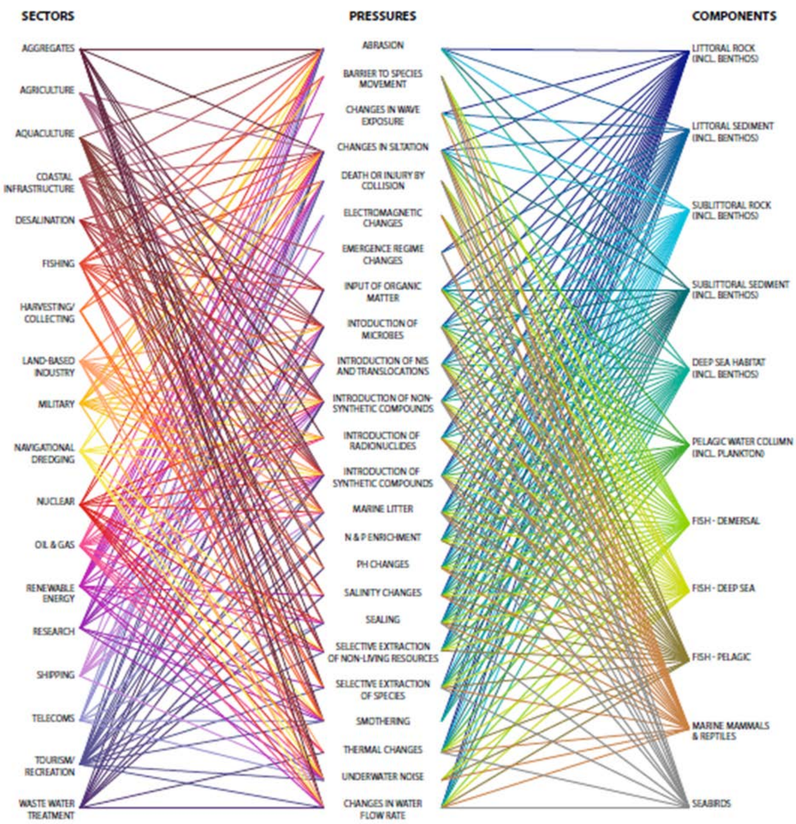


Figure 2 *Comprehensive linkage framework involving all potential impact chains in the North-East Atlantic. Based on Robinson et al. (2014) www.odemm.com.*

Applying a productivity-susceptibility analysis (e.g. (Hobday et al., 2011); Samhouri & Levin, 2012; (Stobutzki et al., 2001) or an exposure-effect evaluation on an interaction network can enable risk to the ecosystem from a single or combination of (anthropogenic) impacts, to be determined (e.g. Bax and Williams, 2001; (Halpern et al., 2007; Knights et al., 2015; Milton, 2001); Stobutzki et al., 2001). If risk represents the cumulative effects of different human activities impacting on multiple ecosystem components through different pressures, then individual impact chains need to be combined into an overall measure of risk, i.e. so-called Impact Risk, such that those risk factors, e.g. sector(s), pressure(s) and ecosystem component(s), introducing the greatest level of risk can be identified (Tamis et al., 2016).
In order to quantify the Impact Risk we have deconstructed the exposure-effect approach where exposure is determined by the spatial extent and temporal overlap of a sector-pressure with an ecological component, while the severity of the effect is determined by the magnitude of the pressure and the sensitivity of the ecosystem component (Tamis et. al., 2016). Most ERA methods derive a measure of sensitivity from model output that is based either on empirical data or expert judgement (Stelzenmuller et al., 2015). Linear relations without thresholds are usually assumed, although these relationships are thought hardly to occur (Halpern & Fujita, 2013). Other relationships (i.e., linear relation with threshold, logistic curve, probability function) could be considered but current information to establish these types of relationships is limited (Halpern & Fujita 2013).

Several statistical methods are available for the aggregation of the (semi-)quantified relationships across impact chains, e.g. summation, multiplication, averaging, or by taking the maximum (Piet et al. in press). Most ERA methods assume additive effects when analysing cumulative pressures (Stelzenmuller et al. 2015) but other possible interactions (e.g., synergistic interactions) between pressures should also be considered. Because of limited knowledge on possible interactions and when and why they occur, the default additive approach remains currently the only feasible option (Halpern & Fujita 2013).

2 Conception

2.1 Background

This assignment follows from a process initiated by the “Dutch science-policy interface for North Sea management issues” (IDON/WKN) to develop an approach for CEA. As part of this process several expert meetings have taken place where several (inter)national initiatives were identified from which methodologies can be adopted and/or to which this CEA initiative needs to be aligned:

- OSPAR ICG-C (Intersessional Correspondence Group on Cumulative Effects (see (Korpinen, 2015))
- Framework Ecology and Cumulation (KEC) Framework for assessing environmental and cumulative effects in relation to offshore wind.
- CUMULEO (see Tamis et al. 2016)
- European Environment Agency (EEA) Topic Centre on Inland, Coastal, Marine (ETC-ICM) where the assessment of cumulative effects and impacts of pressures is put high on the agenda (EEA, 2015) and a methodology for the assessment will be developed for the next reporting for the State of Europe’s Seas in 2022.
- FP7 ODEMM (Options for Delivering Ecosystem-based Marine Management) where an Ecological (or environmental) risk assessment (ERA) was developed (see (Breen et al., 2012; Knights et al., 2013; 2015; Piet et al., 2015; 2017)
- H2020 AQUACROSS (Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU Policies

Based on these sources of information it was decided to adopt the concept of impact chains, i.e. linking human activity-pressure-receptor or more practical sector-pressure-ecosystem component, to link human activities and their pressures to the ecosystem where this pressure may have an effect on one or more of the different components causing an impact.
Because this CEA was expected to be relevant to inform policy the relevance to the OSPAR indicators was chosen as a starting point (see Annex, Table A1.1-1.3). The CEA should be capable to identify the main impact chains in terms of the risk of impact on the ecosystem component or aspect described by that indicator. As such this CEA will not be able to inform on the exact value of this indicator or even whether or not it is in Good Environmental Status (GES) but it should be able to point towards the human activities and their pressures indicating their relative contribution to the failure (if any) to achieve GES because of an impact on the ecosystem component represented by that indicator. The relative importance of impact chains could then be the basis for guidance to more detailed studies on specific (parts of) impact chains and/or potential mitigation measures (e.g. MSFD Program of Measures).

2.2 Purpose of the CEA

The Ecological (or Environmental) Risk Assessments (ERA) or Cumulative Effect Assessments (CEA), considered as the basis for this CEA and introduced in chapter 2.1, show that they (1) either cover only a subset of all the possible impact chains allowing them more sophisticated assessment methods using quantitative information or (2) attempt to be comprehensive restricting them to conduct only, at best, semi-quantitative assessments based on expert judgement. As the CEA presented in this report is supposed to be the next step in the development of CEA we will attempt to develop a methodology that allows a comprehensive integrated CEA (iCEA) which is not only based on expert judgement but, whenever possible, includes the best sources of (preferably quantitative) information available. The aim is to be able to incorporate the level of confidence in that information into the assessment.
In this report we introduce such an iCEA approach based on state-of-the-art scientific findings reflected in the CEA literature review (see chapter 1). Following the recommendation in this literature review that receptors, rather than stressors should be the focal point of CEA our “Proof of Concept” (PoC) consists of the application of this iCEA approach specifically on marine mammals, one of the ecosystem components covered by the OSPAR indicators. As part of this PoC we present

- the relevant information available,
- identify the knowledge gaps and possible solutions to bridge them,
- how these determine uncertainty and a corresponding confidence level and, finally,
- a general discussion on the feasibility of developing an iCEA based on the best possible information available.

The purpose of this iCEA is to apply this in a policy context, specifically for:

- the identification of the main impact chains contributing to the risk that a specific ecosystem component (here marine mammals) is impacted thereby compromising the achievement of policy goals (e.g. GES) and
- an evaluation of the performance of possible management options (as part of the MSFD "Programme of measures") in terms of their contribution to reduce those impacts thereby contributing to the achievement of those policy goals.

2.3 Scope of the iCEA

The scope of this iCEA is partly shaped around the key considerations that emerged from a CEA literature review (see Chapter 1). Thus spatio-temporal scale and regulatory drivers (or threats) for any cumulative effects assessment are critical both in terms of defining the scope of the assessment (to determine which suite of activities, environmental pressures and ecosystem components should be included) and the methodologies which are best suited to making that assessment. CEA methodologies thus need to identify the appropriate spatio-temporal scale to analyse and assess accumulation of effects that may affect an ecosystem, which is determined by the characteristics of the area, the resilience of the resident fauna, the persistence of the pressure and the intensity of activities undertaken in a given area (Smit & Spaling, 1995).

Different from the predictive, EIA-based origins, CEA today also includes retrospective, pressure-based approaches (e.g. Halpern et al., 2007, 2008), predictive, stressor-based approaches (e.g. standard EIAs), and frameworks seeking to integrate both predictive and retrospective approaches (Dubé et al., 2013).

Certainly when developing a receptor-led CEA as is required for this assignment, the focus on receptors that experience the effects of stressors over temporal and spatial scales greater than those typically considered by EIAs clearly requires the application of different methodologies than usually applied in EIAs (Duinker et al., 2012; Therivel & Ross, 2007). Acknowledging that there is no one spatial scale that suits all ecosystem components (while the PoC only considers marine mammals the CEA approach should be able to include the other ecosystem components, e.g. fish or seabirds, as well) we applied a pragmatic criterion and adopted the regional scale most applicable to the policy context this CEA is applied to, i.e. the MSFD (sub)region of the Greater North sea (see Figure 3). For the appropriate temporal scale we considered the persistence of the relevant pressures and the resilience (or recovery potential) of the ecosystem components. This information is presented in chapter 4. For another aspect of spatio-temporal scale, i.e. the resolution, we found no guidance on any minimum resolution and pragmatically decided this should be determined by the information available.

The key consideration on "Ecological Connectivity" lead to an extension of our iCEA so that it now also includes indirect effects (see Chapter 2 and 4.2).

The key consideration on "Endogenic and exogenic sources of pressure" determined our selection of stressors to consider in our CEA (see Chapter 2). For now we decided to focus only on the endogenic pressures as those are created within the system and can be managed (see Chapter 2.2 where one of the applications of the iCEA is to inform the MSFD PoM). In the future it may be worth considering to also include exogenic pressures, such as climate change.

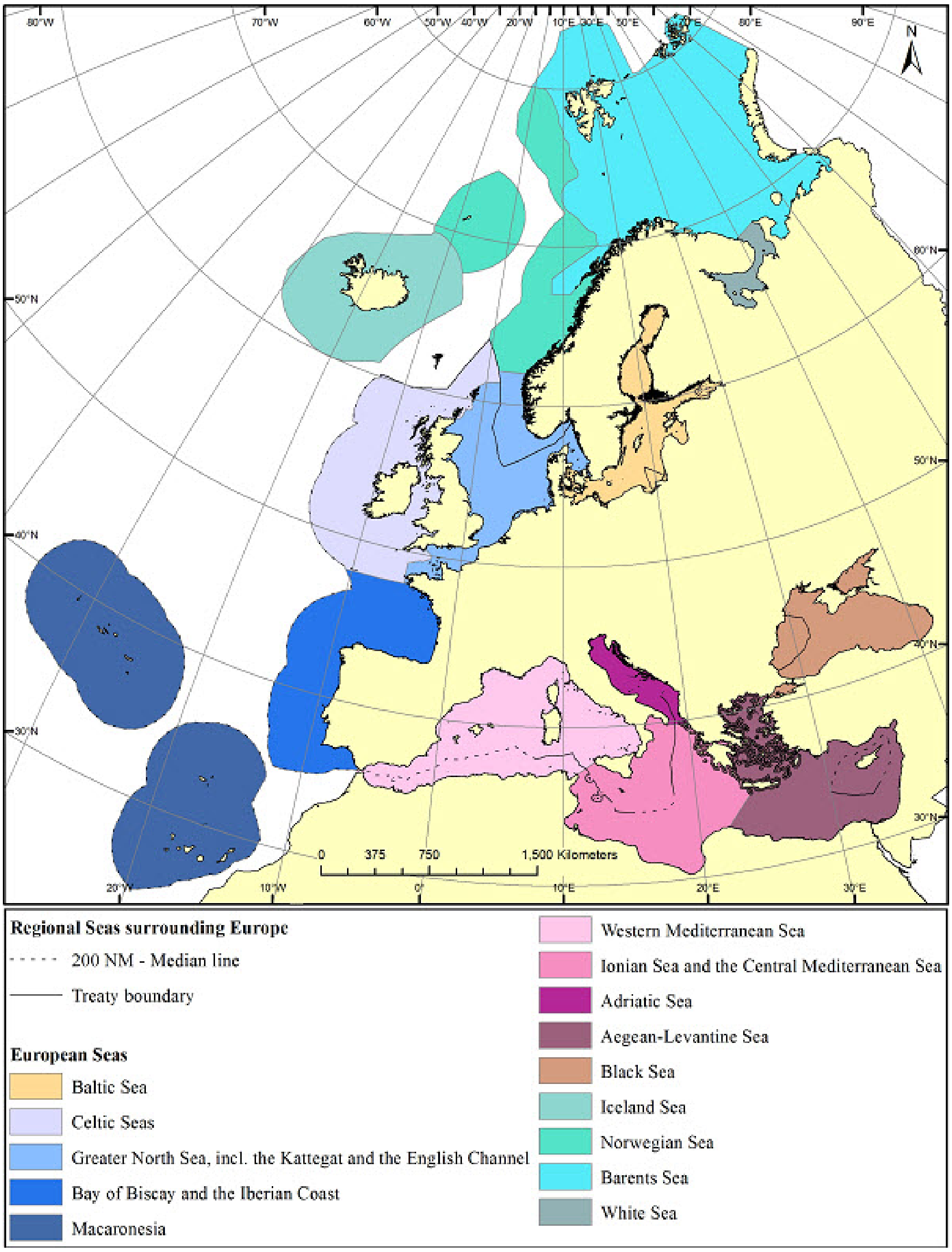


Figure 3 *MSFD regions including the Greater North Sea.*

3 Framework and Approach

3.1 Framework

This iCEA is based on the risk-based framework for defining and undertaking cumulative effects assessments first proposed by (Judd et al., 2015) (see Figure 4) but slightly modified (or further simplified) to suit the purposes of this study. In order to differentiate between the outline of this iCEA framework and that of Judd et al. (2015) we structure the framework using phases instead of the steps in Judd et al. (2015). The 1st step (or 1st phase) is identical in both approaches and we refer to it as the conception phase. We then have an execution phase which is split into a qualitative 2nd phase and a quantitative 3rd phase. The final 4th phase then consists of an evaluation in which the outcomes are compared with the goals, management choices are made and evaluated (which may include an analysis of public and political support and social economic consequences), knowledge gaps are identified, knowledge transfer is set up, and future monitoring and research questions can be formulated (both for filling the knowledge gaps, but also for evaluating the effects of the chosen mitigation measures. Where the iCEA framework and approach also differs from Judd et al. (2015) is that we explicitly consider this an iterative process where the evaluation phase feeds back into any of the previous phases.

Table 1 *iCEA framework based on Judd et al. (2015) but slightly modified so that it has now become an iterative process where the outcome of the 4th phase should feed back into the process at any of the previous phases. The corresponding chapters in the report are indicated.*

iCEA phase		General	Specifics	Report chapter
1	Conception	Purpose and Scope	• How will the iCEA be applied • Identify spatial and temporal scale	2
2	Execution (presence)	Identification of potential effect of human activities and their pressures on the ecosystem	Develop linkage framework based on an appropriate typology of • Human activities, • Pressures and • Ecosystem components and the possible linkages between them	3
3	Execution (importance)	Estimation of the “Impact Risk” per impact chain. This may be based on expert judgement or quantitative information	• Is available information appropriate for the agreed spatial and temporal scale • Likelihood of exposure • Magnitude of the pressure(s) • Sensitivity of the ecosystem component(s) • Occurrence and/or relevance of additive/synergistic/antagonistic processes • Assessment quality of the data • Assumptions, uncertainty and thus level of confidence	4
4	Evaluation	Consider result in the broader context and to inform the next iteration cycle	• Significance of results • Main stressors/threats/ causal factors • Possible Mitigation measures • Application of results in the institutional context • Knowledge gaps	5

For the qualitative part. i.e. the identification of potential impact chains, we combined, for pragmatic reasons, the Judd et al. (2015) steps 2 and 3 leading to a so-called linkage framework (Knights et al. 2015). These impact chains are the basis for the next (3rd) phase in which we assemble the knowledge base for this study where we collate the information available based on the requirements of our integrated Cumulative Effects Assessment (iCEA) with the purpose and scope specified in the 1st phase. If the information allows this 3rd phase should be able to show the relative importance, based on Impact Risk, of each of the impact chains identified in phase 2. In this "Proof of Concept" (PoC) the iCEA will be applied with a focus on only one ecosystem component, i.e. Marine Mammals and as such the iCEA only includes all the impact chains involving marine mammals. Finally in the 4th phase we assess the available information and interpret its quality and usefulness as part of this iCEA. In addition we look forward and discuss how such an iCEA could then be used to identify the main pressures (or actually human activities and their pressures) and how this can inform the planning of the "Program of Measures" (PoM) as required in the MSFD. This iCEA framework and its phases its explicitly intended to be an iterative process where the outcomes of the final 4th phase should feed back into the process at any of the previous phases but, certainly after 1-2 iterations, most likely the 3rd phase. As such the evaluation presented in chapter 5

Thus while the 1st (scoping) phase is addressed in chapter 2 identifying the scope and purpose of this exercise, the presentation of results in chapter 3 consists of both the 2nd (qualitative) phase providing the comprehensive linkage framework consisting of all the impact chains (linkages Human activity-Pressure-Ecosystem component) as well as the 3rd phase in which all the relevant (semi-)quantitative information is collated, arranged in a structure and processed allowing an informed discussion of the potential to develop a full iCEA. Finally, in the 4th phase we discuss the outcome of this iCEA in relation to its purpose and scope as well as the larger context in which it is supposed to be applied in order to guide the next iteration of the iCEA development.

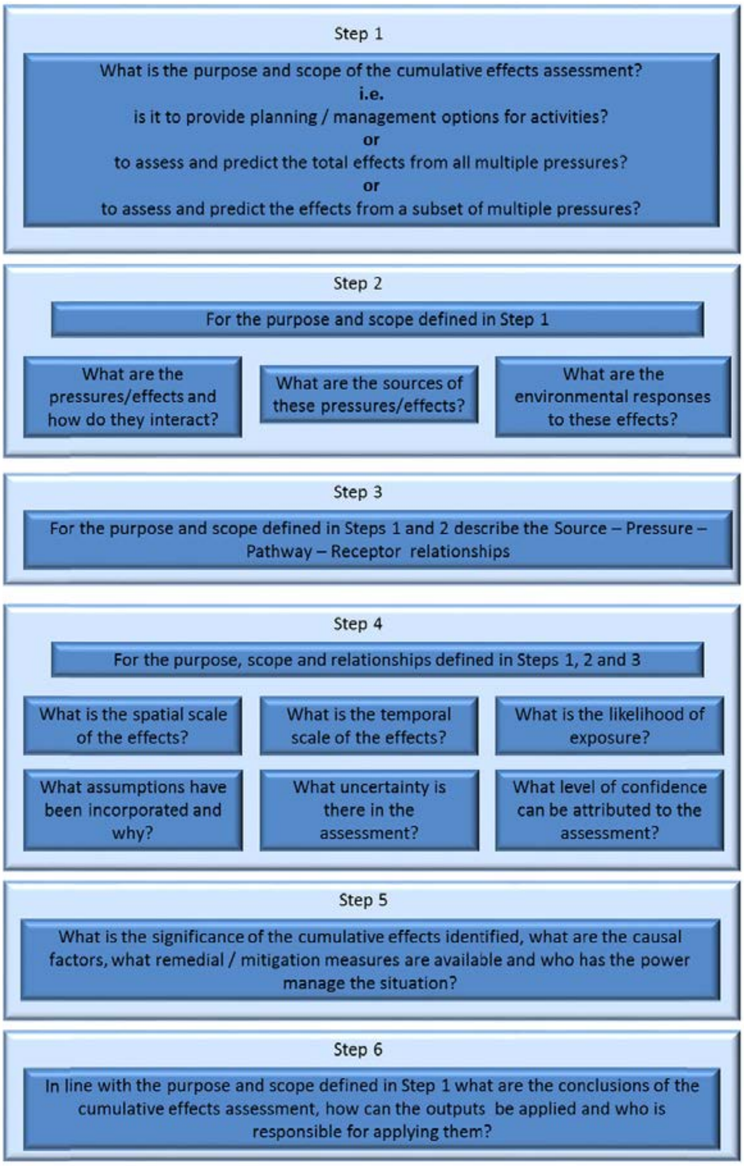


Figure 4 *A simple risk-based framework for defining and undertaking cumulative effects assessments. From (Judd et al., 2015).*

3.2 Approach

Our iCEA approach is deliberately a modular approach where the modules each provide part of the information required for the assessment. This modular approach allows great flexibility in introducing new sources of information (e.g. data, maps, models but also methods to apply expert judgement) if they are considered to be better thereby increasing the confidence in the outcome of the assessment. The modular iCEA framework is based on a comprehensive suite of impact chains where each impact chain requires information on relevant aspects of Impact Risk, the concept we use to cumulate the effects (or rather impacts).

3.2.1 Aspects of Impact Risk

Here we describe our approach in accessing and making relevant information available for the iCEA. As this iCEA is based around the principles of environmental risk assessment we apply the deconstructed exposure-effect where the exposure is determined by the spatio-temporal overlap between the anthropogenic pressure and the ecosystem component and the severity of the effect is determined by the magnitude of the pressure and the sensitivity of the ecosystem component.
For each impact chain identified in the linkage framework we will therefore present the information available to determine:

- Exposure represented by the spatio-temporal overlap
- Magnitude (or intensity) of the pressure for which an appropriate pressure-specific metric will be identified
- Sensitivity of the ecosystem component expressed in terms of the relationship between the chosen pressure metric and an effect on the ecosystem component.

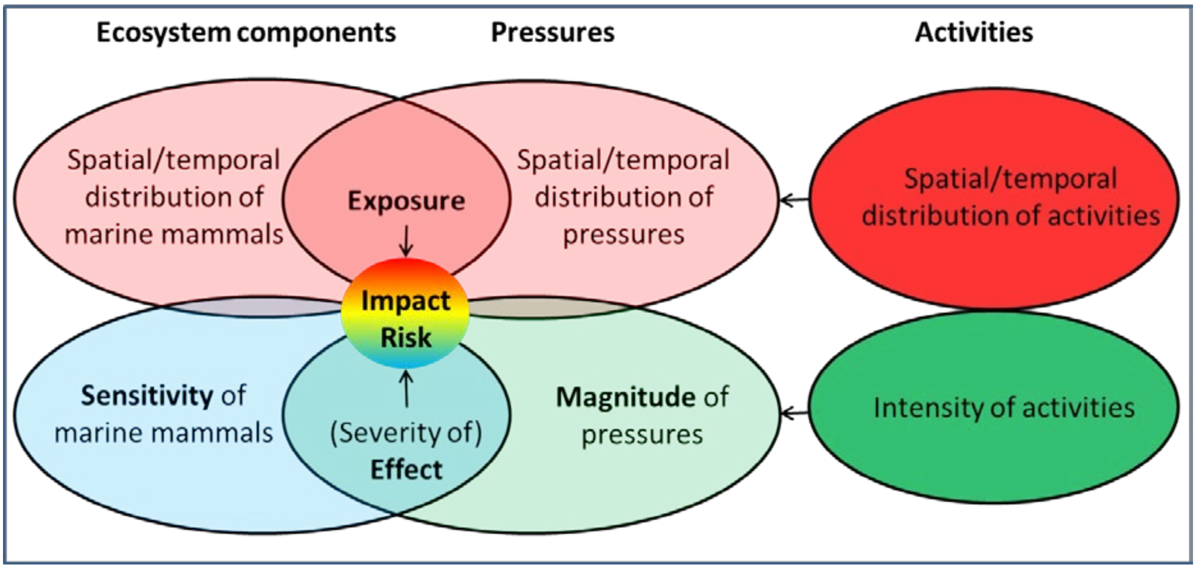


Figure 5 *Impact Risk and how this is based on the aspects of risk, i.e. exposure and effect, which in turn are based on the magnitude of the pressure and the sensitivity of the ecosystem component.*

3.2.2 Marine Mammals Linkages Framework

As the basis for our Marine Mammals Linkages Framework (MMLF) we used the EU FP7 ODEMM risk assessment framework and database selecting marine mammals in the North-East Atlantic region but expanded with visual disturbance as an additional pressure. Also during the workshops that lead to this request for an iCEA it was identified that indirect effects may also play an important role and these are (deliberately) not part of the ODEMM linkage framework. While we acknowledge that including indirect effects (mostly through the foodweb) in this iCEA may cause difficulties in the application of the risk-based approach we will explore the possibility.

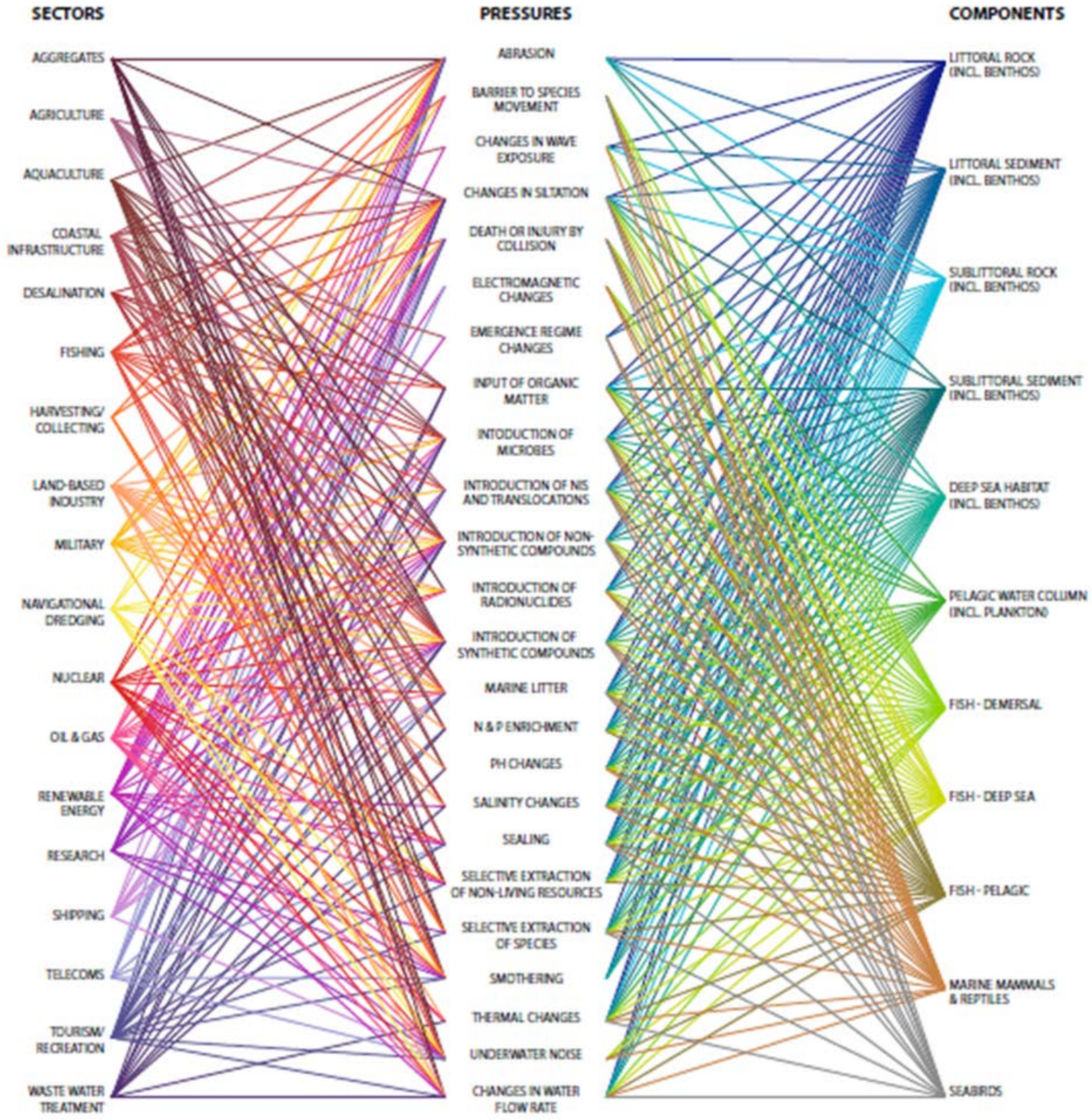


Figure 6 *Marine Mammals Linkages Framework (MMLF) showing all the possible pathways through which human activities may affect two species of marine mammals. Based on ODEMM but expanded based on input from the IDON/WKN process.*

For each of the pressures identified (see Figure 6) we aim to identify the most appropriate metrics to represent this (aspect of) each pressure and present spatial maps of their occurrence including, if relevant, any temporal, i.e. seasonal, considerations. In addition we describe for each pressure how their magnitude can be expressed.

4 Information availability

This chapter describes the different steps/phases in the ICEA. As explained earlier, this is a first 'testing' of the ICEA approach to a specific group of receptors, marine mammals, and not a comprehensive description and analysis of the whole ICEA for this group of receptors.

The emphasis in this study was on the second and third step/phase: a quantitative analysis of the stocktaking of data on pressures, cause-effect relations, and effects, and a first description of the prioritisation based on a limited set of criteria, thus coming to an essential causal network, the "prioritisation phase" (see chapter 3.2). Here we present all the relevant material needed to perform an ICEA focussing on the marine mammals. At the basis we have a comprehensive qualitative linkage framework consisting of all the possible impact chains (human activity-pressure-ecosystem component) through which anthropogenic pressures may affect marine mammals in the Greater North Sea. This includes both direct and indirect effects.

As this chapter covers both the qualitative and the quantitative part of the "Execution phase" (see chapter 3.1), we introduce the distinction between "effects" and "impacts" of stressors. To determine whether a stressor effect is of sufficient magnitude to have a meaningful impact on a receptor, typically requires quantitative information (Boehlert & Gill, 2010). Hence we consider all the qualitative linkages in the marine mammal linkage framework (MMLF) to represent a potential effect whereas only if (semi-)quantitative information exists allowing the assessment of e.g. a significant decline in population we consider this an impact. This is a stricter definition than applied in many studies using the term impact based on findings that would only suggest an effect.

4.1 Evaluation criteria

Below the categories of data availability. Note that these are intended to provide an indication of the data currently available for use at Wageningen Marine Research and Deltares. This is not based on an in depth analyses of all underlying (meta-)data. Therefore the categories do not reflect the actual quality or confidence of the data but only give a broad impression of the availability and type of data. Improvements are discussed in the evaluation (Chapter 5).

Table 2 *General data categories and scores*

Category	Data type and availability		Score
A	Quantitative full	Data is available (although quality/confidence could be improved)	0.8-1
B	Quantitative partial	Data is available but limited (quality/confidence could be improved) and supplemented with expert judgement	0.4-0.7
C	Expert judgement		0.1-0.3
D	No information		0

Table 3 *Criteria exposure assessment - pressure*

	Extent of Human activity	Exposure assessment based on	Spatial scale (extent)	Spatial scale (resolution)	Temporal scale (time period)	Temporal scale (resolution)	Pressure distribution
A	Digital maps (GIS or otherwise)	Measured pressure, linked to activity	Extent covers the entire area.	Resolution is appropriate considering the nature of the pressure	Information on the spatial distribution of the pressure covers a sufficiently long time period (≈ persistence)	Resolution distinguishes all relevant temporal (seasonal) variation.	Process that determines the spatial expansion of the pressure(s) from the activity is known and (could be) quantified.
B	Printed maps and/or estimate of extent of the area covered is known but unclear where this is located	Measured pressure, not specifically linked to activity (although contributors are known) or Pressure derived from activity, based on known, estimated or assumed relationships	Only a (representative or small) part of the area (x%) is covered	Resolution is low (compared to the resolution of relevant pressures)	Only a single timeslot is known. More recent is better.	Resolution does not distinguish (all) relevant temporal (seasonal) variation.	Partial or no information is known on the spatial expansion of the pressure(s) and/or the information on human activity is used as a proxy
C	Expert judgment (broad or little agreement) or personal communication						
D	No information available						

Table 4 *Criteria exposure assessment – ecosystem component*

	Extent of relevant aspect(s)	Spatial scale (extent)	Spatial scale (resolution)	Temporal scale (period)	Temporal scale (seasons)
A	Digital maps (GIS or otherwise) of all relevant species, or subsets or aspects of the community. Better if the most sensitive are covered	Extent covers the entire area	Resolution is appropriate (≈ highest resolution of the relevant pressures)	Information on the spatial distribution of the species(group) covers a sufficiently long time period (≈ recovery time)	Resolution distinguishes all relevant temporal (seasonal) variation
B	Printed maps and/or estimate of extent of the area covered is known but unclear where this is located	Only a (representative or small) part of the area (x%) is covered	Resolution is low (compared to the resolution of relevant pressures)	Only a single timeslot is known. More recent is better	Resolution does not distinguish (all) relevant temporal (seasonal) variation
C	Expert judgment (broad or little agreement) or personal communication				
D	No information available				

Table 5 *Criteria magnitude*

	Metric suitability	Link to exposure	Link to sensitivity
A	Best represents the nature of the pressure	Is identical to the unit of the exposure metric	This metric is identical to that used to describe sensitivity
B	Is at best a (poor) proxy	The relationship between the extent of exposure and magnitude is known and (could be) quantified	The relationship between sensitivity and the magnitude metric is known and (could be) quantified
		Unclear how magnitude relates to the exposure	Unclear how the magnitude metric relates to sensitivity
C	No known metric	No known metric	No known metric
D	No information available	No information available	No information available

Table 6 *Criteria sensitivity*

	Pressure-State Relationship
A	A quantitative Pressure-State relationship exists: i.e. between magnitude and (depending on the ecosystem component) a population-level or community-level impact
B	The P-S relationship is semi-quantitative: e.g. partially based on expert judgement
C	Only a qualitative P-S relationship exists: i.e. entirely based on expert judgement
D	The P-S relationship is unclear and expert judgement is not available

4.2 iCEA context

4.2.1 Species to include

Marine mammals relevant for our PoC are the species that are common in/ to the Dutch part of the North Sea. The six most abundant marine mammal species on the NCP are harbour seal *Phoca vitulina*, grey seal *Halichoerus grypus*, harbour porpoise *Phocoena phocoena*, minke whale *Balaenoptera acutorostrata*, white-beaked dolphin *Lagenorhynchus albirostris* and bottlenose dolphin *Tursipos truncates* (Geelhoed & Van Polanen Petel, 2011). For the sake of this PoC, time and resources considering, we chose to take only the harbour porpoise and the harbour seal into account. These two species have been subject to regular ecological studies, and impact analysis within EIAs for offshore wind farms, habitat changes, and behavioural effects due to various pressures such as fishing, noise, visual disturbance, habitat changes, etc.

4.2.2 Appropriate temporal scale

In order to determine what should be the appropriate temporal scale we considered both the persistence of the relevant pressures as well as the resilience of the relevant ecosystem component(s) (See Table 7 and Table 8).

Table 7 *Persistence defined as the time period over which the pressure continues to cause impact following cessation of the activity introducing that pressure. Based on FP7 ODEMM and published in Knights et al. (2015).*

Persistence categories and description		Pressures
Continuous	The pressure continues to impact the ecosystem for more than 100 years	• Barrier to species movement • Change in Wave Exposure • Changes in Siltation • Electromagnetic changes • Emergence regime change • Introduction of NIS • Introduction of Radionuclides • Salinity Changes • Sealing • Water flow rate changes
High	The pressure continues to impact the ecosystem for between 10 and 100 years.	• Introduction of Non-synthetics • Introduction of Synthetics • Marine Litter • N and P enrichment
Moderate	The pressure continues to impact the ecosystem for between 2 and 10 years	
Low	The pressure continues to impact the ecosystem for between 0 and 2 years	• Abrasion • Death or injury by collision • Input of organic matter • Introduction of microbial pathogens • pH changes • Selective Extraction of Non-living material • Selective extraction of species • Smothering • Thermal Changes • Underwater noise

Table 8 *Resilience defined as the recovery time of the ecological characteristic to return to pre-impact conditions. Recovery times for species assessments were based on turnover times (e.g. generation times). For predominant habitat assessments, recovery time was the time taken for a habitat to recover its characteristic species or features given prevailing conditions. Based on FP7 ODEMM and published in Knights et al. (2015).*

Resilience categories and description		Ecosystem components
None	The population/stock has no ability to recover and is expected to go "locally" extinct. The recovery in years is therefore very high to reflect that unlikely recovery	
Low	The population will take between 10 and 100 years to recover.	• Birds • Fish-Demersal • Fish-Pelagic • Marine Mammals & Reptiles
Moderate	The population will take between 2 and 10 years to recover.	• Littoral rock habitat • Sublittoral Rock habitat • Sublittoral Sediment habitat
High	The population will take between 0 and 2 years to recover.	• Littoral Sediment habitat • Water Column habitat

As the persistence of the relevant pressures, e.g. Introduction of Non-synthetics, Introduction of Synthetics and Marine Litter, are 10-100 years while the resilience of marine mammals is also 10-100 years it is clear that the appropriate time scale should be 100 years. As this is much longer than any available historic time-series of a pressure or existing management cycles, the longest reliable time-series is the best available information and explicitly consider the long term for the evaluation of any management options.

4.3 Information to estimate Impact Risk

4.3.1 Marine mammals: description and distribution

Here we collate all the available information relating to the ecosystem component, marine mammals, for which this ICEA is developed. First we describe the different populations that we selected and that together are considered to sufficiently represent marine mammals. Then we present the available information on the spatial distribution of each of these populations together with any possible temporal (seasonal) considerations that are relevant when assessing their exposure to the various anthropogenic pressures.

4.3.1.1 Spatial distributions and migration patterns

The distribution of marine mammals is mainly determined by food availability and haul-out sites and may also be directed by anthropogenic factors. Furthermore it is expected that the North Sea becomes warmer which will presumably have consequences for food availability and the distribution of marine mammals (Geelhoed & Van Polanen Petel, 2011).

Recent data on the spatial distributions of harbour porpoise and harbour seal come from surveys for impact assessment of offshore wind farms, both national and international in the southern North Sea. SCANS for porpoises etc. (Aarts et al., 2013; Geelhoed et al., 2013; Geelhoed & Van Polanen Petel 2011; Gilles et al. 2016; Hammond et al., 2002; 2013; Jones et al., 2013; Kirkwood et al. 2014, 2016). These data and the resulting distribution maps are described for each of the species separately in the subsections below.

Harbour porpoise

<u>Spatial and temporal distribution</u>

Harbour porpoises are distributed throughout the shelf waters of the Greater North Sea and other OSPAR Regions. Their presence has been found to be strongly related to areas of low tidal current and with water depth between 50 and 150 m and strong seabed slope although these relationships vary with the area/habitat (ICES, 2016a).

The abundance of harbour porpoises on the Dutch Continental Shelf (DCS) was monitored in aerial surveys in July 2010-March 2011 by Geelhoed et al. (2013). Porpoise densities are represented spatially on a 1/9 ICES grid. This grid has latitudinal rows at intervals of 10' and longitudinal columns at intervals of 20'. Within the DCS, this corresponds to approximately 20x20 km grid cells. The density differed among the three seasons (spring, summer, fall) that were surveyed.

Gilles et al. (2016) combined the large-scale international SCANS II survey with the more frequent, small-scale national surveys to produce seasonal distribution maps for the harbour porpoise in the North Sea. Gilles et al. (2016) aggregated a set of survey data of the harbour porpoise, collected in the UK (SCANS II, Dogger Bank), Belgium, the Netherlands, Germany, and Denmark, to develop seasonal habitat-based density models for the central and southern North Sea. Visual survey data were collected over 9 years (2005-2013). The harbour porpoise density differs between seasons (see the paragraph migration below). The map for the spring is shown in Figure 7. Predictions were made on a spatial grid at a resolution of 5 × 5 km. These fine-scale maps of harbour porpoise distribution are relevant for marine spatial planning and suitable to assess risks of human activities at sea. The study by Gilles et al. (2016) currently presents the most comprehensive, seasonal habitat-based estimates of porpoise density in the North Sea, and it is intended to support the management of anthropogenic impacts. Gilles et al. (2016) recommend a SCANS-type survey with larger spatial coverage to be undertaken on a more regular basis (e.g., every 6-8 year). Additionally, knowledge of species-habitat relationships should be improved to aid the assessment of stock status and trends.

The map of the harbour porpoise in Gilles et al. (2016) has a much higher resolution than the map of the harbour porpoise of Aquamaps (Figure 8). The AquaMaps grid cel has a 0.5° cSquares resolution. This responds to half ICES-squares approx. 30 km. The density of the animals is expressed in overall probability ranging from 0.01 to 1.00. So it is possible to show more probability classes than the 5 shown in Figure 8. The AquaMaps map for harbour porpoise is therefore not used for the current project.

Comparisons to the earlier SCANS-1 survey in 1994 (Hammond et al., 2002) indicate that harbour porpoise have shifted their focal distribution from the northern part of the North Sea to the southern part. This redistribution is probably related to the availability of the prey resource.

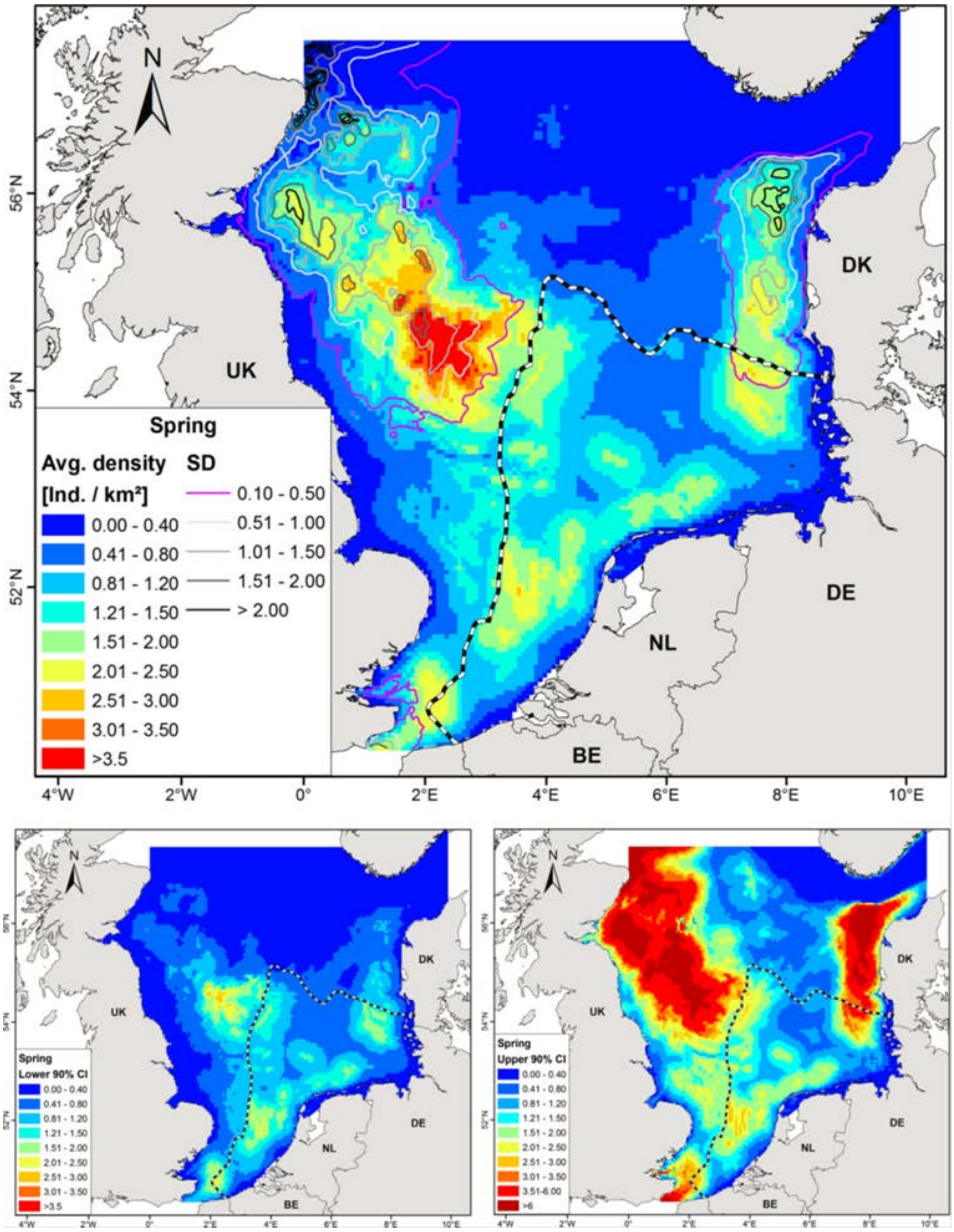


Figure 7 *Predicted harbour porpoise densities in the North Sea in spring (March–May). Upper panel: The overlaid contours are associated jackknife standard deviations (SD), whereas the black and white dashed boundary depicts the sampling coverage in spring. Lower panel: Lower and upper lognormal 90% confidence intervals. (Source: Gilles et al. 2016).*

<u>Migration</u>

Harbour porpoises within European waters show distinct variation in their distribution on seasonal, interannual, and decadal time scales. Gilles et al. 2016 showed distribution maps for 3 seasons (spring, summer, autumn). In spring hotspots of harbour porpoises were found in the southern and south-eastern part. In summer, hotspots shifted toward offshore and western areas. In fall the distribution was spatially heterogeneous and areas with higher densities were predicted north- west of the Dogger Bank and off the German and Danish west coasts (Gilles et al., 2016).

Harbour seal

Spatial and temporal distribution

A distribution map of the predicted distribution of harbour seals based on habitat preferences was produced by Geelhoed & Van Polanen Petel (2011) (see Figure 9). This map has a much higher resolution than the maps of Aquamaps (Figure 8). The resolution of map for the distribution of harbour seal, as well as harbour porpoise, in AquaMaps is 0.5° c Squares (Figure 8). This responds to half ICES-squares approx. 30x30 km. The distribution of the animals is expressed in overall probability of occurrence ranging from 0.01 to 1.00 calculated from an environmental envelope described by parameters: depth, temperature, salinity, primary production, ice concentration and distance to land. The environmental envelope is based on georeferenced occurrence records harvested from GBIF (Global Biodiversity Information Facility) and OBIS (Ocean Biogeographica Information System) as well as from museum collections and the literature available in FishBase and SeaLifeBase (Kesner-Reyes et al., 2012).

Figure 8 *Spatial distribution maps for harbour porpoise (left) and harbour seal (right) in the Greater North Sea. Source: AquaMaps.org. Grid size is approx. 30x30 km.*

High resolution distribution maps for harbour seals in the EEZ of countries surrounding the North Sea have to be collected because a high resolution map for the whole North Sea, like the one for harbour porpoise developed by Gilles et al. (2016), is not available. For the Dutch EEZ such a map for harbour seal derived from habitat preference is available (see Figure 9). An update of this map widening the area from the Dutch EEZ to the adjoining parts of the German EEZ will be published soon by Aarts et al. (Wageningen Marine Research).
A distribution map for the estimated total usage (at-sea and hauled-out densities from telemetry data and aerial surveys) by harbour seals around the UK is also available (from Jones et al., 2013). The map is shown in Figure 10.

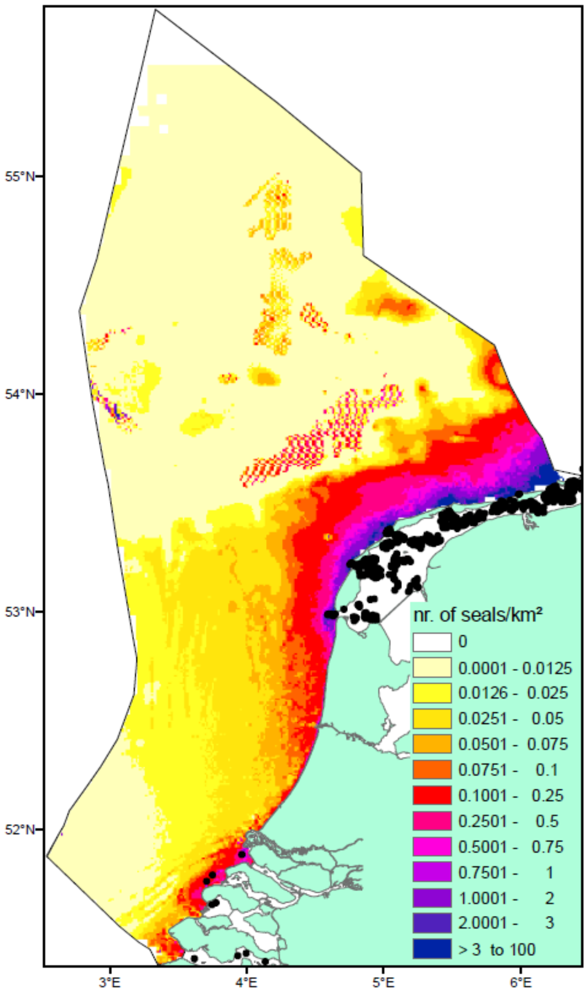


Figure 9 *Predicted distribution of harbour seals based on the habitat preference model of Brasseur et al. (2010) and the number of seals determined in aerial surveys (black spot = haul-out area) (source: Geelhoed & van Polanen Petel, 2011). Grid size is 1x1 km.*

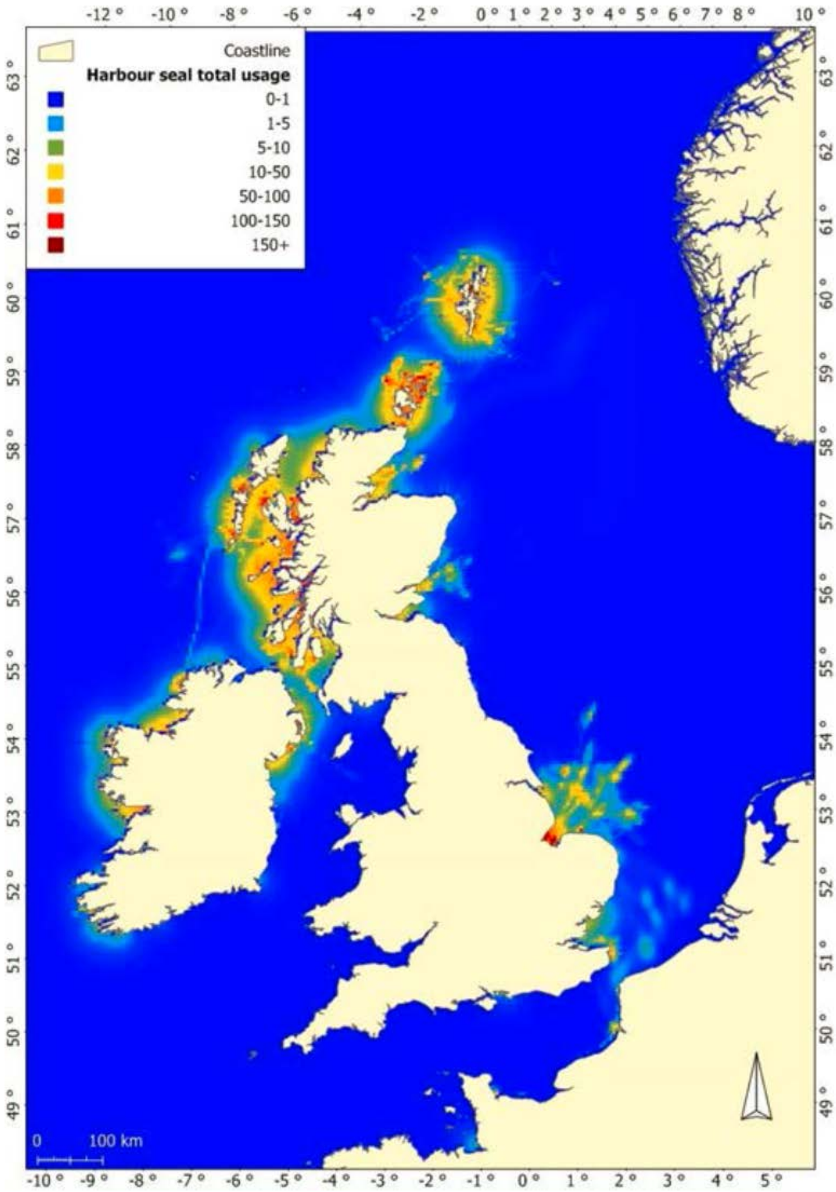


Figure 10 *Estimated total usage (at-sea and hauled-out densities from telemetry data and aerial surveys) by harbour seals around the UK (from Jones et al., 2013).*

<u>Migration</u>
Aarts et al. (2013) demonstrated movement of seals between the Wadden Sea and the Delta region, and suggest this movement is both to forage and to traverse (or relocate) between the two areas. Aarts et al. (2013) suggest human activities, such as construction of a wind farm, may impede use of the coastal zone by the seals. This based on data obtained with GSM-GPS tracking devices attached to harbour seals. There are seasonal patterns in the density of seals in the coastal zone, which vary depending on the seals' changing needs through their annual cycle. Harbour seal numbers peak in winter and are relatively low throughout the rest of the year (Aarts et al. 2013). Tracking data suggest that during spring harbour seals mostly remained within 30 km of the coast and within 50 km of haul-outs (Kirkwood et al., 2016). This observation is in line with the one by ICES (2015a) that harbour seals' foraging areas are reported to be located close to the haul-out sites, often within a distance of 5–30 km.

Data evaluation

Table 9 shows the overall evaluation scoring for the ecocomponents harbour porpoise and harbour seal. Scoring for the two ecocomponents is highly comparable. The data on the extent of exposure is good because digital maps of the distribution of both species are available. However the entire Greater North Sea is not completely covered and therefore the spatial scale (extent) scores medium. The spatial and the temporal resolution score good. The same is true for the temporal scale because the information on the spatial distribution covers a sufficiently long monitoring period.

Table 9 *Exposure evaluation – ecosystem components. Categories and criteria are described in Table 4*

Species	Harbour porpoise	Harbour seal
Extent of relevant aspect(s)	A	A
Spatial scale (extent)	B	B
Spatial scale (resolution)	A	A
Temporal scale (period)	A	A
Temporal scale (seasons)	A	A
Availability Overall	Quantitative partial	Quantitative partial
Confidence Score (range)	0.5-0.9	0.5-0.9
Confidence Score (average)	0.8	0.8
Scope of improvement (focus)	Data sources are known for other countries. Spatial scale (extent) could be improved by obtaining those data	Data sources are known for other countries. Spatial scale (extent) could be improved by obtaining those data

4.3.2 Human activities

Here we describe the available information on the human activities that have been selected for this study (see the MMLF,Figure 6).

Shipping
The North Sea is a busy area for shipping due to the important ports of Rotterdam and Antwerp. An overview of the activities currently taking place in the Dutch part of the North Sea is spatially represented in the Nationaal Waterplan 2016-2021 (Min. IenM & Min. EZ, 2015). This includes information on current shipping routes.

Spatio-temporal coverage
The data in Noordzeeloket are static and it is not clear on what data the map is based (Figure 11). In addition to this static image, there is also an interactive map with all actual current ship movements on https://www.marinetraffic.com/nl/ais/home/centerx:25/centery:37/zoom:9. The latter is not downloadable however. OSPAR has data related to shipping, but that has to do with the dumping and placement of waste and other matter at sea and not directly with shipping routes or the amount of traffic. Additional data are available on the intensity of shipping, which is highly relevant for pressures such as noise, and collision risk. Based on such data, a figure has been created on the shipping lanes and the intensity of their use (Jongbloed et al., 2014). This figure (Figure 12 below) includes maritime shipping lane traffic, but not the traffic from non-shipping lane bound traffic, such as smaller cargo ships, and fishing vessels.

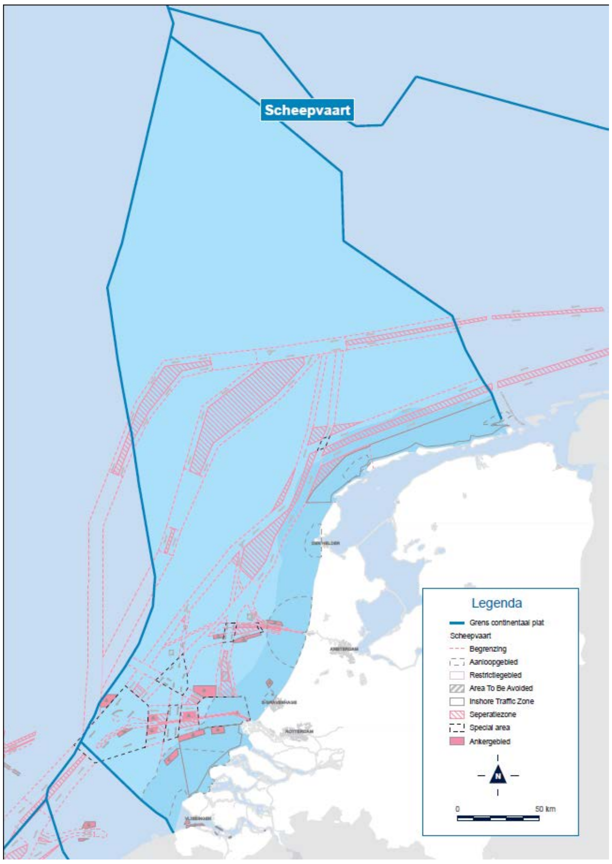


Figure 11 *Current use of space of the Dutch Continental Shelf (DCS). Source: Noordzeeloket.nl.*

Recent data, but still mostly limited to the DCS (Dutch EEZ) can be found at the closely related websites ‘Publieke Dienstverlening Op Kaart’ (www.pdok.nl) and the ‘Nationaal Georegister’ (www.nationaalgeoregister.nl). Additionally, data from the Automatic Identification System (AIS) that is compulsory on most larger vessels, can be obtained from national registry offices. Based on such detailed data, a relatively detailed overview of shipping activities in time and space can be obtained.

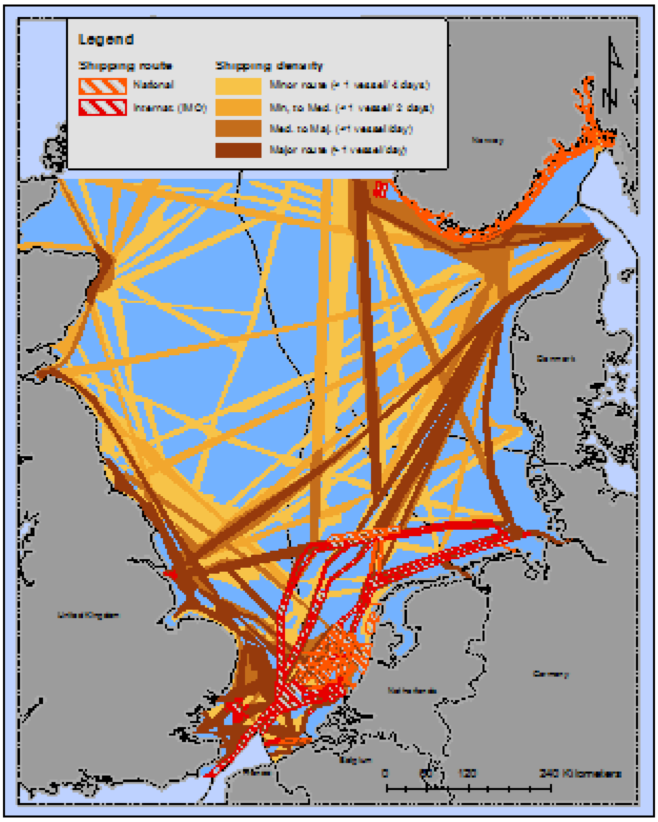


Figure 12 *Map of Shipping routes and Density in the North Sea (Source: Jongbloed et al., 2014).*

Link with pressures
Shipping is known to cause accidental or illegal pollution with oil or Hazardous and Noxious Substances (HNS), the introduction of alien invasive species via ballast water, air pollution, leaching of toxicants from anti-fouling paints, pollution from marine litter (OSPAR website, http://www.ospar.org/work-areas/eiha/shipping). Shipping is also a source for continuous underwater noise and visual disturbance. Other pressures linked to shipping in the context of this project is the death or injury by collision.
The spatial extent of shipping in the North East Atlantic was assessed to be widespread and the frequency as common by Knights et al. (2015).

Data availability and level of confidence
There must be more data available which we were not able to find in this quick-scan project, however, based on the data we have found, the availability of spatially explicit data that can be used in GIS is reasonable; the resolution is limited, but an additional check on data sources is needed to get a better view on data resolution and quality. There is a visual map of the most important areas, however, which can provide opportunities for overlay with the maps of marine mammals. The current level of confidence in the data for shipping is low since it is unclear which data were used, which metadata were used, what the temporal coverage of the data is, etc. A further data check will very likely improve the confidence level. On the longer term, using the AIS data system for quantifying shipping distribution and intensity would be a relevant way forward.

Oil & Gas exploitation
Spatio-temporal coverage
At the Noordzeeloket there is a map with the spatial coverage of the oil and gas exploitation in the North Sea (see Figure 13). In this map, a distinction is made between out of use, currently in use, future and abandoned oil and gas platforms. Furthermore, data is available on the NLOG site, which is supported by TNO and the Geological services Netherland (http://www.nlog.nl/). There is a data portal available here, but not all data are freely available. No spatial data on oil and gas were found at the OSPAR data portal. Other member states have comparable data on oil and gas, which can be found on the internet (UK: https://www.og.decc.gov.uk/information/maps_offshore.htm; Germany: http://www.lbeg.niedersachsen.de/erdoel-erdgas-jahresbericht/jahresbericht-erdoel-und-erdgas-in-der-bundesrepublik-deutschland-936.html) . Based on international data, a map has been constructed in Jongbloed et al. (2014), see Figure 14.
The spatial extent of oil and gas industry in the North East Atlantic is assessed to be local. The oil and gas platforms are present during many years (Knights et al., 2015).

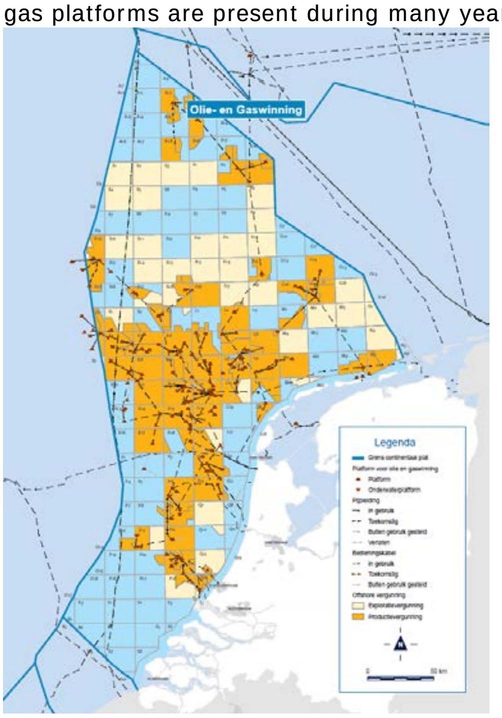


Figure 13 *Spatial representation of oil and gas exploitation of the Dutch Continental Shelf. Source: Noordzeeloket.nl*

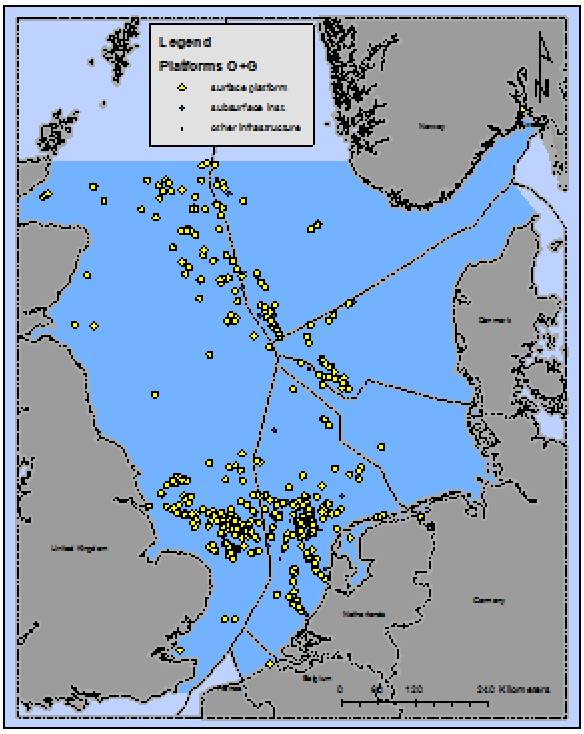


Figure 14 *Map with Oil and Gas Platforms in the North Sea (Source: Jongbloed et al., 2014).*

Link with pressures
Oil and gas exploration is associated with a range of pressures, including underwater noise (during construction and demolition of platforms), spread of contaminants (water-based mud drillings, spills) and decreases in air quality (OSPAR, 2016). In a stocktacking report, OSPAR identified impacts on the benthic environment, high concentrations of toxicants and effects on fish and other organisms (OSPAR, 2016). Out of these, the first two pressures are most relevant for the target species. Seismic exploration for gas and oil in the subsoil is as loud as pile driving for an offshore wind farm and should therefore not be disregarded. Data on seismic activity are collected at the ICES registry for under water noise (see paragraph 4.3.3). The next step in exploration is when a mobile rig is moved into position and oil or gas wells are drilled. In this step, (water-based) muds and possibly other contaminants can be released to the marine environment. Drilling is bound to generate loud noise, though probably not as loud as that from seismic exploration.
Platforms may also locally influence fish and (thereby) marine mammals distribution.
For the two pressures that are selected for this project focused on potential risks for marine mammals, the spatial extent and frequency of the pressures by oil and gas industry in the North East Atlantic were assessed to be local and occasional for introduction of contaminants, and site and common for underwater noise (Knights et al., 2015).

Data availability and level of confidence
Maps on the presence of oil and gas platforms are available in GIS format from Jongbloed et al. (2014). Seismic activity maps are available at http://underwaternoise.ices.dk/map.aspx, and these data are also downloadable in GIS vector data. The level of confidence is good, since the data sources are recent and reliable. Also, the temporal coverage of the data is good.

Tourism
Spatio-temporal coverage
In the Noordzeeloket there is also a map available of the recreation and tourism activities in the Dutch Continental Shelf, which mainly take place on the beaches and in the coastal zone (Figure 15).
The spatial extent of tourism in the North East Atlantic was assessed to be local and the frequency as common by Knights et al. (2015). The greater North Sea is a more intensively used part of the NEA, which means that the spatial extent and frequency may be somewhat larger.

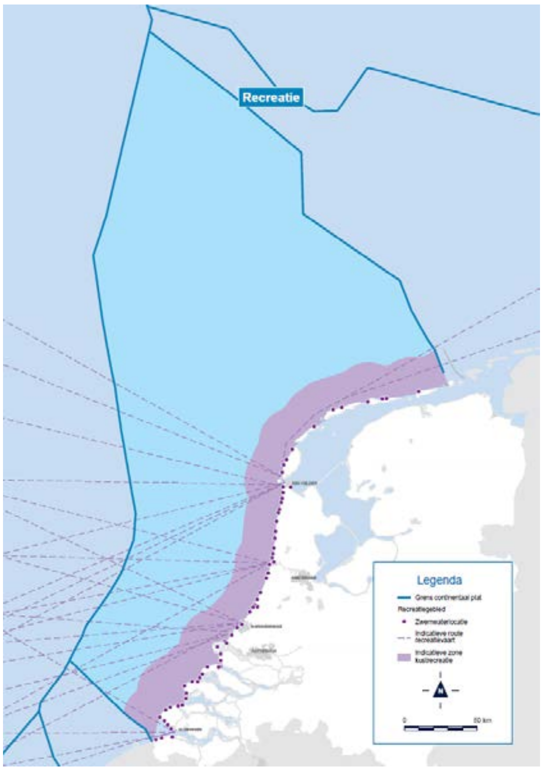


Figure 15 *Map of the recreational and tourism areas in the Dutch Continental Shelf. Source: Noordzeeloket.*

International data on tourism in the marine environment have been collected at the EEA website. The EEA supplies maps with data on tourism intensity in coastal zones (see Figure 16), and bathing water quality (Figure 17), which reflects a link of tourism with the pressures.

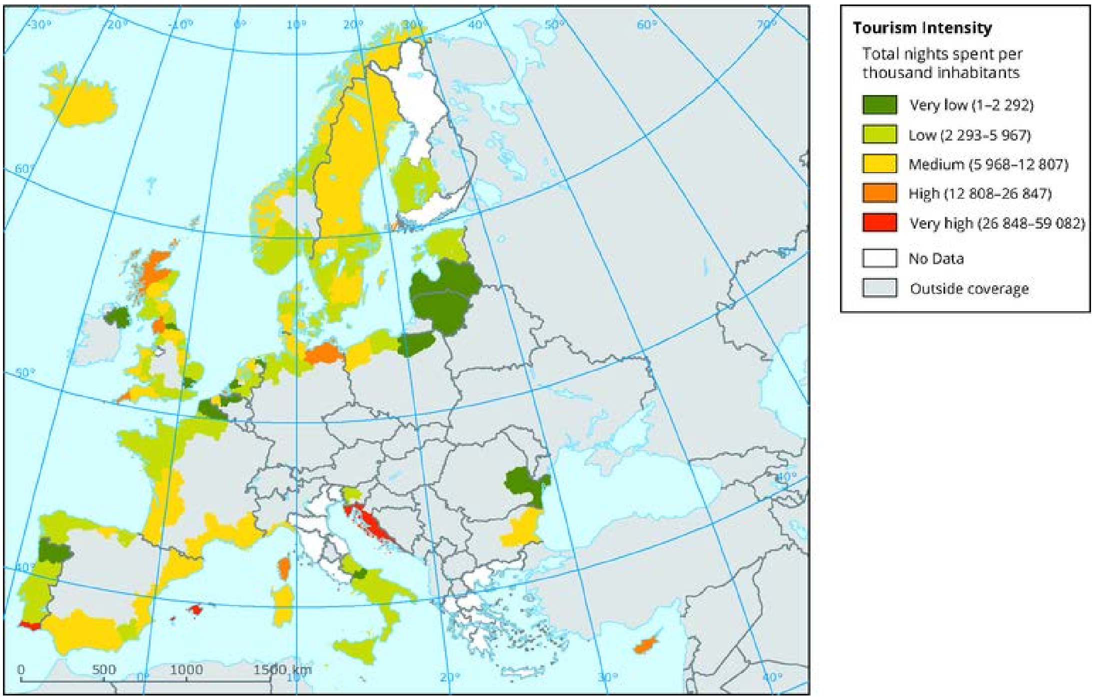


Figure 16 *EU-wide map of data on tourism intensity (source EEA website: http://www.eea.europa.eu/data-and-maps/figures/tourism-intensity-in-coastal-areas/map_24333.eps/image_large).*

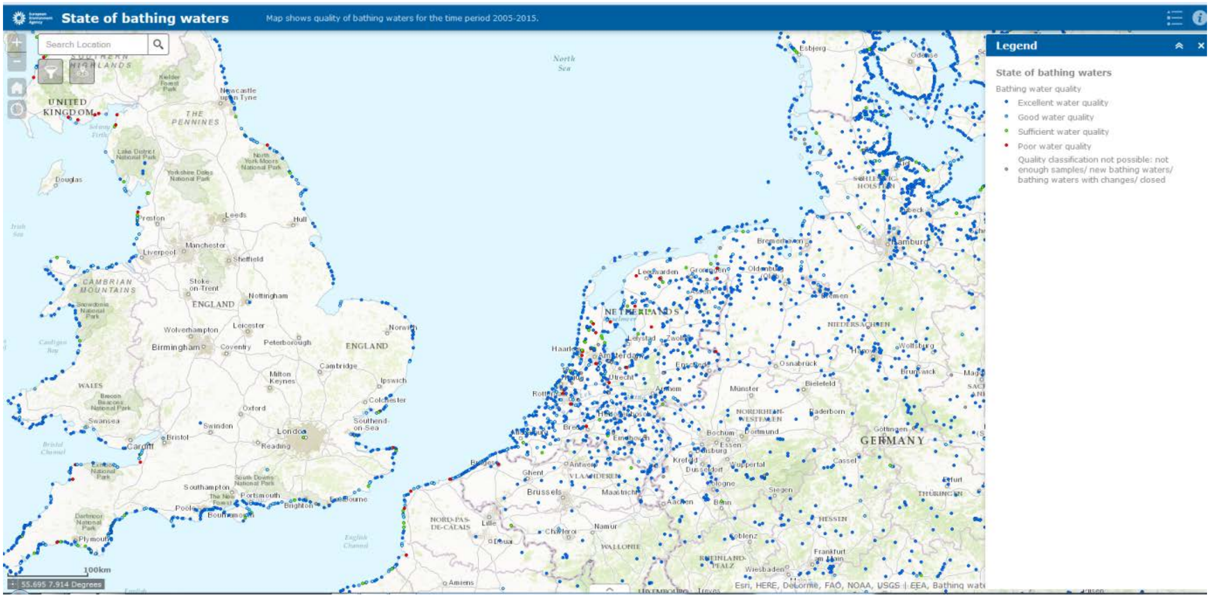


Figure 17 *EU-wide map with bathing water quality in EU member states. Maps also include inland bathing water quality. (Source EEA website http://maps.eea.europa.eu/wab/stateofbathingwaters/).*

No maps or data were found on offshore tourism (mostly boating, recreational fishing).

Link with pressures

The potential impacts of the tourism and recreational use of the North Sea area are myriad and include the presence of a high number of people in fragile systems (leading to stressing of animals, erosion, etc.). Other activities related to recreation that take place directly at sea cause for example disturbance, noise, waste creation, releases of toxic substances, introduction of non-indigenous species and illegal fishing practices (OSPAR, 2008). Furthermore, in order to expand the tourism and recreation opportunities, habitat is converted, which leads to loss of habitat and effects on biodiversity.

Data availability and level of confidence

The data available have a good spatial coverage, however, it is unclear when the activities occur. For tourism and recreation it is expected that a seasonal effect can be observed, however, based on the available data such an effect cannot be established. Furthermore, the underlying data and standards used for metadata are unclear. The level of confidence in the data is therefore moderate, since the institutes involved in the creation of the maps are reliable.

Renewable energy

Spatio-temporal coverage

On the North Sea, only wind energy is currently exploited on a large scale. Therefore, we focus this activity on offshore wind farms. There is a (commercial) UK website that keeps track of planned and installed offshore wind farm sites. They supply an interactive website that is well up to date and with a high spatial resolution of wind farm areas. These areas are clickable for more information. Figure 18 below shows an overview (screen dump) of the interactive website.

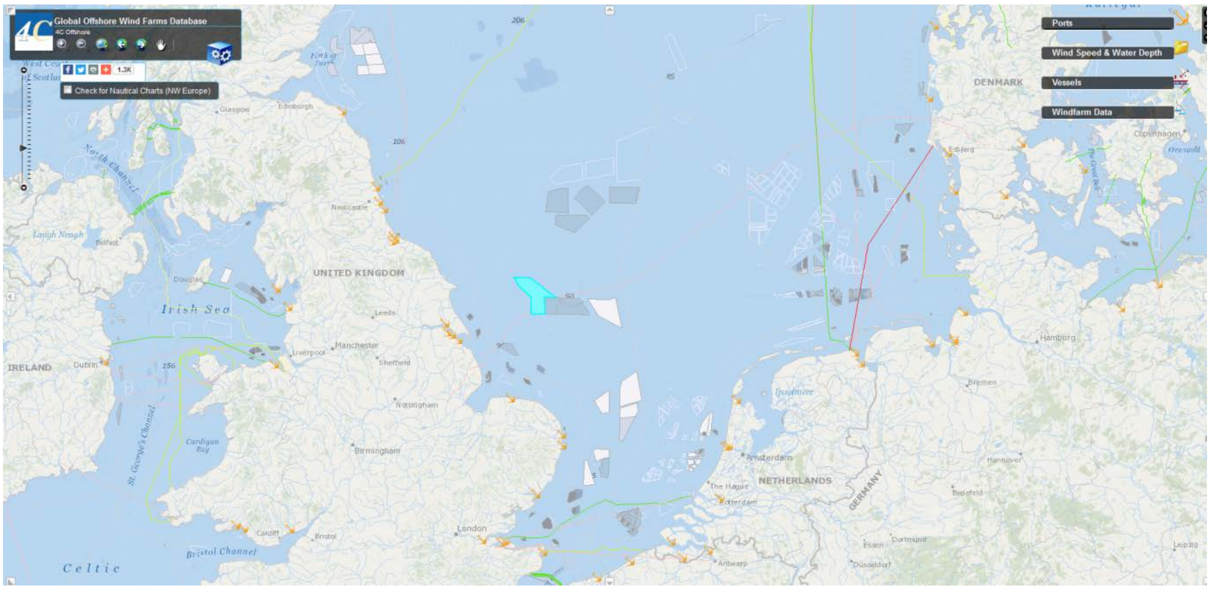


Figure 18 *Map with the current and designated areas for renewable energy exploitation in the southern North Sea. (Source: www.4coffshore.com/offshorewind).*

OSPAR has a dataset available from 2009-2015 at its datacenter, which should be downloadable and importable into GIS; at the moment of writing, this could not be confirmed. Maps are available in reporting (see OSPAR 2014). But these are not available for download.

Link with pressures
Renewable energy is associated with several pressures, including underwater noise (impulsive noise during construction and continuous noise during operation), introduction of hard substrate, with concomitant effects on benthic communities, marine mammals and fish (WGMBRED, ICES, 2016b). Furthermore, other related pressures are changes to the benthic and pelagic habitats, with effects on hydrodynamics, changes in grain size and suspended particles as well as changes in habitat which in turn leads to changes in the diversity of artificial structures and biodiversity (Degraer & Brabant 2009).
The only pressure type that is selected for renewable energy in this project focused on potential risks for marine mammals is underwater noise. The spatial extent of underwater noise by renewable energy in the North East Atlantic was assessed to be local with a frequency classified as common (Knights et al., 2015).

Data availability and level of confidence
The data availability is good, since there are visual maps available as well as GIS exploitable data through the OSPAR database ODIMS. The level of confidence in the data is therefore also high.

Military
Spatio-temporal coverage
An map on military activities throughout the North Sea is available from Jongbloed et al. (2014), see Figure 19 below. The spatial extent of military activities in the North East Atlantic was assessed to be local and the frequency as occasional by Knights et al. (2015).

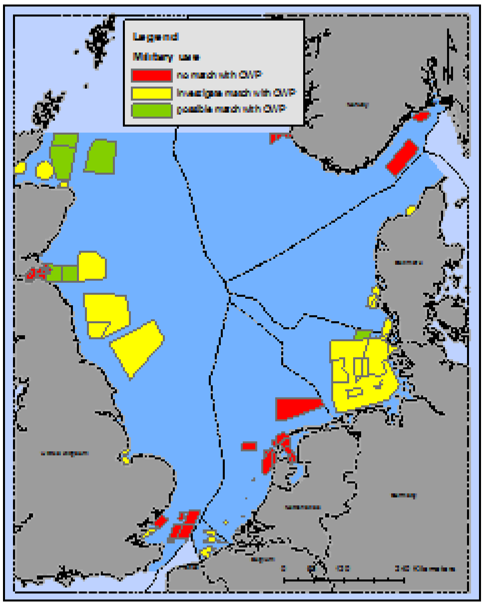


Figure 19 *Map of military use in the North Sea (from: Jongbloed et al., 2014).*

Link with pressures

Military activities can lead to disturbance of marine fauna as a result of underwater noise and vibrations due to sonar, explosions and shipping. Furthermore, as a result of target practice, ammunition is released into the marine environment, leading to environmental impacts (see https://www.noordzeeloket.nl/functies-en-gebruik/militair-gebruik/ for Dutch examples). Shipping of high-speed frigates and other military vessels may cause collision with marine mammals.

Next to the military activities themselves, there are still considerable dumps of (chemical and regular) ammunition in the North Sea, coming from the 20th century World Wars. Some of these areas have been marked on maritime charts, but to our knowledge there is no detailed inventory publicly available of these dump sites. Maybe the collected ministries if Defence of the member states around the North Sea have such data in their possession.

Two pressures, underwater noise and death or injury by collision exerted by military activities, are selected for this project. In another project the spatial extent and frequency of these pressures by military activities in the North East Atlantic were assessed to be local and occasional (Knights et al., 2015).

Data availability and level of confidence

There are spatial data available with a good extent, but the resolution is low. Next, it is unclear what data are used to create these maps. Furthermore, this map is static and therefore not very suitable for overly with target species in GIS. The level of confidence in the data is therefore low.

Based on AIS and shipping information, more detailed maps could be made selecting military vessels (if available).

Aquaculture

Spatio-temporal coverage

In the Dutch georegistry (http://nationaalgeoregister.nl/geonetwork/srv/dut/search#) spatial data are available on mussel seed collect installations. These cover only the Dutch part of the North Sea, but they do not extend offshore. The aquaculture in the Netherlands, apart from some pilot sites for research projects, is currently taking place in the inland waters, and focuses mainly on shellfish (mussels and oysters).

Link with pressures

Aquaculture of shellfish is associated with a high nutrient content in the surrounding waters and seabed and thus decreases in water quality. Furthermore, shellfish are highly efficient filterers and therefore can have negative impacts if the shellfish are grown in competition with other marine organisms.

The only pressure type that is selected for renewable energy in this project focused on potential risks for marine mammals is introduction of compounds (contaminants). The spatial extent of this activity-pressure combination in the North East Atlantic was assessed to be local and the frequency as occasional (Knights et al., 2015).

Data availability and level of confidence
No relevant data were found.

Land based industry

Spatio-temporal coverage
The most important input to the North Sea of nutrients and polluting substances is via rivers through land-based industries. Also agriculture and forestry contribute significantly to nutrient and pollutant input. No relevant spatial data on land-based industry were found, but there are data on the river-based contribution to nutrients and pollutants, such as is OSPAR 2015. The number of emission (discharge) points is not reported in OSPAR (2015). The direct discharge per year is reported for countries and for regions including the North Sea. There are sites at which water samples are collected for chemical analyses within the RID Programme. Five heavy metals are mandatory in the RID Programme: cadmium, copper, lead, mercury and zinc.
When influx of river water and nutrients and pollutants is available, North Sea wide hydrodynamic modeling can predict the distribution of these substances in the North Sea basin. Such modeling efforts have been carried out for the southern North Sea, but not for the whole of the North Sea.

Link with pressures
Compounds that are released in rivers through land-based industry (and also fertilizer and pesticide compounds used by agriculture) are largely transported to the marine environment, where they pollute coastal waters, sediments and biota. Waste water from industries and households contains low concentrations of pollutants, nutrients and microplastics.
The only pressure type that is selected for land-based industry in this project focused on potential risks for marine mammals is introduction of compound (contaminants). The spatial extent of this activity-pressure combination in the North East Atlantic was assessed to be local and the frequency as occasional (Knights et al., 2015).

Data availability and level of confidence
Data on the influx of pollutants and nutrients from rivers are available on a member state level, and are collated at the OSPAR level. No data are available on the spatial coverage of land-based industries that are responsible for these compounds. As a result, confidence in these data is low.

Data evaluation
Table 10 shows the evaluation scoring for the activities. For most activities spatial data is digitally available, although area coverage is not fully covering the Greater North Sea. No spatial data was found for land based industry, mainly because the study area is limited to the marine environment and thus the actual land based activities are therewith outside the scope of this study. Available data on tourism/recreation is also limited.

Table 10 *Evaluation of extent of activities Categories and criteria are described in Table 3*

Activity	Type of data	Area coverage
Aquaculture	Digital map	Not complete
Fishing	Digital map	Part of the study area, with sufficient coverage
Land-based Industry	No maps available	-
Military	Digital map	Part of the study area, with sufficient coverage
Oil and gas	Digital map	Part of the study area, with sufficient coverage
Renewable energy	Digital map	Part of the study area, with sufficient coverage
Shipping	Digital map	Part of the study area, with sufficient coverage
Tourism/Recreation	Printed maps	Not complete

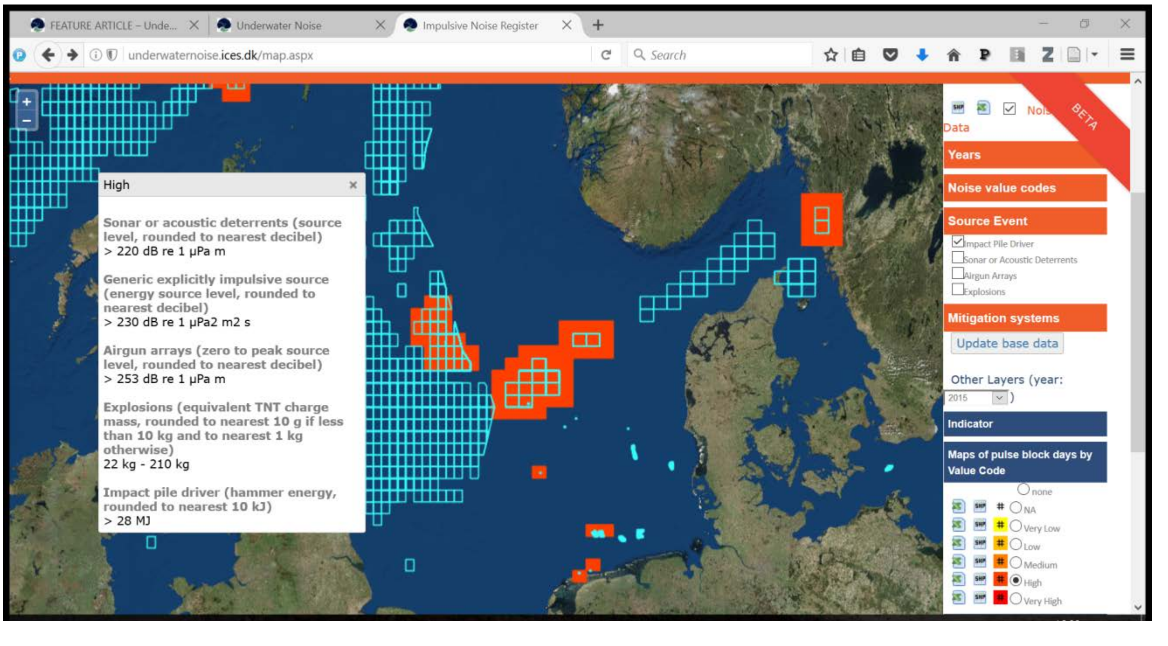
4.3.3 Anthropogenic pressures: underwater noise

Underwater noise is one of the recent fields of research in the study of human impact on marine mammals, and is related to effects on given their dependence on sound as a means for communication, habitat reconnaissance and/or foraging (Madsen et al., 2006). Basically, two types of underwater noise can be discerned: impulsive noise (low- and mid-frequency), and continuous noise (low-frequency), which have been included in the MSFD descriptors 11. Impulsive noise is caused by activities such as piling, use of sonar, and air guns. Continuous noise is mostly generated by shipping, dredging, sand and gravel extraction, bottom fishing, operational renewable energy, offshore gas and oil platforms, etc.. Impulsive noise has been considered a larger threat to marine mammals than continuous noise (Tasker et al., 2010), although this probably largely depends on the species and its habitat. Since the main marine mammal species in the (southern) North Sea are the harbour porpoise, the harbour seal and the grey seal, extended studies have and are being conducted into the effects of impulsive noise from wind farm piling on these species (and assuming the harbour seal is a good proxy species for grey seals) (Carstensen et al., 2006, Kastelein et al., 2010). Below, we shortly present what currently is known on the occurrence and magnitude of these two types of underwater noise in the North Sea, their sources, and their monitoring and measuring units.

Impulsive noise

Impulsive noise (low and mid-frequency) is being collected at ICES in a register as the result of an agreement of all member states taking part in the MSFD Technical SubGroup Underwater Noise. Member states can upload data to ICES, which are included in the register and presented at the ICES website (see below). Within OSPAR (Northeast Atlantic), countries are now sharing data on activities, which are usually provided through the regulatory consenting process (e.g. for pile driving activities, or seismic surveys for oil and gas exploration). This data is being gathered centrally into the Impulsive Noise Register (http://underwaternoise.ices.dk/map.aspx), which has been created and is being maintained by ICES. Data are presented as pile block days, in a varying grid (ICES sub-rectangle, points, UK license blocks, German Naval polygon) with a relative magnitude of very low, low, medium, high and very high intensity, per year and per source. The OSPAR Intersessional Correspondence Group on Noise (ICG-NOISE) is currently working closely with the ICES data team to produce the 2017 OSPAR Intermediate Assessment for impulsive noise. This will be the first regional assessment of its kind, and will give policy-makers and regulators a regional overview of cumulative impulsive noise activities in the Northeast Atlantic, including the noise source types and intensity. The 2017 Intermediate Assessment will serve as a 'roof report' to inform the subsequent 2018 MSFD assessments of EU Member States within the OSPAR region.

The above mentioned website presents the collected data in a map viewer, and users can download the data and GIS shapefiles for use in their own studies.



As can be seen from the above screen dump from the ICES website, the value codes of the specific activities have been quantified into the energy or sound pressure related to the activity. For example, the minimum limit for value code ‘high’ for airgun arrays has been set at a source level (zero to peak) of 253 dB re 1 µPa m. For other activities, other minimum levels have been used, but note that also other units have been used. Due to the complexity of underwater acoustics, there has been a lot of debate around the appropriate unit for underwater impulsive noise. In various reports (e.g. Ainslie et al., 2011, Van der Graaf et al., 2012, Dekeling et al., 2013) suggestions have been put forward for a standardized unit for impulsive noise, and an ISO standard is currently under development.

Continuous noise

There is no registry for continuous noise, such as generated by shipping. A spatial representation of continuous noise would be possible, based on known shipping routes, the intensity of shipping, AIS data of larger vessels, VMS data. Such maps have been made for the Dutch part of the North Sea by Popper and Hawkins (2016), Chapter 124 and by Sertlek et al. (2016), (see Figure 20).

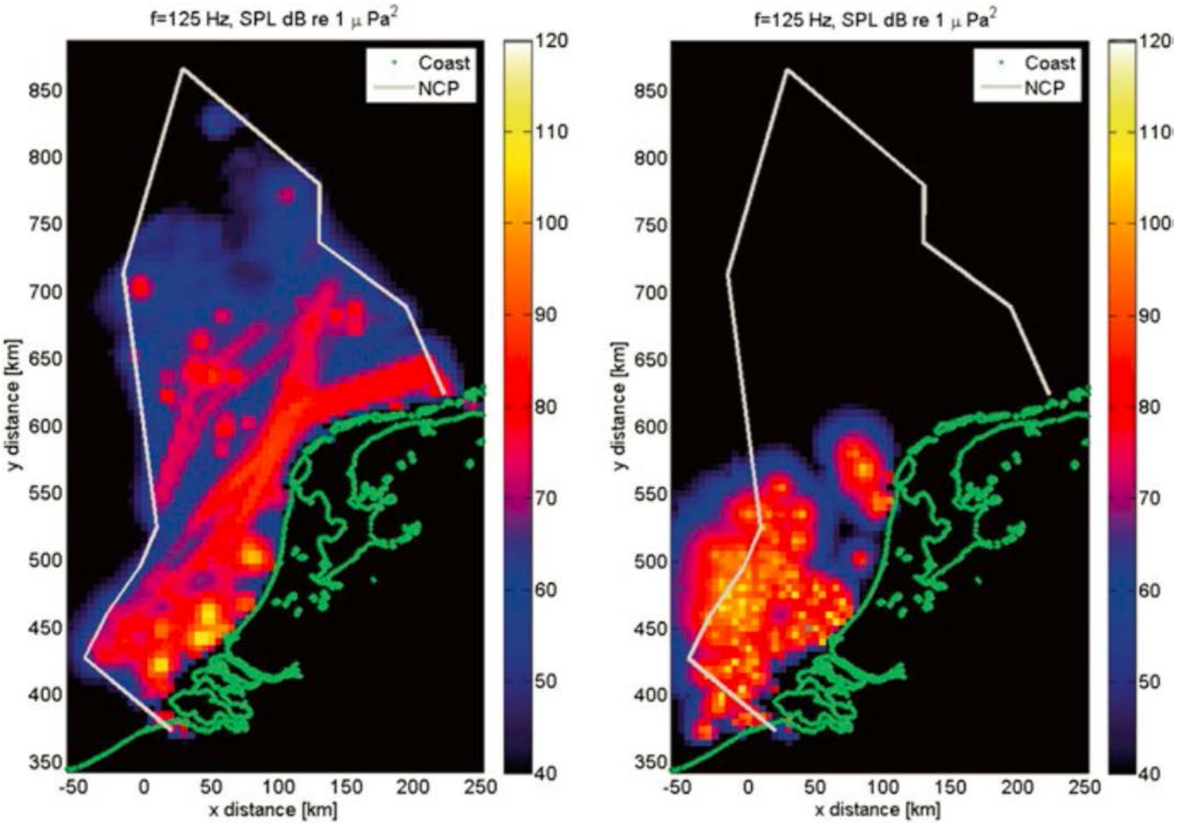


Figure 20 *Annually averaged sound maps for shipping (left) and underwater explosions (right) at 125 Hz at 1 m below the sea surface. SPL sound pressure level, f frequency. This figure is taken from Sertlek et al. (2016).*

Data evaluation

Tables 11 to 13 show the overall evaluation scoring for the pressure underwater noise. Scoring for the two categories of effects, ‘injury’ (caused by impulsive, high-energy noise levels), and disturbance (caused by both other impulsive noise levels, and continuous noise) is highly comparable. Data on the areal coverage of the linked activity data (GIS) is good, but not fully quantitative on spatio-temporal extent and resolution of the pressures themselves (or only printed). For high-energy, impulsive noise, this pressure data level is more quantitative than for the other types of noise, GIS shapefiles can be constructed from downloadable data. This is not the case for e.g. continuous noise (leading probably to disturbance). Comparable scores have been given to the ‘magnitude’ evaluation. Although some data on the actual noise levels are available, and the metrics are well suitable for the noise level, much of the magnitude is only available through expert knowledge, or through (no well-known) for exposure or receptor sensitivity. ‘Sensitivity’ scoring is medium; effects on individuals of porpoise and seals are relatively well known for PTS, TTS and displacement, but effects on individual fitness or population impact is (as for all stressors) unknown, or a matter of expert judgement.

Table 11 *Exposure evaluation. Categories and criteria are described in* Table 3

Pressure	Noise	Noise
Effect	Injury	Disturbance (change in behaviour, displacement)
Activity	Oil and gas, military, renewable energy	Military, Fishing, Shipping, Oil & Gas, Renewable Energy
Extent of Human activity	A	A
Exposure assessment based on	B	B
Spatial scale (extent)	B	B
Spatial scale (resolution)	B	B
Temporal scale (time period)	A	B
Temporal scale (resolution)	B	B
Pressure distribution	B	B
Availability Overall	Quantitative partial	Quantitative partial
Confidence Score (range)	0.5-0.9	0.5-0.9
Confidence Score (average)	0.7	0.7

Table 12 *Magnitude evaluation. Categories and criteria are described in Table 5*

Pressure	Noise	Noise
Effect	Injury	Disturbance (change in behaviour, displacement)
Activity	Oil and gas, military, renewable energy	Military, Fishing, Shipping, Oil & Gas, Renewable Energy
Metric (chosen)	Noise level (dB re 1 μPa^2 (m^2))	Noise level (dB re 1 μPa^2 (m^2))
Exposure assessment based on	B	B
Metric suitability	A	A
Link to exposure	B	B
Link to sensitivity	B	B
Confidence Score (range)	0.6-0.9	0.6-0.9
Confidence Score (average)	0.7	0.7

Table 13 *Sensitivity evaluation. Categories and criteria are described in* Table 6

Pressure	Noise - impulsive	Noise – continuous
Effect	Injury	Disturbance (change in behaviour, displacement)
Metric (chosen)	Noise level (dB re 1 μPa^2 (m^2))	Noise level (dB re 1 μPa^2 (m^2))
Pressure-State Relationship (chosen)	Threshold values (individuals), incl population impact	Threshold values (individuals), incl population impact
Exposure assessment based on	B	B
Pressure-State Relationship	B	B
Confidence Score (range)	0.6	0.6
Confidence Score (average)	0.6	0.6

4.3.4 Anthropogenic pressures: introduction of contaminants

For the purpose of this study, we identified those substances that are both 'OSPAR priority chemicals' as well as specifically identified as a potential threat to marine mammals (see Annex 1). These are: Hg, Cd, PCBs and brominated flame retardants (i.e. PBDEs).

Exposure
For the selected substances sufficient data is available to assess the distribution and intensity (i.e. concentration), covering most of the study area. Main sources of data are:

- DOME (Marine Environment). Data portal used by OSPAR, HELCOM, AMAP and Expert Groups in the management of chemical and biological data for regional marine assessments. Including data on e.g. metals and brominated flame retardants in sediment and biota. Available at: http://www.ices.dk/marine-data/data-portals/Pages/DOME.aspx

- EEA database of hazardous substances (e.g. WISE_TCM_Biota.mdb. Available at: http://forum.eionet.europa.eu/etc-icm-consortium/library/subvention-2013/tasks-and-milestones-2013/1.5.1.d-wise-soe-data-flows/milestone-7-2013-reference-databases-wise-soe-data-flows-tcm-tcm-water-quality/index_html).

Magnitude
The magnitude of the introduction of contaminants should ideally be expressed by a metric that:

- Best represents the nature of the pressure;
- Is identical to the unit of the exposure metric;
- Is identical to that used to describe sensitivity.

Addressing the nature of the pressure, i.e. *introduction* of contaminants, the magnitude is best described by the quantity of emission, i.e. load and involves a unit of time. In other words, x amount of chemical is introduced per x unit of time. For example, an oil/gas production platform discharges produced water into the marine environment causing introduction of contaminants with a magnitude of x kg dispersed oil per month per platform. This metric is however not identical to the unit of exposure. Marine mammals are mainly exposed to contaminants via food. Therefore the magnitude of the pressure (i.e. load) needs to be transformed into a concentration in the water column and subsequently concentration in food (i.e. fish). This transformation requires a calculation of the dilution (concentration in water) and bioaccumulation data (concentration in food). Another option would be to use monitoring data to describe the concentration in food/biota, therewith using the best metric concerning exposure but only a proxy of the nature of the pressure. Sensitivity (i.e. effect values) is also based on concentration in food.

Sensitivity
A passive monitoring study of stranded animals showed that levels of Hg, Se, Zn, Cd and V appeared to be higher in porpoises that died from infectious diseases compared to healthy porpoises that died from physical trauma, although synergetic effects of metallic contaminants on health status was not elucidated (Mahfouz et al., 2014). The findings indicate that metallic contaminants may influence the health of harbour porpoises and contribute to the increased stranding numbers encountered over the last decade for the population in the southern North Sea.
Persistent organic pollutants (POPs), bio-accumulating in the blubber of harbour porpoises include polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and brominated flame retardants (OSPAR, 2009). Harbour porpoises stocks with relatively high PCB levels were from the southern North Sea (Netherlands and Belgium) and had the lowest reproductive rate (OSPAR, 2009).

Weijs et al. (2009) investigated the accumulation and biomagnification of PCB and PBDE congeners in blubber of harbour seals and harbour porpoises from the Southern North Sea. Harbour seals showed a higher ability to metabolize PCBs and PBDEs compared to harbour porpoises (Weijs et al., 2009).

The dose-response relationship for marine mammals exposed to contaminants via food can be described by a logistic function (Jak et al., 2000). Exposure via the water column was disregarded. Effect values (LC50, NOEC) are required to parameterise the function but are lacking for marine mammals. NOECs for Cd, (Methyl-)Mercury and PCBs for seal and porpoise were extrapolated from other species groups by Jak et al. (2000), following the methodology developed by Jongbloed et al. (1995) and were calculated as 1.4, 0.2 and 3.0 mg substance / kg food respectively. These values should be corrected for the caloric value of the different food types and for laboratory-field differences, for which Jak et al. (2000) use a correction value for seal and porpoise of 0.15. This results in NOECs of 0.21 (Cd), 0.03 (methyl-) mercury and 0.45 (PCB) mg/kg food. A different literature source reports effect values for PCB (Kannan et al., 2000). The no observed adverse effect level (NOAEL) represents the least exposure treatment tested and the lowest observed adverse effect level (LOAEL) represents the greatest exposure. It appears that mink, otter and harbour seals are comparably sensitive to toxic effects of PCBs (Kannan et al., 2000). Daily dose NOAEL for seals exposed to PCBs is reported at 5.2 ug/kg bw/d, daily dose LOAEL at 28.9 ug/kg bw/d, dietary NOAEL at 100 ng/g wet wt and dietary LOEAL at 200 ng/g wet wt (Kannan et al., 2000).

Data evaluation

Following the above, the evaluation scoring of the pressure 'contaminants' is given in the tables 14 to 16 below. Exposure scoring varies strongly due to the large number if substances to be reported. Usually the extent of the activities related to the pressure is well reported, but not for all substances. Links of the pressures to the activities is not well known for all substances. Spatial and temporal extent and resolution usually is good, as are the linkages of the metrics to the exposure. For contaminants in biota, linkages of the metrics to receptor sensitivity is good, but not for contaminant concentrations in water and sediment. Also, effects within the receptor of contaminants in water and sediment cannot be well assessed.

Table 14 *Exposure evaluation. Categories and criteria are described in Table 3*

Pressure	Introduction of contaminants	Introduction of contaminants
Effect	Increase of internal concentration (directly from environment)	Increase of internal concentration (indirectly through food)
Activity	Shipping, Aquaculture, Land-based Industry, Oil & Gas	Shipping, Aquaculture, Land-based Industry, Oil & Gas
Extent of Human activity	A-C	A-C
Exposure assessment based on	B	B
Spatial scale (extent)	B	B
Spatial scale (resolution)	A	A
Temporal scale (time period)	A	A
Temporal scale (resolution)	A	A
Pressure distribution	B	B
Availability Overall	Quantitative partial	Quantitative partial
Confidence Score (range)	0.3-0.9	0.3-0.9
Confidence Score (average)	0.7	0.7

Table 15 *Magnitude evaluation. Categories and criteria are described in Table 5*

Pressure	Introduction of contaminants	Introduction of contaminants
Effect	Increase of internal concentration (directly from environment)	Increase of internal concentration (indirectly through food)
Activity	Shipping, Aquaculture, Land-based Industry, Oil & Gas	Shipping, Aquaculture, Land-based Industry, Oil & Gas
Metric (chosen)	Concentration in water (e.g. mg/l)	Concentration in fish (e.g. mg/kg)
Exposure assessment based on	B	B
Metric suitability	B	B
Link to exposure	A	A
Link to sensitivity	B	A
Confidence Score (range)	0.5-0.9	0.6-0.9
Confidence Score (average)	0.7	0.8

Table 16 *Sensitivity evaluation. Categories and criteria are described in* Table 6

Pressure	Introduction of contaminants	Introduction of contaminants
Effect	Increase of internal concentration (directly from environment)	Increase of internal concentration (indirectly through food)
Metric (chosen)	Concentration in water (e.g. mg/l)	Concentration in fish (e.g. mg/kg)
Pressure-State Relationship (chosen)	Unknown	Logistic pressure-state relationship based on effect values (individuals), incl population impact
Exposure assessment based on	B	B
Pressure-State Relationship	C	A
Confidence Score (range)	0.2	0.8
Confidence Score (average)	0.2	0.8

4.3.5 Anthropogenic pressures: marine litter

Exposure

An inventory of data for marine litter was done (see Annex 2). Three data sources were selected as most appropriate data to determine exposure:

- OSPAR Marine Litter Beach Monitoring (as a proxy for large marine litter items in the sea)
- OSPAR Plastic particles in the stomachs of Seabirds (as a proxy for small floating litter on the sea-surface)
- Deltares plastic transport model (Delft-3D PART transport model).

The main conclusion is that very little data are available for the Greater North Sea for the exposure risk of seals and porpoises to marine litter:

- Spatial and temporal scale: most data are point measurements in space and time rather than areal estimations throughout the year. Also, verified and coordinated datasets among EU Member States are not spatially explicit. For example, the OSPAR marine litter in seabirds' dataset is based on birds that could have eaten the plastics anywhere and are thus not spatially explicit. This makes it difficult to determine hotspots of marine litter based on these data. However, based on the data on exposure there is a chance that marine mammals ingest or get entangled in marine litter items anywhere at sea.
- Matrix: the most spatially explicit dataset is on the beach. Model schematisations are made for areas of the sea surface too, which is helpful and can be a tool in extrapolating data within an area.
- Data quality: Only the OSPAR datasets are INSPIRE compliant and therefore meet the EU meta-data standards, for other data the quality of data is unknown. INSPIRE compliance adds to comparability, availability and quality of the data.

Magnitude

Most data sources look at the amount of particles present in the environment. For the water column, this is expressed in number of particles/m^3 (Deltares model) or, looking at the proxy of litter on the water surface, Northern fulmars, weight of litter items/stomach (OSPAR dataset). For the beach this is expressed in the amount of items/category of litter on a stretch of 100 m of beach (OSPAR Marine Litter Beach Monitoring dataset). For the sea floor this is expressed in number of litter items/km^2 sea floor (for large items), or in particles/m^3 for microplastics .

Sensitivity

- No data sources were found that described the effects of ML on the target species, since no direct relationship between marine litter ingestion and mortality has been described.
- No data were found on the effects of microplastics on marine mammals, only some data are available on the occurrence of microplastics in biota, including fish and other relevant food sources. There are incidence reports on the entanglement of large plastics and choking of seals on large plastics, but there is no dedicated reporting and inventory of locations. There

are data from lab studies for the effects of microplastics on lower trophic levels with a potential for food web effects, however these are often carried out with high concentrations of microplastics and are therefore less relevant in the field. Furthermore, these data represent an indirect exposure route, which is less relevant for the target species.

- There are some (citizen science) data available for observations of entanglement of marine mammals washed up on Dutch beaches. Also available are pathological reports and some scientific articles on the occurrence of plastic particles in the stomachs of (washed up) seals and porpoises.
- There are no clear data (dose-response) on the effects of macroplastics and microplastics on the target species. An assumption can be (albeit worst case) that entanglement leads to death. But ingestion does not necessarily lead to decreased survival. Data on effects on survival through direct ingestion of macroplastics or through food-web effects of microplastics are virtually absent. There are no data directly linking the presence of plastics in an organism to death since most animals are found washed up on the beach and were unlikely to have died from ML ingestion.

What assumptions, uncertainty and thus level of confidence

- The main assumptions around this pressure are:
  - That there are no known direct effects of microplastics on the target species.
  - There is a risk of entanglement or ingestion of ML from the seafloor, from beaches (seals only) and floating ML on the sea surface or in the water column. The effect of entanglement or ingestion is not well known.
  - Indirect effects through the food web are largely unknown and cannot be used in the risk assessment.
- The uncertainties around the presence of ML in the environment are high, since the material is very heterogeneously distributed in the environment, and data points on the ML presence are few. For floating litter on the water surface for example, the currents, wind and wave energy are important processes determining the transport and fate of ML. The most useful data for exposure of seals and porpoises is the data for the North Sea on floating marine litter; this ML can cause choking or entanglement of seals and porpoises leading to direct effects of decreased survival. Currently, results are available that models the distribution of large, floating ML through the North Sea, an important assumption here is that the only source of ML input is from rivers (for more information see Van der Meulen et al., 2016).

Determine Risk of Impact

- The potential risk of the impact of marine litter on the target species is considered too uncertain to assess due to the lack of data on effects. The risk of exposure is thought to be moderate since the amounts of litter items found in the environment can be high locally (i.e. on the beach), however, in looking at floating litter the pressure is so diluted that it is difficult to say anything about the risk of an encounter between ML and the target species. This is also due to the heterogeneous nature of floating litter.

Data evaluation

Pressure evaluation is scored in the Tables 17 to 19 below. Data on the activity related to the entanglement through marine litter (fishery) is well known, as are the marine activities related to the ingested marine litter (except for Tourism/Recreation). Temporal extent of the pressures scores well, due to the recent character of litter data and knowledge. Spatial coverage is poor, but some data are available. The metrics related to entanglement are poor, and so is the linkage to exposure and the receptor sensitivity; we don’t know which litter property causes entanglement. For litter ingestion, this is better known, but still the relationship to the exposure (how much are the animals exposed to and through which pathways) and the possible effect are mostly a matter of expert judgement.

Table 17 *Exposure evaluation. Categories and criteria are described in* Table 3

Pressure	Marine litter	Marine litter
Effect	Entanglement	Ingestion
Activity	Fishing	Shipping, Tourism/Recreation, Fishing
Extent of Human activity	A	A-B
Exposure assessment based on	B	B
Spatial scale (extent)	B	B
Spatial scale (resolution)	B	B
Temporal scale (time period)	A	A
Temporal scale (resolution)	A	A
Pressure distribution	D	B
Availability Overall	Quantitative partial	Quantitative partial
Confidence Score (range)	0-0.9	0.6-0.9
Confidence Score (average)	0.6	0.7

Table 18 *Magnitude evaluation. Categories and criteria are described in* Table 5

Pressure	Marine litter	Marine litter
Effect	Entanglement	Ingestion
Activity	Fishing	Shipping, Tourism/Recreation, Fishing
Metric (chosen)	Unknown	Number of particles/m^3
Exposure assessment based on	B	B
Metric suitability	C	A
Link to exposure	C	B
Link to sensitivity	C	B
Confidence Score (range)	0.2	0.5-0.9
Confidence Score (average)	0.2	0.6

Table 19 *Sensitivity evaluation. Categories and criteria are described in* Table 6

Pressure	Marine litter	Marine litter
Effect	Entanglement	Ingestion
Metric (chosen)	Unknown	Number of particles/m3
Pressure-State Relationship (chosen)	Unknown	Unknown
Exposure assessment based on	B	B
Pressure-State Relationship	C	C
Confidence Score (range)	0.2	0.2
Confidence Score (average)	0.2	0.2

4.3.6 Anthropogenic pressures: bycatch

Using the phrases in the linkage framework this section represents the impact chain fisheries-biological extraction-marine mammals.

A relatively small part, approximately 15%, of the total fishing effort (Gross Tonnage*days reflecting the size of the vessel and the amount of days spent fishing) in the North Sea comes from fishing activities that may bycatch marine mammals, i.e. Pelagic trawl/Seine (11%), Gillnets/Pots/Traps (3% but this is an overestimate as only gillnets may cause bycatch of marine mammals) and possibly longline (1%). Effort of all these gears, except longline, is decreasing (Figure 21). While this may provide some indication of the relative importance, this is not an appropriate metric for the static gears, i.e. gillnets and longline as the magnitude of the pressure is determined by the amount of gear in the water (e.g. expressed in kmNet*days for gillnet or number of hooks*days for longline).

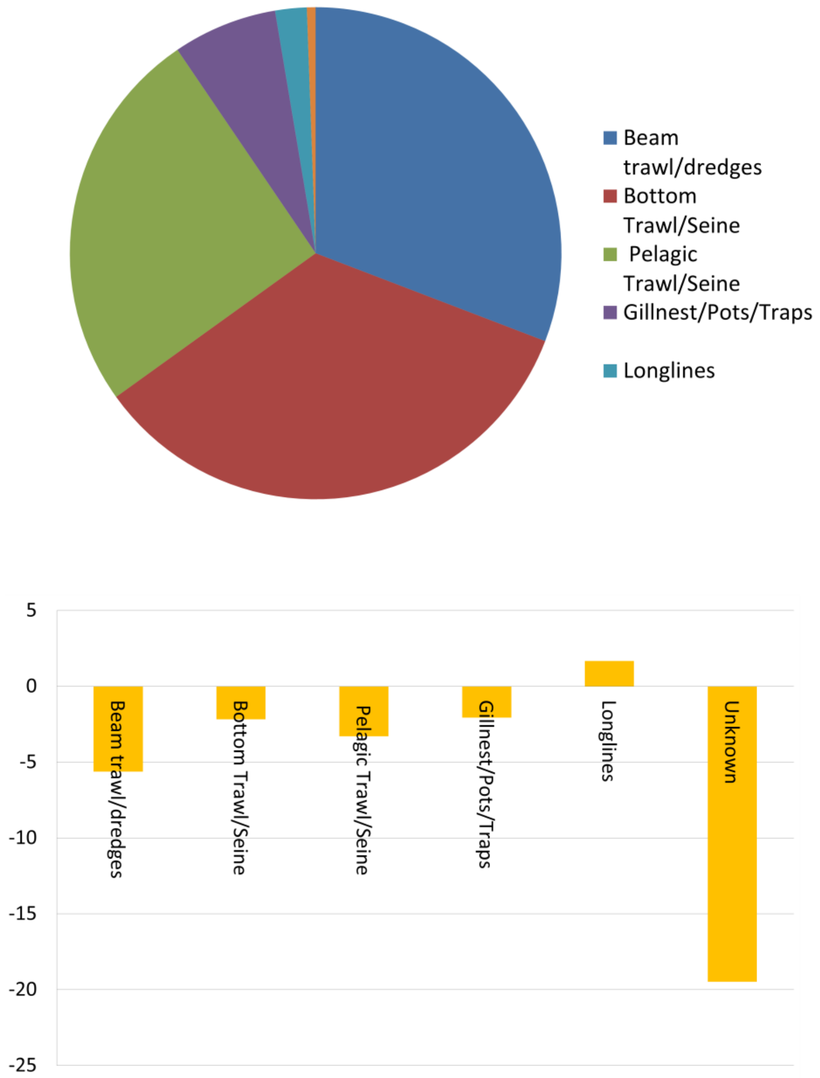


Figure 21 *Deployment of fishing effort (Gross Tonnage*days) of categories of fishing techniques/gears (based on 2014) and their change over time (period 2005-2014)*

It is very likely that marine mammals are exposed to these fishing activities as a study in the Dutch sector of the North Sea shows that gillnets are fairly widespread, certainly in the coastal zone off the Dutch mainland (Figure 22). International data on the distribution of the pelagic fishery also show this is fairly widespread, covering areas where marine mammals occur (Figure 23). Note also that sometimes these sources of information apply a metric that is useful as it directly relates to the magnitude of the pressure (i.e. kmNet*days) while other are more difficult to relate to any magnitude of the pressure (i.e. value in euro).

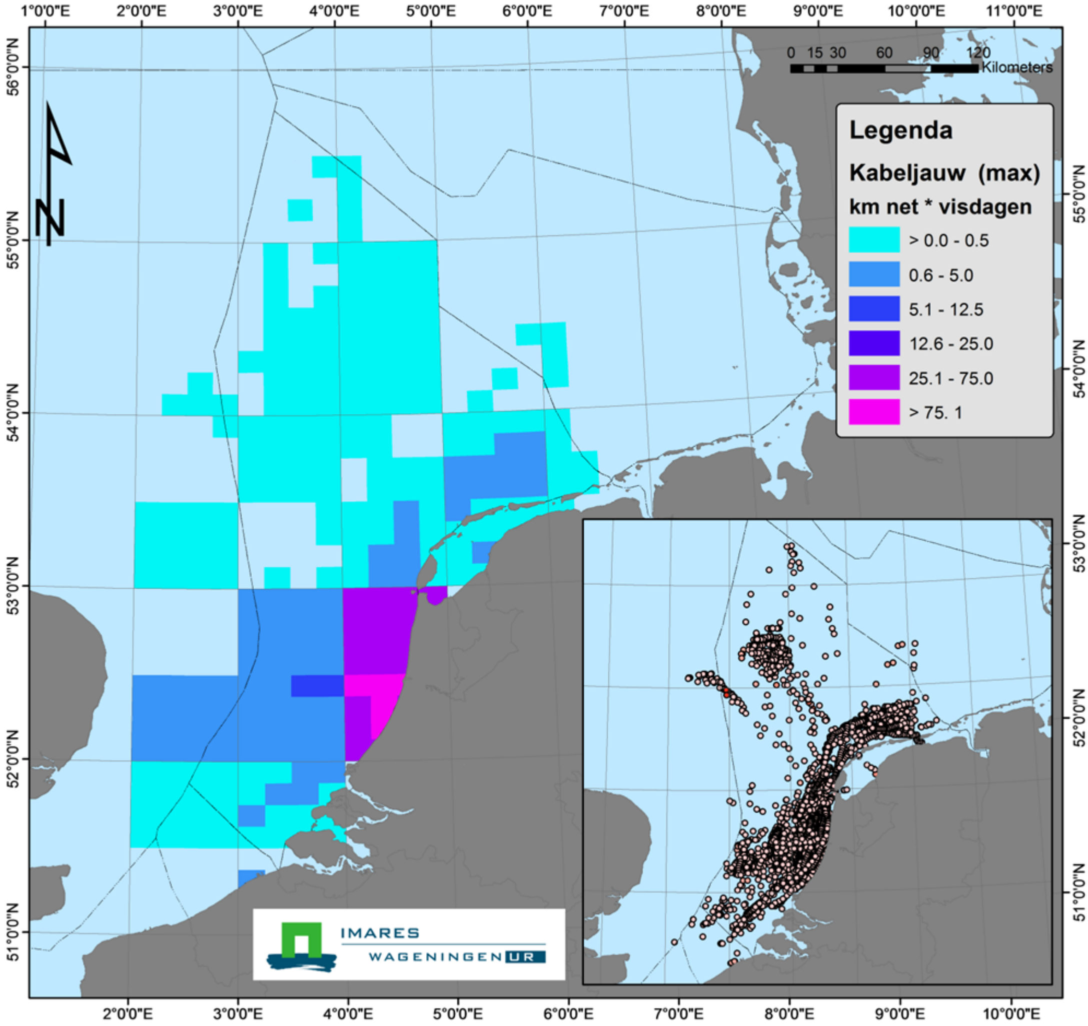


Figure 22 *Spatial distribution of gillnet effort in the Dutch sector of the North Sea. At a spatial resolution of 1/16th ICES rectangle or approx. 15 x 15 km. The small map shows the location of VMS pings (signals) of gillnet vessels. These do not necessarily correspond to the location of the nets.*

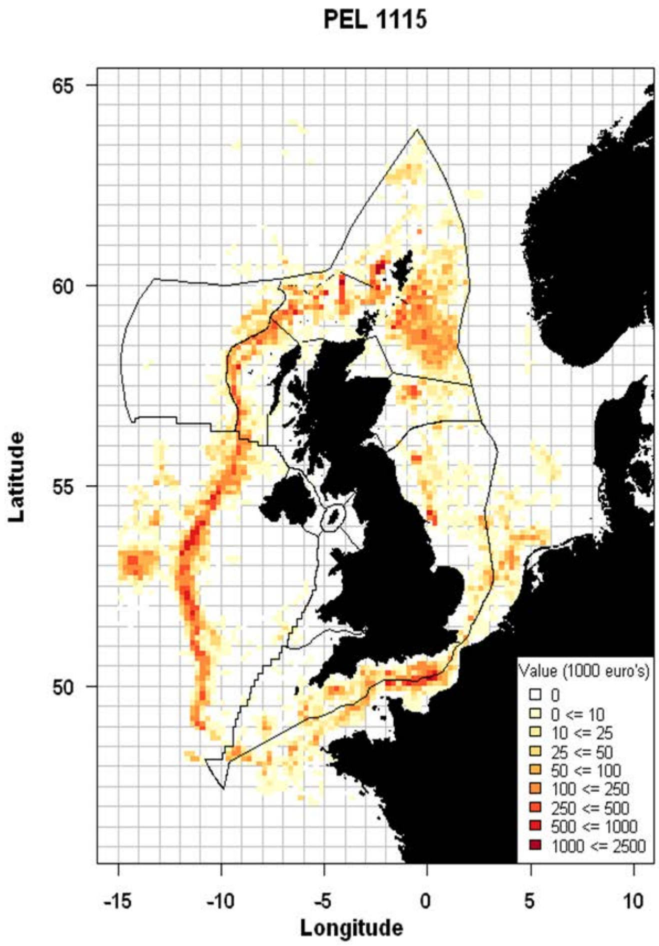


Figure 23 *Spatial distribution of the international pelagic fishery.*

The relevance of this pressure follows from various studies including a study by Vinther & Larsen (2004) based on extrapolations of bycatch in Danish bottom-set fisheries in the North Sea showed that over the period 1987-2001 on average 5591 harbour porpoises were caught in this fishery with some distinct seasonal patterns. This estimate, however, is probably an overestimation as these bycatch estimates above were made without considering the numbers of animals that could have been saved if they had deployed pingers which back then were not regularly used. Assuming 100% effectiveness, these would have amounted to approximately a 10-15% reduction of the estimate.

Due to the large numbers of animals taken as by-catch by a variety of fisheries, this is considered the most significant threat to harbour porpoise (OSPAR, 2009). Porpoises are taken incidentally in several different gear types (driftnets, pelagic trawls, etc.), but mostly in bottom-set gillnets. In the UK, by-catch was the cause of death in 24.8% of stranded porpoises (Pinn, 2008 in OSPAR, 2009), in the Netherlands it was over 50% (Leopold & Camphuysen, 2006 in OSPAR, 2009), and in Germany 46% (Siebert et al., 2001 in OSPAR, 2009). However for The Netherlands the mortality was reduced to approx. 20% according to Begeman et al. (2013).

A Bycatch Risk Assessment for harbour porpoise in the Kattegat and Belt Seas by ICES WGBYC (ICES, 2015c), suggests that for this small part of the North Sea it is very unlikely that more than 0.66% of the harbour porpoise population is being removed annually due to bycatch in commercial fisheries. To what extent this is representative for the entire North Sea is unclear, as is the contribution to the bycatch numbers by recreational fisheries, using set-nets.

Thus while this appears to be a relevant impact chain more work is needed to identify the best sources of information and process these into useful estimates of exposure and magnitude. This could, for example, involve methods to that allow the translation of measures of effort such as GrossTonnage*days into a more meaningful metric such as kmNet*days.

Data evaluation

Data evaluation for the pressure 'bycatch' is given in the tables 20 to 22 below. There are good data on the activity causing the bycatch, but bycatch data themselves have a medium spatial and temporal coverage; data are fragmented and do not cover the North Sea well. The metric itself is a proxy for bycatch, length of net per days per year, and relates well to the exposure, and to receptor sensitivity, since it is a direct effect on the individual organism. The impact on the population is not well known, therefore the sensitivity scoring is medium.

Table 20 *Exposure evaluation. Categories and criteria are described in* Table 3

Pressure	Selective extraction
Effect	Bycatch
Activity	Fishing but distinguishing between gillnets and pelagic
Extent of Human activity	A
Exposure assessment based on	B
Spatial scale (extent)	B
Spatial scale (resolution)	B
Temporal scale (time period)	A
Temporal scale (resolution)	B
Pressure distribution	A
Availability Overall	Quantitative partial
Confidence Score (range)	0.5-0.9
Confidence Score (average)	0.7

Table 21 *Magnitude evaluation. Categories and criteria are described in* Table 5

Pressure	Selective extraction
Effect	Bycatch
Activity	Fishing
Metric (chosen)	Gillnets: km net days per year Pelagic: days at sea or Gross Tonnage * days at sea
Exposure assessment based on	B
Metric suitability	A
Link to exposure	A
Link to sensitivity	A
Confidence Score (range)	0.8
Confidence Score (average)	0.8

Table 22 *Sensitivity evaluation. Categories and criteria are described in* Table 6

Pressure	Selective extraction
Effect	Bycatch
Metric (chosen)	Gillnets: km net days per year Pelagic: days at sea or Gross Tonnage * days at sea
Pressure-State Relationship (chosen)	Unknown
Exposure assessment based on	B
Pressure-State Relationship	B
Confidence Score (range)	0.6
Confidence Score (average)	0.6

4.3.7 Anthropogenic pressures: visual disturbance

Visual disturbance of marine mammals at sea is unlikely to be relevant. Noise of recreational boats and transport ships will cause disturbance before visual effect will. The pressure type underwater noise is described in section 4.3.3. Harbour seals and grey seals resting and feeding their pups at sand banks and coasts are sensitive towards disturbance by people and boats in case they approach within certain distance. These disturbance distances were investigated by a.o. Brasseur & Reijnders (1994) and others and depend on the type of boats. Seals flee into the water and may return after a certain period. Frequent disturbance at certain locations may lead to abandonment of these locations or effects on the conditions and survival of pups. Consequences of disturbance of individual seals on the population development are possible but cannot be assessed reliably.

However, ICES (2015a) concluded for the effects of visual disturbance on marine mammals that "there is no evidence of direct mortality but concern on the individual fitness and population consequences of observed displacement and change of behaviour" (Table 32). This may apply to some marine mammal species, but with a low threat for harbour porpoise and a medium threat for harbour seal in the Greater North Sea (Table 33).

Data availability

The evaluation scoring for the data on exposure, magnitude, and sensitivity for the pressure 'visual disturbance' is given in tables 23 to 25 below. The scoring on all parts of the assessment is mostly low; there is no digital spatial distribution map of the activities (i.e. tourism/reaction) causing visual disturbance of seals and porpoises at sea. There is no agreed metric, and the best available knowledge on the threat for harbour porpoise and harbour seal is expert opinion (ICES, 2015a). There are studies available on behaviour effects on individuals, however effects on mortality and/or reproduction are lacking.

Table 23 *Exposure evaluation. Categories and criteria are described in* Table 3

Pressure	Visual disturbance
Effect	Change in behaviour, displacement
Activity	Tourism/Recreation
Extent of Human activity	B
Exposure assessment based on	C
Spatial scale (extent)	C
Spatial scale (resolution)	C
Temporal scale (time period)	C
Temporal scale (resolution)	C
Pressure distribution	B
Availability Overall	Qualitative
Confidence Score (range)	0.3-0.6
Confidence Score (average)	0.4

Table 24 *Magnitude evaluation. Categories and criteria are described in* Table 5

Pressure	Visual disturbance
Effect	Change in behaviour, displacement
Activity	Tourism/Recreation
Metric (chosen)	Unknown
Exposure assessment based on	C
Metric suitability	C
Link to exposure	C
Link to sensitivity	C
Confidence Score (range)	0.2
Confidence Score (average)	0.2

Table 25 *Sensitivity evaluation. Categories and criteria are described in* Table 6

Pressure	Visual disturbance
Effect	Change in behaviour, displacement
Assessment based on	Expert judgment (Broad agreement)
Metric (chosen)	Unknown
Pressure-State Relationship (chosen)	Unknown
Pressure-State Relationship	Only a qualitative P-S relationship exists: i.e. entirely based on expert judgement
Confidence Score (range)	0.2
Confidence Score (average)	0.2

4.3.8 Anthropogenic pressures: death or injury by collision

A recent literature review (IAMMWG et al., 2015) found that mortality and serious injury of cetaceans resulting from ship strikes is mainly reported in slow-swimming (e.g. sleeping) large baleen whales. Literature does not contain many reports of ship strikes with smaller cetaceans such as harbour porpoise. It is mentioned that vessel strikes are perhaps not likely to occur frequently, due to the avoidance behaviour of porpoises. Some quantitative data on the potential effect of this pressure:

- Fast ferries travelling at speeds of 13-14 knots or more have proven to be particularly lethal, with most collisions leading to severe injury or death of cetaceans (IAMMWG et al., 2015).
- At 40 knots, approaching a cetacean at 600 m leads to a maximum reaction time of 30 seconds (IAMMWG et al., 2015).

ICES (2015a) concluded for the effects of death or injury by collision on marine mammals that “Direct mortality observed in a wide range of species, particularly baleen whales and large odontocetes such as sperm whale; population consequences difficult to determine” (Table 32). This was assessed as being a medium threat for harbour porpoise and a low threat for harbour seal in the Greater North Sea (Table 33).

Data evaluation

The evaluation scoring for the pressure ‘death or injury by collision’ is presented in the tables 26 to 28 below. The activities and their extent are well known, but data on collisions themselves are mostly based on expert judgement, especially for smaller marine mammals such as seals and porpoises. There is no proper metric chosen for collision, and the link to sensitivity is weak. The direct effect of collision on seals and porpoises is not well known. For larger species (such as whales) collision may result in death, but for smaller species the effect is not well known, and neither is the population impact.

Table 26 *Exposure evaluation. Categories and criteria are described in* Table 3

Pressure	Death or injury by collision
Effect	Death or injury
Activity	Military, Fishing, Shipping
Extent of Human activity	A
Exposure assessment based on	C
Spatial scale (extent)	C
Spatial scale (resolution)	C
Temporal scale (time period)	C
Temporal scale (resolution)	C
Pressure distribution	A
Availability Overall	Qualitative
Confidence Score (range)	0.3-0.9
Confidence Score (average)	0.5

Table 27 *Magnitude evaluation. Categories and criteria are described in* Table 5

Pressure	Death or injury by collision
Effect	Death or injury
Activity	Military, Fishing, Shipping
Metric (chosen)	Unknown
Exposure assessment based on	C
Metric suitability	C
Link to exposure	C
Link to sensitivity	C
Confidence Score (range)	0.2
Confidence Score (average)	0.2

Table 28 *Sensitivity evaluation. Categories and criteria are described in* Table 6

Pressure	Death or injury by collision
Effect	Death or injury
Metric (chosen)	Unknown
Pressure-State Relationship (chosen)	Unknown
Exposure assessment based on	C
Pressure-State Relationship	C
Confidence Score (range)	0.2
Confidence Score (average)	0.2

4.3.9 Anthropogenic pressures: biological selective extraction through food web

This is an indirect pressure caused by the selective removal of fish through fishing which may affect the marine mammals through the food web. The influence of the possible depletion of prey is less clear. Considering that many fish species consumed by harbour porpoise have commercial value and are overfished in OSPAR waters, this could have a negative influence, e.g. if animals have to switch to fish of lower nutrient value where the preferred type is not available (OSPAR, 2009).

ICES (2015a) concluded for the effects of removal of target and non-target species (prey depletion) on marine mammals that this is “probably a major determinant of spatio-temporal variation in species distributions. Population consequences more difficult to determine” (Table 32). This was assessed as being a medium threat for harbour porpoise and a low threat for harbour seal in the Greater North Sea (Table 33).

Tables 29 to 31 show the data evaluation scoring for the pressure ‘biological selective extraction’. The scores are comparable to those of the pressure ‘collision’: the activity causing the pressure is well known, but which fishery is exactly causing the effect is not well known, and thus neither its spatial and temporal extent and resolution. This is mainly due to a lack of current knowledge on prey species items and distribution, and how the specific fisheries affect these species’ stocks and distribution. How seals and porpoises respond to changes in abundance of prey species is not well known and neither is the population impact.

Table 29 *Exposure evaluation. Categories and criteria are described in* Table 3

Pressure	Selective extraction – food availability
Effect	Reduced food uptake through decrease food availability
Activity	Fishing
Extent of Human activity	A
Exposure assessment based on	C
Spatial scale (extent)	C
Spatial scale (resolution)	C
Temporal scale (time period)	C
Temporal scale (resolution)	C
Pressure distribution	B
Availability Overall	Qualitative
Confidence Score (range)	0.3-0.9
Confidence Score (average)	0.4

Table 30 *Magnitude evaluation. Categories and criteria are described in* Table 5

Pressure	Selective extraction – food availability
Effect	Reduced food uptake through decrease food availability
Activity	Fishing
Metric (chosen)	Unknown
Exposure assessment based on	C
Metric suitability	C
Link to exposure	C
Link to sensitivity	C
Confidence Score (range)	0.2
Confidence Score (average)	0.2

Table 31 *Sensitivity evaluation. Categories and criteria are described in* Table 6

Pressure	Selective extraction – food availability
Effect	Reduced food uptake through decrease food availability
Metric (chosen)	Unknown
Pressure-State Relationship (chosen)	Unknown
Exposure assessment based on	C
Pressure-State Relationship	C
Confidence Score (range)	0.2
Confidence Score (average)	0.2

4.3.10 Ecosystem component: sensitivity

The sensitivity of (the species that make up) the ecosystem component for each of the pressures identified in the MMLF is described here. Any method that provides a relationship between the magnitude of the pressure and a population-level effect or impact on the ecosystem component is a likely candidate.

Pressure-effect relationships
Pressure-effect relationships have been established for relevant pressures to a selection of North Sea species (Jak et al., 2000; Karman et al., 2009). These relationships have been used in the so-called CUMULEO-RAM methodology, see section 4.4.3.

A review of the effects of anthropogenic activities and their pressures in the North Sea (shipping, windfarms, fishery, disturbance, contaminants and climate change) on marine mammals was carried out by Geelhoed & Van Polanen Petel (2011) but insight is rapidly increasing since (Aarts et al., 2016; National Academies of Sciences, Engineering, and Medicine, 2016).

Recently the ICES Working Group on Marine Mammal Ecology (WGMME, ICES, 2016a) presented the threats/pressures that were thought to have most relevance to marine mammals (ICES, 2015a; ICES 2016a). These pressures have been extracted from the list of pressures agreed by the Intersessional Correspondence Group on Biodiversity Assessment and Monitoring (ICG-COBAM, 2012). The evaluation is based on the ASCOBANS threat matrix, and evaluations of ecosystem status conducted for regional seas and individual MS evaluations under the MSFD and Habitats Directive as well as expert knowledge.

Table 32 *Compilation of examples of the known effects of pressures on marine mammals. Source: ICES (2015a, 2016a). Only the relevant pressures for current project are shown.*

Pressure	**Comments on known effects on marine mammals**
Contaminants	Effects on reproduction caused by polychlorinated biphenyl (PCBs), immunosuppression leading to disease susceptibility; organ damage by heavy metals
Litter (including microplastics and discarded fish gear)	Some species, i.e. beaked whales, believed to be particularly at risk due to their mode of feeding that can make them especially vulnerable to the ingestion of marine debris
Underwater noise (sonar)	Strandings of beaked whales, possibly for other species, have been linked to the use of sonar in military exercises. Effects include hearing damage, multi-focal gas emboli, behavioural disruption
Underwater noise (seismic surveys)	There is no evidence of direct mortality but concern on the individual fitness and population consequences of observed displacement and change of behaviour
Underwater noise (pile-driving)	There is no evidence of direct mortality but concern on the individual fitness and population consequences of displacement and change of behaviour
Underwater noise (shipping)	There is no evidence of direct mortality but concern on the individual fitness and population consequences of displacement and

Pressure	Comments on known effects on marine mammals
	change of behaviour
Death or injury by collision (ships)	Direct mortality observed in a wide range of species, particularly baleen whales and large odontocetes such as sperm whale; population consequences difficult to determine (especially for seals and porpoises (pers. com. M.F. Leopold))
Removal of target and non-target species (prey depletion)	Probably a major determinant of spatio-temporal variation in species distributions. Population consequences more difficult to determine. (Pers. com. M.F. Leopold: Large range-shift seen in porpoises expected to be related to crash in North Sea sandeels). Evidence of poor nutritional status. (Pers. com. M.F. Leopold: 14% of the harbour porpoises on the Dutch coast have starvation as the cause of mortality (Begeman et al. 2013)).
Removal of non-target species (marine mammal bycatch)	Pers. com. M.F. Leopold: research revealed that the part of bycatch in the mortality of harbour porpoises is approx. 20% (Begeman et al. 2013)
Disturbance (e.g. wildlife watching)	There is no evidence of direct mortality but concern on the individual fitness and population consequences of observed displacement and change of behaviour. Pers. com. M.F. Leopold: No effect on harbour porpoise. Negative effect of watching seals, leading to departure of haul-out sites (e.g. Oudeschild).

Subsequently ICES (2015a) classified the threat levels as high, medium or low (i.e. following a traffic light system), for each species-region combination, using the following criteria:
High (red) = evidence or strong likelihood of negative population effects, mediated through effects on individual mortality, health and/or reproduction;
Medium (yellow) = evidence or strong likelihood of impact at individual level on survival, health or reproduction but effect at population level is not clear;
Low (green) = possible negative impact on individuals but evidence is weak and/or occurrences are infrequent.
"Other" (no colour) = little or no information on the impact of these pressures on marine mammals or the threat is absent or irrelevant.

ICES (2015a) identified the key pressures for marine mammals in the Greater North Sea. See the 2013 Article 17 Favourable Conservation Status reports that each Member State is required to produce under the Habitats Directive (http://bd.eionet.europa.eu/article17/reports2012/). The result is listed in Table 33.

Table 33 *Threat matrix for the Greater North Sea (ICES, 2015a). Only the relevant pressures for current project are shown.*

Pressure	Pressure (specif.)	Harbour porpoise	Harbour seal
Contaminants		H	M
Litter (including microplastics and discarded fish gear)		L	M
Underwater noise	Military activity	M	L
Underwater noise	Seismic surveys	M	L
Underwater noise	Pile-driving	M	M
Underwater noise	Shipping	M	L
Death or injury by collision (with ships)		M	L
Removal of target and non-target species (prey depletion)		M	L
Removal of non-target species (marine mammal bycatch)		H	M
Disturbance (e.g. wildlife watching)		L	M

According to ICES (2015a) a key anthropogenic pressure for harbour porpoise is bycatch in static nets. Underwater noise by e.g. pile driving, ordonnance explosions, geophysical surveys can lead to changes in distribution and direct mortality. There are concerns with respect to pollutants such as persistent

organic pollutants (POPs) (including PCBs) leading to immunosuppression and possibly reproductive failure in harbour porpoise.
Current key anthropogenic pressures on seals in the Greater North Sea region are pollutants, disturbance while on land, and interactions with vessels (ICES, 2015a).

For human activities that have a direct negative impact on cetaceans (e.g. fisheries bycatch and collisions by ships), the impact on populations is, at least in theory, possible to assess. However, a lack of data on, among other population abundance, makes even these direct impacts difficult to assess. For indirect impacts of e.g. underwater noise by shipping, seismic activities, oil, gas and renewable energy; prey depletion caused by overfishing; chemical pollution it is much more difficult to demonstrate cause and effect at a population level (ICES, 2016a).

4.4 Quantitative analysis

4.4.1 Choice for analytical tools and models

There are several tools and models available for (semi-)quantitative effect assessment of human activities. These are mostly developed for a single pressure and/or impact chain.
Main tools and models are described below.

4.4.2 Choice for analytical tools and models: PCoD and Interim PCoD

The US National Academy of Sciences (NRC) developed a “conceptual model” that outlined the way marine mammals respond to anthropogenic sound and how the population-level consequences of these responses could be inferred on the basis of observed changes in behaviour (NRC, 2005). This model is called population consequences of acoustic disturbance (PCAD).
The PCAD was extended with forms of disturbance other than noise and to address the impact of disturbance on physiology as well as on behaviour. That model was called PCoD: population consequences of disturbance and described by New et al. (2014). See Figure 24a with further explanations.

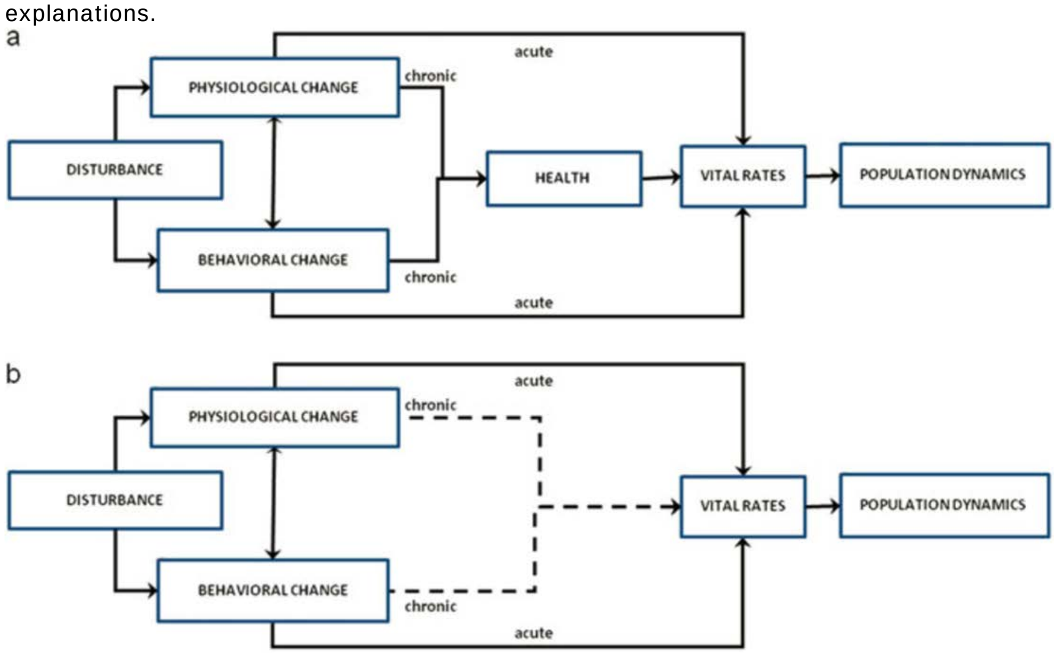


Figure 24 *(a) Framework for modeling the population consequences of disturbance (PCoD). The term “health” is used to describe all aspects of the internal state of an individual that might affect its fi ness. “Vital rates” refers to all the components of individual fitness (probability of survival and producing offspring, growth rate, and offspring survival).*
(b) A simplified version of the PCoD framework used in the interim PCoD approach. Dotted lines, functions that determine the chronic effects of physiological and behavioural change on vital rates, indicating that their form is determined using the results of an expert elicitation process rather than empirical evidence. From: Harwood et al. (2016).

The empirical information that is required to estimate the parameters of the full PCoD model is not available for most marine mammal species. Therefore Harwood et al. (2016) developed a simplified, interim version of the PCoD model (Figure 24b) in which the information required to quantify the potential effects of behavioural and physiological changes on vital rates, shown by the dotted lines in Figure 24b, was obtained using a formal expert elicitation process. The resulting relationships were then incorporated into stage-structured stochastic population models similar to those used in population viability analyses, which were developed for five marine mammal species (harbour seal, grey seal, harbour porpoise, bottlenose dolphin, and common minke whale).

The PCoD models attempt to capture many of the major sources of uncertainty involved in the calculations of the potential effects of offshore renewable energy development on marine mammal populations.

With PCoD differences between the size of the undisturbed and disturbed populations can be predicted at different time intervals after underwater noise exposure. This can be indicated as percentages of declines of a population.

This interim PCoD model is also applied in the Kader Ecologie en Cumulatie (KEC) for marine mammals in the Netherlands (Heinis et al., 2015). The number of animal disturbance days is seen as a good indicator for population-effects.

At the moment, Interim PCoD is the probably only operational model that provides a quantitative relation between disturbance and population consequences. Therefore it may be the only method to determine the cumulative effects of disturbance by various types of activities. The framework is described in detail by Harwood et al. (2013) en the software written in *R* (www.r-project.org) can be downloaded via the website of The Scottish Government (www.smru.co.uk/pcod and www.scotland.gov.uk/Topics/marine/science/MSInteractive/Themes/pcod).

4.4.3 Choice for analytical tools and models: CUMULEO-RAM

The relationship between the intensity of seven types of human based disturbances and their resulting effects on survival and reproduction of 30+ species were described as a function of increased mortality or reduced reproduction in the report of Jak et al. (2000). The numerical values of the parameters in these functions were, as far as possible, estimated on the basis of data from literature, dealing with the sensitivity of the considered species, or otherwise of related species or biota in general, for the regarded disturbance. The disturbance-effect relationships were applied in an integral ecological risk analysis for human activities at the North Sea: RAM (Risk Analysis instrument for the Marine environment). The aim of RAM was to rank the human activities on the basis of their environmental risk. The RAM – GIS model was developed in the nineties by the National Institute of Coastal and Marine Management / RIKZ (currently part of Deltares), in cooperation with TNO (currently part of IMARES), WL (currently part of Deltares) and Geodan (Karman et al., 2001). The model has also been applied in a case study of the Wadden Sea (de Vries et al., 2012).

The RAM methodology comprises the disturbance and effect chain from activity to species and can be described in five steps (Karman et al., 2001):

1. quantifying the potential exposure
2. combining each potential exposure with a specific disturbance-effect relationship
3. integrate the effects of all potential exposures
4. combine effects of mortality and reproduction to derive a single population measure
5. analyses of the results: the ranking of disturbances and human activities based on their ecological risk.

Exposure

The disturbances (i.e. pressures) identified within RAM are presented in Table 34. These generally correspond to the pressures as identified within the Marine Strategy Framework Directive (MSFD) (EC, 2008).

Table 34 *Pressures included in Jak et al. (2000)*

Pressure	Impact
Chemical pollution	Exposure through water phase
	Exposure through food
	Exposure to floating layers (i.e. oil)
Eutrophication	Exposure to reduced oxygen concentrations resulting from degradation of organic (algae) material
Mechanical disturbance	Exposure to (5) different types of fishing gear on the seabed
	Exposure to increased concentration of suspended matter in the water column
	Exposure to the deposition of a layer of sediment with a thickness > 20 cm
	Trampling by humans
Extraction of species	Extraction of target and non-target species by fishing
	Extraction of benthic species by dredging and aggregation
Change in substrate	Permanent change in hard substrate or gravel
Acoustic disturbance	Exposure to (continuous) noise
	Exposure to shock waves
Visual disturbance	Presence of humans; boats; airplanes; constructions; and flairs.

Only those impacts directly affecting two population dynamical parameters of the relevant species were considered in RAM: mortality and (re)production (Jak et al., 2000; Karman et al., 2001).

Disturbance-effect relationships

The relationship between the intensity of seven types of human based disturbances and their resulting effects on survival and reproduction of selected "AMOEBE-species" has been described with simple functions. The values of the parameters in these functions were, as far as possible, estimated on the basis of data from the literature, dealing with the sensitivity of the considered species, or otherwise extrapolated from data on related species or biota in general, for the regarded disturbance.

Furthermore, the “suitability” of information was given a score to reflect the uncertainty of parameter values. Factors contributing to the ‘suitability” were, e.g., the amount of information available, and the comparability of the published results with the parameters used to describe the dose-response relationships. The uncertainty scores were applied to calculate minimum and maximum values around the parameter value, and thus reflect the uncertainty range.

An exposure matrix has been developed indicating the relevant exposure types of disturbances to species. For the relevant exposures, disturbance-effect relationships have been established.

The disturbance-effect relationships describe the relation between the intensity of a potential exposure (e.g. the cadmium concentration in water) and the effect on the survival or reproduction on a species. The effect is expressed as a fraction between 0 and 1:

Fraction Effect = f (Exposure intensity)

Under the preconditions:

- if the exposure intensity = 0, than effect = none = 0
- if the exposure intensity = maximum, than effect = maximum = 1

Many types of functions can describe the above relationships, i.e. logistic curve, linear relation, etc. An appropriate function type per pressure/impact has been selected (Table 35). The function has been quantified based on several calibration points, which have been derived from literature information on the sensitivity of the species for that pressure/impact.

A few general parameters have been used as much as possible in the different functions:

m = median effect intensity, intensity of disturbance at which effect = 50%
d = threshold value, disturbance intensity at which effect will occur
c = intensity-effect coefficient, indicating the slope of the function

The variables are:

y = *the effect on survival and/or reproduction (fraction between 0 and 1)*
x = *the disturbance intensity of the potential exposure.*

Table 35 *The function type and related parameters as applied in the description of the pressure-effect relationships of the different pressures (Jak et al., 2000; Karman et al., 2001)*

Pressure	**Function type**	**Parameters**	**Unit**
Toxicants	Logistic function	m, c	µg.l^{-1} (water column); µg.kg^{-1} (susp. matter and sediment); m^{2} (oil layer on water surface)
Hypoxia (due to eutrophication)	Negative linear relation with threshold	c, d	Algae density (spring max and summer average in µg.l^{-1} chlorofyl-a); nutrient concentration in winter (orthophospate, total inorganic nitrogen and silicate in mmol.l^{-1}); Oxygen concentration; primary production in mg C.m^{-2} per year
Mechanical disturbance by trawling	Random probability function	c	Fraction of seafloor that is fished per season
Increased SPM and turbidity	Negative/positive linear relation with threshold	c, d	Duration and extent of more than 200 and 500 mg.l^{-1} suspended matter concentrations*
Smothering	Homogenic probability function	c	Seafloor surface that is covered by new material in m^{2}
Trampling	Random probability function	c	
Extraction of species by fishery	Negative linear relation without threshold	d	PK-hours per km^{2} for heavy beamtrawlers otter trawlers and pelagic trawlers
Extraction of species by dredging and aggregation	Homogenic probability function	c	Removal of benthic organisms by dredging and aggregation activities (in m^{2} dredged surface per season)
Noise	Not included		
Shock wave	Not included		
Removal of hard substrate	Homogenic probability function	c	hard substrate surface (in m^{2})
Removal of gravel	Homogenic probability function	c	gravel surface (in m^{2})

* Thresholds represent sensitivity thresholds to suspended matter concentrations

4.4.4 Choice for analytical tools and models: Individual based modelling / DEPONS

Individual- based models (IBMs) follow the fate of individuals through their life cycle, assigning to them specific features and behavioural rules, under the assumption that individual behaviour influences population dynamics. These models are sometimes referred to as "agent-based" models with the "individual/agent" being represented by either individual animals, or composite units such as fish schools or fishing fleets. The 'individual-based' approach is receiving increasing attention among ecologists. IBMs have typically been applied to investigate the dynamics of a single population within the marine environment (ICES, 2015). In IBMs, population dynamics can be predicted based on simulated animals that move in the landscape in a realistic manner (Grimm & Railsback 2005). For the harbour porpoise an IBM has already been developed for the inner Danish waters (Nabe-Nielsen et al. 2014), where local porpoise densities were used as a proxy for food availability. Animals were simulated to respond to disturbances by being displaced, resulting in reduced food intake and potentially reduced population sizes.

When individual animals are exposed to human disturbance, this may lead to changes in their behaviour. From a management point of view, the main question is whether such behavioural changes lead to decrease (or increase) in the individual fitness and whether this ultimately has consequences at a population level. Individual-based or Agent-based models (i.e. IBM or ABM) can be used to forecast population level consequences based on behavioural responses of individual animals as a consequence of human activities. The principal idea is to model the 'natural' behaviour of all individual animals (including movement, foraging, mating, etc.). In general, developing such individual-based models for marine mammals is extremely challenging as many detailed data are required but often lack.

The Department of Bioscience - Marine Mammal Research (DEPONS) can be considered as front runner in the field of individual based models (agent-based models) for harbour porpoise. The reports of DEPONS can be found on http://depons.au.dk/ .

Currently individual based modelling of Harbour seals in the Netherlands receives a lot of attention. An IBM for the harbour seal has still to be developed but it would be a suitable study species because a large set of individual tagging data is available, and furthermore, pup-production, population development, and distribution on land are accurately monitored using aerial surveys conducted in the Wadden Sea since 1970. After such a model is developed it can be used to better understand the dynamics of the seal population in general and form a base for the understanding of other seal populations, where data may be too scarce to monitor possible changes. Currently Wageningen Marine Research cooperated with other research institutes to elaborate several proposals for IBM for seals in different geographic regions. IBM model consist of a set of modules, including:

- Movement
- Behaviour
- Habitat model and Prey field
- Energy budget
- Prey depletion and intra-species competition
- Disturbance
- Calibration with population survey data

It can be concluded that IBM is in development and cannot be used for our purpose yet. IBM is certainly interesting for application as a module in our CEA in the future.

4.5 Execution of the iCEA

This is where the information provided above is combined into an iCEA. This includes determining the likelihood of exposure based on the combination of the spatial distribution of the ecosystem component with the occurrence of the pressures and the combination of the magnitude of the pressure and the sensitivity of the ecosystem component to that pressure to determine the severity of the effect. Following the risk-based approach the likelihood of exposure and the severity of the effect are then combined into a level of risk, i.e. impact risk sensu (Knights, 2015; Piet, 2015), for each of the impact chains presented in Figure 1. By aggregating impact risk across the impact chains we can then determine the cumulative effect of all these human activities and their pressures on the ecosystem component, i.e. marine mammals. For now we assume that these impacts are additive. However, if information exists showing that impacts of any combination of impact chains is different from additive, i.e. synergistic or antagonistic, it is possible to factor that into the CEA. The most appropriate method to do this is probably Bayesian Belief Network (BBN).

4.5.1 Description of Bayesian Belief Network

A Bayesian Belief Network is a probabilistic graphical model (a type of statistical model) that represents a set of random variables and their conditional dependencies via a directed acyclic graph (DAG). An example DAG is shown in Figure 25.

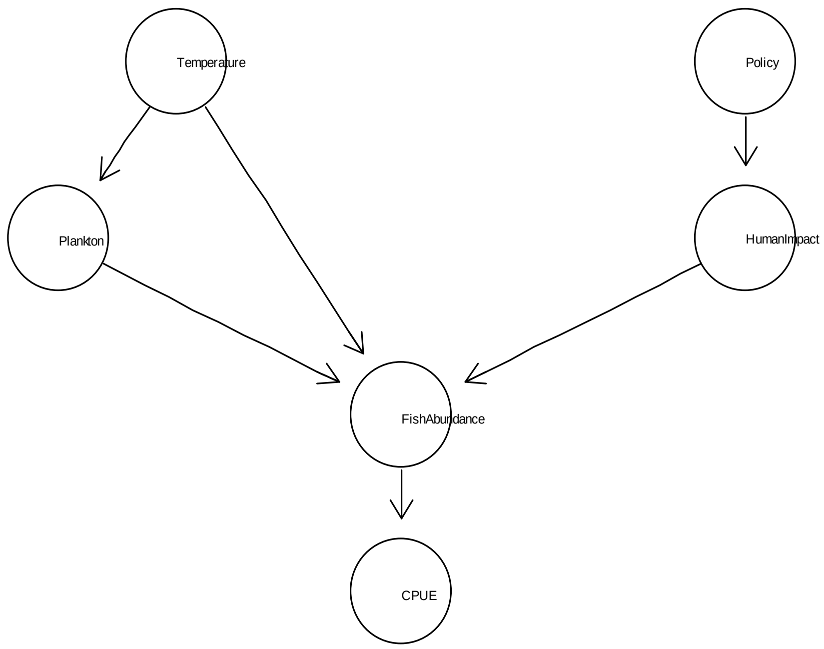


Figure 25 *An example DAG of a very simplified marine ecosystem effected by human impacts which are regulated by some form of policy.*

The DAG consists of a number of nodes (corresponding to the variables of interest) connected by arcs (arrows) which show where there is a direct (dependence) relationship between two variables (nodes). Nodes contain a number of possible outcomes (states). Indirect relationships are not explicitly represented in the graph but can be read as sequences of arcs leading from one variable to the other through one or more mediating variables.

Bayesian networks are DAGs whose nodes represent random variables in the Bayesian sense, i.e. they may be observable quantities (such as temperature or CPUE's), latent variables (such as human impact, which cannot be directly measured but inferred from other variables that are observed), unknown parameters or hypothesis. Each node is associated with a probability function that takes a particular set of values for the nodes parent variables as input and gives the probability of the variable represented by the node as output. For example, in the case shown in Figure 25, the probability of achieving a certain value of CPUE could be calculated given a particular temperature and a specific policy regulating human impact.

The model 'learns' (is configured from) conditional probability tables (CPTs) through the input of a priori data (= qualitative/quantitative knowledge available for each variable prior to model development). Predictive analysis are conducted by forward or backward propagation of probabilities through the network und various user-defined scenarios or conditions.

Forward propagation provides the probability of a state being reached given the probability of a parent node being observed. Backwards propagation can be applied to assess ecosystem process by a 'what

if' analysis through updating the network with different hypothetical sets of evidence to understand their effects on the states. Changes in the probabilities of a response variable can be used to identify key drivers and quantify the extent of ecosystem shift at spatial and temporal scales relevant to the dataset.
Scenarios can thus be tested such as "which policy gives the highest probability of a CPUE above a certain value and how may this change under different temperature scenarios?". The development of the conceptual diagram is an interactive process. Failure to capture causal links between processes and disturbances can lead to BBN predictions with high uncertainty

BBNs (as models in general) are useful if they help gain a better understanding of the world or system that is being modelled as well as enabling predictions to be made about how the system may behave under different scenarios. Scenarios can be "experimented with" in the model easier than in the real world.
A particular strength of the model is that, as opposed to a more mechanistic type model where relationships between variables are based on deterministic relationships which require detailed knowledge and qualitative data, BBNs are able to express the probabilistic relationships between variables based on qualitative or quantitative data and even expert opinion. In this way a range of information types can be included in the model. This flexibility has allowed BBNs to be applied to a wide range of issues, including environmental (Barton et al. 2008; Borsuk et al. 2004; Raphael et al. 2001) and natural resource management (Bromley et al. 2005), assessment of the impact of alternative management measures (Marcot et al. 2001; Nyberg et al. 2006) and marine spatial planning (Stelzenmüller et al. 2010b).

Useful features of BBNs can be summarised as follows:

- quantify uncertainties of model and data
- use qualitative and quantitative data from incomplete datasets, model simulations and expert opinion
- can be of high resolution to detect ecosystem changes through incorporation of all available sources of data in conditional probability tables (CPTs)
- provide predictive analysis of uncertain, complex and multi-state ecosystems
- can be easily created, updated, modified and extended
- provide a graphical representation of complex ecosystem interactions that can be useful in management and science integration

These features compliment national/international standards which may be presented as single threshold values despite the suite of regulatory drivers.
Note that both sensitivity analysis (assessing accuracy of relationships between nodes) and uncertainty analysis (assessing robustness of model output without referencing interactions between individual nodes) are important in validating BBNs before applying the decision framework to management decisions.

4.5.2 Current progress and applications of Bayesian Belief Network

ICES WGINOSE

Bayesian Belief Networks are currently being explored in the ICES working group on Integrated North Sea assessment (WGINOSE) as a potentially useful tool to support ecosystem advice. In 2015 a first concept of a BBN was drawn up for just the southern North Sea and with a focus on the benthic ecosystem components (Figure 26). The processes reflected in the model structure cover the influence of the winter bottom temperature on zooplankton and phytoplankton in the second quarter. The availability of phytoplankton triggers the density of crustaceans as a prey for cod (CPUE_Cod) and plaice (CPUE_Plaice). The otter (OT) and beam trawl (BT) effort reflect fishing mortality which in turn should influence the CPUE of cod and plaice. Also there should be a positive and strong relationship between OT and cod landings and BT and plaice landings, respectively according to ICES WGINOSE (ICES, 2015b).
Although a number of scenarios could be experimented with (influence of high bottom temperatures, high density of crustaceans, high intensity of fishing) a high level of parameterisation uncertainty was encountered. This was mainly related to the weak correlations between the variables depicted in the

model. A difficulty with the BBN is finding the most simple model that at the same time captures the most important links.

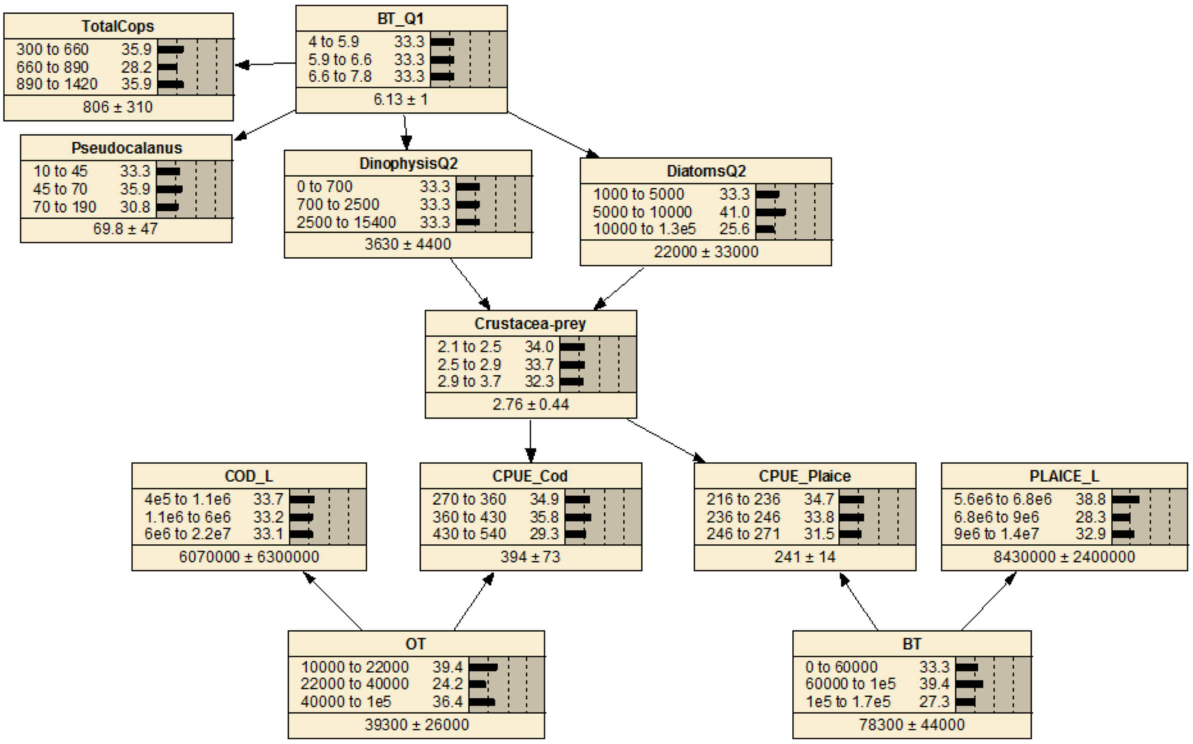


Figure 26 *Refined structure of the BN model of the southern North Sea (baseline). Node states have been discretized by the equal-frequency method.*

EU H2020 AQUACROSS

In the AQUACROSS project we aim to develop a BBN framework as a tool to support assessment of the risks to meeting Good Environmental Status (GES) on two different timeframes (by 2020 and timeless). GGES is a high-level objective of the Marine Strategy Framework Directive (MSFD). The BBN approach seemed most suitable due to the combination of empirical and qualitative data, as well as expert judgement that is required to describe the relationship between human activities, the impacts of their pressures, the responses of the ecological components and ability to achieve GES.

A first draft of a BBN, with the appropriate nodes and arcs is shown in Figure 27. The probability tables behind the relationships in the current model are based on work by Knight et al. (in prep) but are currently incomplete. The numbers presented here are therefore not meaningful, however the figure show how management measures may be tested by means of scenarios that simulate their implementation and therefore may provide the combination of measures most likely to support achievement of GES.

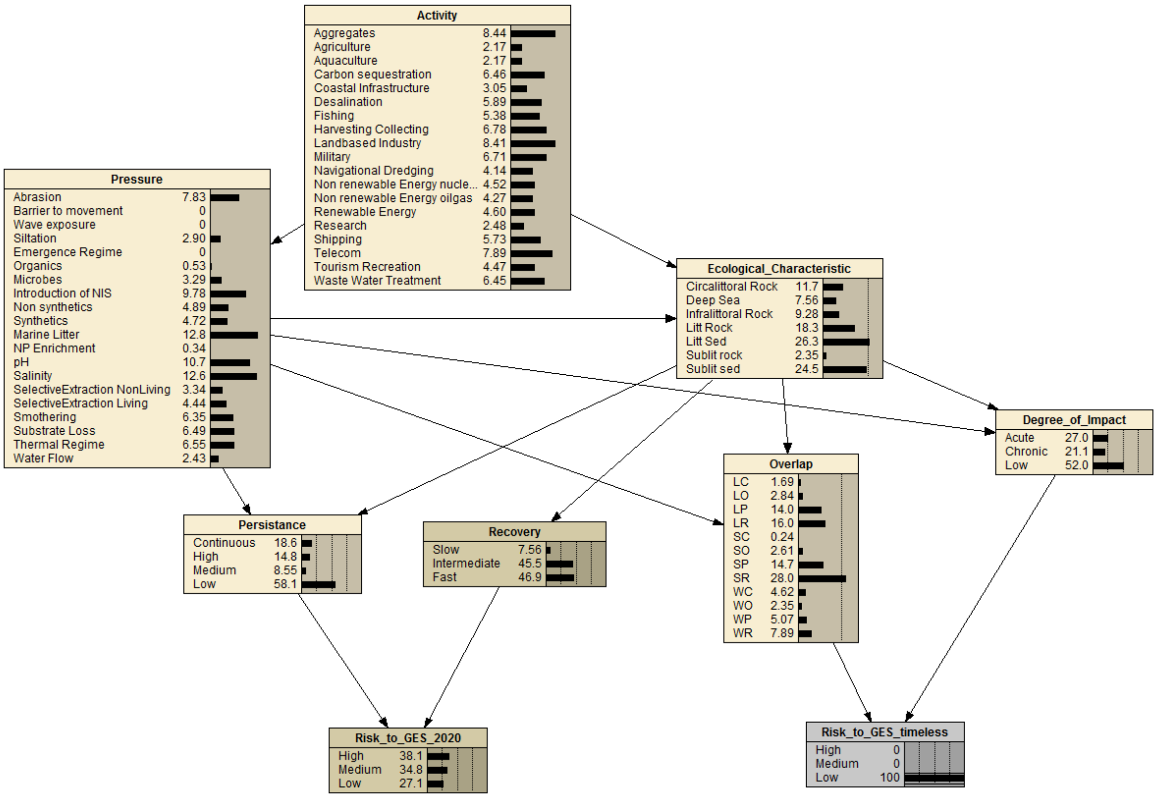


Figure 27 *Potential structure of a BN model to assess the likelihood of failing to achieve GES by 2020 and at any point in the future (timeless).*

5 Evaluation

The purpose of this evaluation is to assess the information availability and quality required to develop and conduct an iCEA and to be able to describe a priority (relevance) in impact risks and steps forward to improving the iCEA. This evaluation is entirely based on our chosen topic for our Proof of Concept (PoC), i.e. marine mammals in the North Sea. Furthermore, we will attempt to extrapolate the outcome of this exercise to a more general discussion on the feasibility of developing and conducting an iCEA which should ultimately include all ecosystem components and all the human activities and pressures potentially affecting them.
Our approach to develop an iCEA is deliberately a modular approach where the iCEA framework consists of different modules each providing part of the information required for the assessment. This modular approach thereby allows great flexibility in introducing new sources of information (e.g. data, maps, models but also methods to apply expert judgement) if they are considered to be better hence increasing the confidence in the outcome of the assessment. The modular iCEA framework is based on impact chains where each impact chain requires information on three aspects of risk: Exposure, Magnitude and Sensitivity. In principle we have a different module for each aspect of risk per impact chain but in reality often the same module can be applied for the same aspect of risk but several related impact chains (e.g. the application of PCoD to determine sensitivity to several pressures). Thus for the PoC evaluation process we described each modular cell corresponding to a specific source of information and/or information tool, from now on referred to as information modules, in terms of:

- Level of confidence depending on the availability and quality of the information (based on Table 36 and presented in Table 37).
- The potential for improvement based on our expectation to advance the available information towards higher confidence levels. This will be based on the criteria in Table 36.
- The importance of each information module in terms of its contribution to impact risk (Table 38).

5.1 Confidence scores

In Table 36 we present the criteria we applied to determine the level of confidence based on the availability and quality of the information available per information module (presented in Chapter 4). Our estimated level of confidence based on the source and type of information available is described in Table 38.

Table 36 *Confidence scores for the aspects of risk, i.e. Exposure (consisting of ecosystem component and pressure), Magnitude (of the pressure) and Sensitivity (of the ecosystem component), that determine the information modules. The scores are based on specific criteria characterising the information availability. The fully quantitative information should be based on peer-reviewed or grey literature. A range of confidence scores is indicated where the final confidence score is determined by the different combinations of the column where the confidence per column should decrease toward the bottom of the table. The final confidence score can also be based on the need for assumptions where the highest score applies if there is no need for assumptions, i.e. 1 in case of fully quantitative information, the medium score applies if based on well-founded/realistic assumptions, i.e. 0.9 in case of fully quantitative information and the lowest applies if the assumptions are unfounded , i.e. 0.8 in case of fully quantitative information.*

Exposure: Ecosystem component				
Information	Extent of relevant aspect(s)	Scale Spatial	 Temporal	Confidence Score
Quantitative Full	Digital maps (GIS or otherwise) of all relevant species, or subsets or aspects of the community. Better if the most sensitive are covered.	Extent covers the entire area. Resolution is appropriate (≈ highest resolution of the relevant pressures)	Information on the spatial distribution of the pressure covers a sufficiently long time period (≈ recovery time) Resolution distinguishes all relevant temporal (seasonal) variation.	0.8-1
Quantitative partial	Only printed maps.	Extent is sufficient to be representative for the area (Covering >x%)	Only a single timeslot is known. More recent is better. No seasonality.	0.4-0.8
	Estimate of extent of the area covered is known but unclear where this is located	Only a small part of the area (<x%) is covered		
Qualitative	Expert judgment (Broad agreement)			0.3
	Expert judgment (Little agreement)			0.2
	Personal communication			0.1
No Information available				0

Exposure: Pressure					
Information	Extent of Human activity	Scale: Spatial	Scale: Temporal	Activity to Pressure	Confidence Score
Quantitative Full	Digital maps (GIS or otherwise).	Extent covers the entire area. Resolution is appropriate considering the nature of the pressure	Information on the spatial distribution of the pressure covers a sufficiently long time period (≈ persistence) Resolution distinguishes all relevant temporal (seasonal) variation.	Process that determines the spatial expansion of (each of) the pressure(s) from the activity is known and quantified.	0.8-1
Quantitative partial	Only printed maps.	Extent is sufficient to be representative for the area (Covering >x%)	Only a single timeslot is known. More recent is better. No seasonality.	No information is known on the spatial expansion of (each of) the pressure(s) and the information on human activity is used as a proxy	0.4-0.8
	Estimate of extent of the area covered is known but unclear where this is located	Only a small part of the area (<x%) is covered			
Qualitative	Expert judgment (Broad agreement)				0.3
	Expert judgment (Little agreement)				0.2
	Personal communication				0.1
No Information available					0

Magnitude				
Information	Metric	Link to exposure	Link to sensitivity	Confidence Score
Quantitative Full	Best represents the nature of the pressure	Is identical to the unit of the exposure metric	This metric is identical to that used to describe sensitivity	0.8-1
Quantitative partial	Is at best a poor proxy	The relationship between the extent of exposure and magnitude is known and quantified	The relationship between sensitivity and the magnitude metric is known and quantified	0.4-0.8
		Unclear how magnitude relates to the exposure	Unclear how the magnitude metric relates to sensitivity	
Qualitative	No known metric			0.1-0.3
No Information available				0

Sensitivity		
Information	Pressure-State Relationship	Confidence Score
Quantitative Full	A quantitative Pressure-State relationship exists: i.e. between magnitude and (depending on the ecosystem component) a population-level or community-level impact	0.8-1
Quantitative partial	The P-S relationship is semi-quantitative: e.g. partially based on expert judgement. A formalized approach that translates expert judgement into a (semi-)quantitative score exists.	0.4-0.8
Qualitative	Only a qualitative P-S relationship exists: i.e. entirely based on expert judgement. No formalized approach to interpret the qualitative information exists.	0.1-0.3
No Information available		0

5.2 Information status per module

The status of each information module in terms of the availability and quality of the data is reflected in Table 37. This shows that the main information gap involves the sensitivity for several of the pressures, i.e. Introduction of contaminants affecting the marine mammals directly from environment, Marine litter, Selective extraction through food availability, Death or injury by collision and Visual disturbance, as this is where we observe on average low confidence scores. This also applies to the Magnitude of most of these pressures but not contaminants whereas Exposure only has low minimum confidence scores and appears thus less critical.

Table 37. *Evaluation of the information availability indicated by the colour of the cell, i.e. Quantitative Full (Dark Green), Quantitative Partial (Light Green), Qualitative (Orange) or No (Red) and, if possible, the level of confidence per information module. This is based on the information provided in chapter 4 and the criteria in Table 36. We distinguish the Ecosystem components/receptors (upper) and pressures (lower).*

Ecosystem Component	Species	Exposure
Marine mammals	Harbour porpoise	
	Common seal	

Pressure	Effect	Exposure	Magnitude	Sensitivity
Noise	Injury			
	Disturbance (change in behaviour, displacement)			
Introduction of contaminants	Increase of internal concentration (directly from environment)			
	Increase of internal concentration (indirectly through food)			
Marine litter	Entanglement			
	Ingestion			
Selective extraction	Bycatch			
	Reduced food uptake through decrease food availability			
Death or injury by collision	Death or injury			
Visual disturbance	Change in behaviour, displacement			

5.3 Scope for improvement per information module

The scope for improvement is given in *Table 38* showing considerable potential for the extent of the ecosystem components (which determines exposure) and for the pressures notably contaminants, Death or injury by collision and Bycatch where each risk aspect can be easily improved.

***Table 38**. Scope for improvement based on the current level of confidence per information module (see Table 37) and an expert opinion on what improvement(s) are feasible. Colours indicate level of effort and/or feasibility, distinguishing the following: achievable with relatively low effort (Dark Green), achievable with relatively high effort (Light Green), achievability uncertain (Orange)*

Ecosystem Component	Species	Exposure
Marine mammals	Harbour porpoise	Data sources are known for other countries. Spatial scale (extent) could be improved by obtaining those data
	Harbour seal	Data sources are known for other countries. Spatial scale (extent) could be improved by obtaining those data

Pressure	Effect	Exposure	Magnitude	Sensitivity
Noise	Injury	Spatial scale, Pressure distribution	Metric is still under discussion. ISO standard is under development	Further improvement is complicated
	Disturbance (change in behaviour, displacement)	Spatial scale, Pressure distribution	Metric is still under discussion. ISO standard is under development	Further improvement is complicated, although inclusion of threshold values instead of expert judgement could improve the assessment
Introduction of contaminants	Increase of internal concentration (directly from environment)	Extent of human activity and pressure distribution	Link between metric (conc. in water) and pressure (introduction of contaminants). Simple approach possible based on assumptions for discharge, dilution and distribution. More realistic modelling of environmental fate is considered not appropriate. Link to sensitivity (uptake from water) is unclear	Literature search can reveal whether a relationship between exposure via water column and effects exists
	Increase of internal concentration (indirectly through food)	Extent of human activity	Link between metric (conc. in fish) and pressure (introduction of contaminants). Simple approach possible based on assumptions for discharge, dilution and distribution. More realistic modelling of environmental fate is considered not appropriate	Parameter values are unsure and not complete for all substances. This should be improved (literature search/desk study)

Pressure	Effect	Exposure	Magnitude	Sensitivity
Marine litter	Entanglement	Pressure distribution, monitoring program	Agree on metric, based on simple assumptions. For a further outlook focus could be on the probability of entanglement based on different types/sizes of material	Approach that links the known data on mortalities of individuals to the pressure and translates it into population impacts
	Ingestion	Extent of human activity, monitoring program	Exposure and sensitivity relations	Approach that links the known data on mortalities of individuals to the pressure and translates it into population impacts
Selective extraction	Bycatch	Extent of human activity	Translate information into more appropriate metric	Approach that links the known data on mortalities of individuals to the pressure and translates it into population impacts
	Reduced food uptake through decrease food availability	Exposure assessment based on pressure, derived from activity (instead of expert judgement). Difficult to achieve because of food web effects	Complex processes are involved	Further improvement is complicated
Death or injury by collision	Death or injury	Exposure assessment based on pressure, derived from activity (instead of expert judgement)	Agree on metric, based on simple assumptions	Approach that links the known data on mortalities of individuals to the pressure and translates it into population impacts
Visual disturbance	Change in behaviour, displacement	Exposure assessment based on pressure, derived from activity (instead of expert judgement) & extent of human activity	Agree on metric, based on simple assumptions	Currently, best available knowledge is expert opinion (ICES, 2015). If the data on the activity is improved, and an appropriate metric is chosen, a (semi-)quantitative assessment is possible. This is based on threshold values (individuals), incl. population impact. However, current parameter values are unsure and should be improved (literature search/desk study)

5.4 CEA relevance per information module

The relevance of the different information modules as part of an iCEA is determined by their contribution to the impact risk. Those impact chain(s) that contribute more to risk are considered more important candidates to be assessed accurately than those that hardly contribute to risk. This order of relevance is also applicable to resolve priorities in management options. Similarly, this applies to the aspects of risk, i.e. exposure, magnitude and/or sensitivity, that mostly determines this impact risk; these should be the focus for further improvement. Given the time constraints for this report it was not possible to conduct the iCEA with the information provided in chapter 4. Therefore we used the ODEMM risk assessment database where we selected the marine mammals in the North East Atlantic and identified the risk scores (Table 39).

Table 39. *Importance of pressure information modules in terms of their contribution to impact risk. Indicated is the average risk score in bold and the range (minimum-maximum) if not equal to the average risk score. For impact risk both the average (bold) and summed risk (bold italics) is shown. Based on the ODEMM risk assessment database specifically for the North East Atlantic.*

EcoComp / Pressure	Detail	Exposure	Sensitivity	Impact Risk
Marine mammals	Harbour porpoise			
	Common seal			
Noise	Noise injury Noise disturbance	**0.20** (0.003-1)	**0.05** (0.01-0.125)	**0.01** ***0.04***
Introduction of contaminants	Direct Indirect	**0.10** (0.003-0.333)	**0.125**	**0.01** ***0.19***
Marine litter	Entanglement Ingestion	**0.10** (0.003-0.667)	**0.125**	**0.02** ***0.15***
Selective extraction	Direct (Bycatch)	**0.04** (0.003-0.1)	**1**	**0.04** ***0.11***
	Indirect through food availability			
Death or injury by collision	Death or injury by collision	**0.07** (0.003-0.1)	**1**	**0.07** ***0.52***
Visual disturbance	Direct			
	Indirect			

Based on this *Death or injury by collision* emerges as the most important pressure because of the high sensitivity to the pressure. Followed by the about equally important *Introduction of contaminants, Marine litter and Selective extraction*. For the first two because of the relatively high exposure, for the last two because of the high sensitivity. *Noise* comes up as the least important pressure.

When using these ODEMM results to determine the relevance of the different information modules as part of an iCEA there are several issues to consider.

- The “Exposure” scores apply for the situation in the North East Atlantic (NEA) based on the information available to the experts at the time of the ODEMM risk assessment, i.e. 2014. This probably hinders the applicability of these results for a North Sea assessment aimed at including some emerging pressures such as Noise from the construction of windfarms. Exposure of marine mammals to several of these pressures is likely to be very different in the North Sea from those in the NEA.
- The “Sensitivity” scores do not include the risk aspect “Magnitude”. Instead ODEMM assessed a different aspect of risk, i.e. the very crude “Degree of Impact” (DoI), which represents the impact on an individual and as such can be best compared to our “Sensitivity” but then representing a worst case scenario, effectively in case of the highest possible pressure magnitude. Thus the DoI-based Sensitivity scores in Table 39 are severely hampered by the lack of any consideration of

pressure magnitude. This underlines the necessity to include this into any future CEA developments.
- The "Impact Risk" is based on an average and a summed score resulting in different prioritisations of the impact chains. As Piet et al. (2015, in press) point out average scores are more relevant when identifying the main impact chains contributing to the risk that a specific ecosystem component (here marine mammals) is impacted whereas the summed scores are more relevant for an evaluation of the performance of possible management options. As described in the purpose (chapter 2.2) any future CEA should be fit for both these applications.

Therefore the main guidance coming from this exercise is that independent of the impact chain to consider the methodology to calculate Impact Risk needs to be improved and that Magnitude is probably a key aspect of risk as in the CEA framework being developed it ties together the risk aspect of Exposure with that of Sensitivity into an improved estimate of Impact Risk.

5.5 Guidance for further development of iCEA

Here we show how the information we collected and the approach we developed can be used to propose the information modules we consider the best candidates for (further) development. The guidance is based on the current level of confidence, the potential for improvement and the importance of a specific information module in terms of its contribution to Impact Risk.

In addition to this we recommend the (further) development of the Bayesian Belief Network (BBN) which is the best (or as it appears only) candidate to combine all the different sources of information while taking account of the different levels of confidence that apply to that information when conducting the iCEA in order to guide decision-making. This BBN can take various forms and levels of detail. As a tool (probabilistic graphical model) it can encompass various forms of error in a casual network, and results in an assessment of the likelihoods of outcome in terms of the risk each impact chain contributes to the overall cumulative effects on any specific ecosystem component (=receptor). It assesses thereby the most probable pressure(s) causing specific impacts, but, reversely, it can also assess which change in pressure is needed for having a desired effect level. It does not test for significance, but calculates the most likely effect of a specific set of causes. It is advised to start developing such a BBN for the PoC we carried out here for the marine mammals. This BBN does not need any high level of detail; which is the advantage of any BBN: it can grow together with the increasing information and knowledge level during each iteration of the assessment being carried out. Such a BBN will ultimately also be required to assess the effectivity and efficiency of management scenarios for improving the state of any receptor in the marine environment.

5.5.1 Best candidates for further development

To identify the best candidates for (further) development we combined the information in tables 37, 38 and 39 such that we selected those information modules with
- relatively high (or unknown) impact risk (Table 39),
- low scores on information availability (Table 37), i.e. Qualitative (Orange) or No (Red),
- high scores in terms of their scope for improvement (Table 38), i.e. achievable with relatively low effort (Dark Green), achievable with relatively high effort (Light Green).

This resulted in Table 40 identifying several potential candidates. One specific issue we want to highlight covers several information modules involving the risk aspect "Sensitivity". All the information modules have in common that they try to capture how an individual organism experiences an effect, e.g. from disturbance, to behavioural change, to physiological effects, thereby decreasing its chances on survival and reproduction, which in turn results in a population effect. Translating information on individual effects to a population effect is probably the main scientific challenge. Depending on the specific impact chain and the available data and knowledge, different types of models need to be developed, and may range from expert judgement assessments (which can be developed into proper statistical assessment approaches) to actual numerical modelling of environmental fate of contaminants, or dynamical energy budget modelling for food deprivation and behavioural change. This one issue covering several of the information modules should therefore have the highest priority.

Table 40. *Table indicating the information modules we propose for further development based on the contents in Tables 37-39 and the type of work required. First priority or short term (Dark Green), Second priority or medium term (Light Green), Uncertain or long term (Orange)*

Ecosystem Component	Species	Exposure
Marine mammals	Harbour porpoise	Data sources exist for other countries. North Sea wide coverage can be achieved by obtaining those data
	Harbour seal	

Pressure	Effect	Exposure	Magnitude	Sensitivity
Noise	Injury	Determine spatial extent of pressure based on distribution human activities		
	Disturbance			
Introduction of contaminants	Increase of internal concentration (directly from environment)	Determine spatial extent of pressure based on distribution human activities	Calculate appropriate metric (conc. in environment and conc. in fish)	Literature search can reveal whether a relationship between exposure via water column and effects exists
	Increase of internal concentration (indirectly through food)			
Marine litter	Entanglement		Determine appropriate metric	
	Ingestion			
Selective extraction	Bycatch	Extent of human activity	Calculate appropriate metric	Approach that links the known data on mortalities of individuals to the pressure and translates it into population impacts
	Reduced food uptake through decrease food availability			
Death or injury by collision	Death or injury	Determine spatial extent of pressure based on distribution human activities	Determine appropriate metric	Approach that links the known data on mortalities of individuals to the pressure and translates it into population impacts
Visual disturbance	Change in behaviour, displacement	Determine spatial extent of pressure based on distribution human activities	Determine appropriate metric	Desk study to determine if it is possible to go beyond expert judgement

Noise

Noise causing injury was assessed as a low impact risk. This is especially due to the low level of exposure, since at that time of assessment only small areas are affected by the noise level associated with this type of effect. For this pressure, sensitivity is more important for the impact risk than exposure and magnitude. Due to the scoring on pressures exposure, and magnitude (Table 37), more appropriate data are needed on spatial and temporal resolution and extent, and on the modelling effort for level of exposure and sensitivity (but these already relatively good). Scope for improvement is low to medium, but probably well achievable for level of exposure (improved acoustic modelling), and to some extent also for sensitivity of the individual organism (deriving improved TTS and PTS threshold limits for the species). The sensitivity scored medium on confidence of the pressure-state relationship for individual effects, but population effects are (as with all other pressures) not easily assessed.

Noise causing disturbance was not assessed. Larger areas are affected by the noise level associated to this type of effect, but the impact of this noise level obviously is less than for the injury noise level. Due to the scoring on pressures exposure, and magnitude (Table 37), more and relevant data are needed on spatial scale and resolution, and on temporal scale and resolution. Like with the noise injury level, additional efforts can be carried out for the modelling effort for level of exposure and sensitivity (but these already relatively good). Scope for improvement is low to medium, but probably well achievable for level of exposure (improved acoustic modelling), and to some extent also for sensitivity of the individual organism (deriving improved disturbance threshold limits for the species). The sensitivity scored medium on confidence of the pressure-state relationship for individual effects, but population effects are (as with all other pressures) not easily assessed.

<u>Contaminants</u>

Direct ingestion and uptake of contaminants is ranked as a low to medium impact risk. For this impact, exposure and magnitude are more important for the impact risk. Due to the scoring (Table 37), more appropriate (GIS) data are needed, with a low scope for improvement overall, but highly achievable for this issue. Metric suitability is low at best, since there is no well-established relationship between concentration and ingestion, nor is there a well-established relationship of the magnitude metric with sensitivity to determine a population effect. Scope for improvement is low to medium, but can be achieved fairly easily by assuming a specific relationship between the two. Calculation of an appropriate magnitude metric is key both for the environment as well as its primary food source, i.e. fish. The sensitivity scored low on confidence of the pressure-state relationship for individual effects, and population effects are (as with all other pressures) not easily assessed.

<u>Marine litter</u>

Entanglement by litter has been assessed as a low to medium impact risk. For this impact, exposure and magnitude are more important for the impact risk than in the above pressures (where sensitivity was more important). The confidence scores (Table 37) show more appropriate data are needed on spatial extent, and spatial resolution of the larger marine litter items, and there is no metric linked to exposure or sensitivity specifically for risk on entanglement. Scope for improvement is high for all issues, achievability is medium for spatial extent and resolution (high effort needed), and good for development of metrics, the latter at least as a simple set of assumptions. Confidence in the sensitivity of the population for entanglement is low, since it is not well known how individuals suffer from entanglement. As with the above-mentioned pressures, knowledge on population effects is low.

<u>Death or injury by collision</u>

From the importance table (Table 39), this pressure is considered (one of) the main impacts on marine mammals. Harbour porpoise is likely to be a more important victim than harbour seal, due to the larger exposure of the species to shipping North Sea wide. Sensitivity of marine mammals to this pressure is a key contributor to the impact risk, since collision often results in death.

Due to the relatively high ranking of the impact, and the confidence scores (Table 37), more appropriate data are needed on spatial and temporal resolution of shipping, and related collision risks. The need for improvement is high, and the scope for improvement is medium, so achievable, but with a relatively high effort. Especially additional data on shipping intensity with a higher spatio-temporal resolution is needed. This could possibly be based on AIS data from shipping. Next, a species-specific collision risk needs to be established. Ship size, but especially speed can be a determining factor here, in combination with size and agility of the species. Confidence on the sensitivity of the species is high for impulsive noise, but not for continuous noise. Knowledge on population effect is low for both porpoise and seal.

Visual disturbance

Visual disturbance has an unknown, but probably low risk of impact on seals and porpoises. Due to the scoring (Table 37), there is a need for better data on the activities causing the visual disturbance, an agreement on a metric, and some basic understanding of effect on the individual level.

6 Conclusion

For further development of this iCEA towards its intended applications we can distinguish between the first purpose, i.e. identification of the main impact chains contributing to the risk that a specific ecosystem component is impacted, which can be achieved with the approach presented here focussing on one specific ecosystem component and the second purpose, i.e. an evaluation of the performance of possible management strategies, which would require all ecosystem components to be included as would be required for ecosystem-based management.

Thus to further the development and application of this iCEA towards its (two) purpose(s) the recommendation is to:

1. Include the available information presented in this report into the iCEA and develop the Bayesian Belief Network such that it can process this information and its associated confidence into an assessment that identifies the main impact chains for the marine mammals. At present the most likely candidate to be applied for an iCEA is the ODEMM risk assessment framework which is entirely based on expert judgement. The work presented here shows that it should be possible to improve this framework using existing (often quantitative) information.
2. Extend the framework and approach to (all) the other ecosystem components so that a truly integrated CEA is possible. In addition to the marine mammals we focussed on in this exercise a similar approach could be applied for fish, seabirds, seafloor habitats and their associated benthic invertebrate communities, water column habitat and their associated invertebrate communities. Note that this is likely to affect the identification of what should be considered the main pressures to guide management.
3. Improve the information modules that emerged from the evaluation as the most promising to increase the confidence in the outcome of the iCEA. These are what should be considered the "low-hanging fruits" resulting in a relatively large increase in the quality of the iCEA at relatively little expense. Note that the previous two steps may result in a different prioritisation of the information modules as the importance of pressures and hence impact chains changes.

These three steps could be conducted in parallel where information from step 1 now only focussing on marine mammals can be applied to guide step 2 now exploring another ecosystem component. Step 2 then focussing on this other ecosystem component will point towards other "low-hanging fruits" for that ecosystem component which can then be elaborated in step 3 for that ecosystem component and so on until all ecosystem components have been included and we can go through the iteration cycles, now for the full iCEA, in a process of continuous improvement.

As part of this PoC we have elaborated step 3 showing how the existing information and the approach we developed can result in a proposal for the information modules considered the best candidates for (further) development. This proposal is based on the current level of confidence, the potential for improvement and the importance of a specific information module in terms of its contribution to Impact Risk.

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Justification

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The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Dr. M.F. Leopold
Researcher

Signature:

Date: 31 January 2017

Approved: Dr. T. van Kooten
Researcher

Signature:

Date: 31 January 2017

Approved: Drs. J. Asjes
Manager Integration

Signature:

Date: 31 January 2017

Annex 1 OSPAR Indicators

Table A1.1: *OSPAR indicators, Relevant*

Indicator	Explanation / title	State of play included including likely contribution to IA2017
D1 Mammals 3	Seal abundance and distribution	Assessment for Region II. Assessment values to be proposed.
D1 Mammals 4	Cetacean abundance and distribution	Recommended for **promotion** in regions III and IV. PT can only provide partial information. Assessment dependent on SCANS III. UK is providing funding for a SCANS III "light" option that we hope will deliver for the IA2017. Partial assessment to be provided for regions II, III and IV. Assessment values to be proposed.
D1 Mammals 5	Grey seal pup production	Recommended for **promotion** in region III (used by UK and Ireland but not France). PT seals not present. SE does not monitor pup production in Kattegat and Skagerrak. Partial assessment to be provided for regions II and III. Assessment values to be proposed.
D1 Mammals 6	Marine mammal bycatch	Recommended for **demotion** to candidate indicator. Continue to develop as a candidate indicator but over longer timeframe. Awaiting developments within the EU. Will not contribute to IA2017.
D1 Birds 1	Marine bird abundance	Recommended for **promotion** to Region IV. PT and North Sea: no information on distribution at sea outside of breeding season. Will contribute to IA2017 in Regions II, III and IV. Indicator to be further investigated for application in Region I, with a partial assessment for this region. Assessment values to be proposed.
D1 Birds 3	Breeding status of marine birds	Recommended for **promotion** to regions III and IV. Assessment to be delivered for selected species. SE/DK: potential problem with data format. Will contribute to IA2017 in Regions II, III and IV. Indicator to be further investigated for application in Region I, with a partial assessment for this region. Assessment values to be proposed.
D1 Fish Ceph 1	Fish abundance	FR has reservation on methodology. Will contribute to IA2017 for region II and a partial assessment for region III. Assessment values to be proposed.
D1 Fish Ceph 2	OSPAR EcoQO proportion of large fish (LFI)	FR has reservation on methodology. Will contribute to IA2017 for region II and a partial assessment for region III. Assessment values to be proposed.
D1 Fish Ceph 3	Mean maximum length of demersal fish and elasmobranchs	PT may not be able to contribute on time. Will contribute to IA2017 for Region II, III and IV. Assessment values to be proposed.
D1/6 BentHab2	Condition of benthic habitat defining communities. (Multi-metric indices)	PT difficulty with historic data. Limited contribution. Partial assessment expected for regions II, III and IV. Unlikely to propose assessment values.
D1/6 BentHab3	Physical damage of predominant and special habitats	Recommended for promotion in regions II, III, and IV with partial assessment in regions II, III and IV. Region II – no contribution from NL or DK; SE may not have sufficient data.

Indicator	Explanation / title	State of play included including likely contribution to IA2017
		Region IV – PT not able to contribute. Proposed to investigate whether possible to extend to regions I and V. Unlikely to propose assessment values.
D1 PelHab 1	Changes of plankton functional types (life form) index Ratio	Recommended for **promotion** in Region II. Includes FW5 and will cover trophic elements. Will mainly use CPR data. Not accepted by DE. NL will not provide additional data; BE currently no monitoring programme. SE may have problems with data format. Will provide contribution to IA2017 for Regions II, III, IV. Unlikely to propose assessment values.
D1 PelHab 2	Plankton biomass and/or abundance	Recommended for **promotion** in regions III and IV. NL will not provide additional data; IE may not be able to contribute data; PT partial information only. Will contribute to IA2017 for Region II and III, with partial assessment for Region IV. Unlikely to propose assessment values.
D2 NIS	Rate of new introductions of NIS	Recommended for promotion in regions II, III and IV. Region II – reservations for DK, NL, and FR; Region III - IE and FR may have problems to deliver data; SE cannot deliver data for IA2017. Region IV anticipated data problems for FR and PT; Region I and V to be investigated further. Will contribute partial assessment for region II, III and IV (either partial in terms of geographic scope or due to restricted data availability). Recommended for testing in Region I and V. Unlikely to propose assessment values.
D4 FoodWeb 2	Production of phytoplankton	Will contribute partial assessment for regions II, III and IV. Assessment thresholds to be proposed.
D4 FoodWeb 3	Size composition in fish communities (LFI)	Recommended for promotion in regions II and IV. PT not able to contribute in short term. Will contribute to IA2017 for region II and III, contributing a partial assessment for Region IV Assessment thresholds to be proposed.
D5 chlorophyl	Chlorophyll concentration	Indicator being made operational on basis of OSPAR eutrophication monitoring and will provide data for IA2017 – indicator technical template led by CPs in JMP NS/CS case study on chlorophyll. Trend assessment.
D5 Phaeocystis	Species shift/indicator species: Nuisance species Phaeocystis	Indicator being made operational by 3-4 CPs involved and will provide data for IA2017. Trend assessment.

Table A1.2: *OSPAR indicators, Possibly relevant*

Indicator	Explanation / title	State of play including likely contribution to IA2017
D8 metals (biota)	Metal (Hg, Cd, Pb) concentrations in biota	Common indicator. Will provide data for IA2017
D8 PCBs (biota)	PCB concentrations in biota	Common indicator. Will provide data for IA2017
D8 PAHs (biota excluding fish)	PAHs concentrations in biota	Common indicator. Will provide data for IA2017
D8 Organotin	Organotin	Too few CPs with intention to monitor.

Indicator	Explanation / title	State of play including likely contribution to IA2017
(biota)	concentrations in biota	
D8 PBDE (biota)	PBDE concentrations in biota	Common indicator. Will provide data for IA2017
D8 HCB (biota)	HCB (hexachlorobenzene) concentrations in biota	Where relevant for WFD purposes may be continued also in adjacent areas under MSFD. Will not contribute to IA2017.
D8 HCBD (biota)	HCBD (hexachlorobutadiene) concentrations in biota	Not priority candidate indicator
D8 imposex	Imposex/intersex	Common indicator. Will provide data for IA2017
D10 in Fulmar	Fulmar litter ingestion (impact and floating litter)	ES and FR were investigating other species (e.g. fish and turtles) as an alternative to Fulmars DE was also investigating and indicator on plastic particles in fish EIHA added a request on the ICES work programme to see if the ICES fish disease surveys could be used for this purpose. Will be an assessment of the quantities, types, sources and **trends** of marine litter, including the impact of litter on the marine environment

Table A1.3: *OSPAR indicators, Not relevant*

Indicator	Explanation / title	State of play included including likely contribution to IA2017
D1 Mammals 1	Distribution seals	Not priority indicator
D1 Birds 2	Breeding success of kittiwake	Not priority indicator
D1 Birds 4	Non-native/invasive mammal presence on island seabird colonies	Not priority candidate indicator
D1 Birds 5	Marine bird bycatch	Not priority candidate indicator
D1 Birds 6	Distribution marine birds	Demoted from common to candidate by OSPAR 2014.
D1 Fish Ceph 4	By-catch rates of Chondrichthyes	Not priority candidate indicator
D1 Fish Ceph 5	Conservation status of elasmobranch and demersal bony-fish species (IUCN)	Not priority candidate indicator
D1 Fish Ceph 6	Proportion of mature fish	Not priority candidate indicator
D1 Fish Ceph 7	Distributional range	Not priority candidate indicator
D1 Fish Ceph 8	Fish distributional pattern	Will not contribute to IA2017. BDC Recommended for demotion to candidate indicator. No lead.
D1/6 BentHab1	Typical species composition	Will not contribute to IA2017
D1/6 BentHab4	Area of habitat loss	Will not contribute to IA2017
D1/6 BentHab5	Size-frequency distribution of bivalve or other sensitive/indicator species	Not priority candidate indicator
D1 PelHab 3	Changes in biodiversity index (s)	Recommended for promotion in region III but demotion in Region IV. IE may not be able to

Indicator	Explanation / title	State of play included including likely contribution to IA2017
		contribute data; Not supported by DE; SE indicator not fully tested. Will contribute to IA for Region III. Unlikely to propose assessment values.
D4 FoodWeb 1	Reproductive success of marine birds in relation to food availability	Not priority candidate indicator
D4 FoodWeb 4	Changes in average trophic level of marine predators (cf MTI)	Will contribute partial assessment for region IV. Assessment thresholds to be proposed.
D4 FoodWeb 5	Change of plankton functional types	BDC agreed to merge with PH1. Propose to **delete** from list.
D4 FoodWeb 6	Biomass, species composition and spatial distribution of zooplankton	Not priority candidate indicator
D4 FoodWeb 7	Fish biomass and abundance of dietary functional groups	Funding available. Work is still needed for further development of this indicator
D4 FoodWeb 8	Biomass trophic Spectrum	Not operational by December 2014 and therefore unlikely to contribute to IA2017 assessment.
D4 FoodWeb 9	Ecological Network Analysis diversity)	Not operational by December 2014 and therefore unlikely to contribute to IA2017 assessment.
D5 nutrient input water & air	Nutrient inputs in water and air	Indicator being made operational on basis of OSPAR RID monitoring and will provide data for IA2017. Trend assessment.
D5 nutrient input water	Nutrient inputs in water	Indicator being made operational on basis of OSPAR CAMP monitoring and additional modelling and will provide data for IA2017. Trend assessment.
D5 nutr conc	Winter nutrient concentrations	Indicator being made operational on the basis of OSPAR eutrophication monitoring and will provide data for IA2017 – indicator technical spec led by Germany. Trend assessment.
D5 oxygen	Oxygen	Indicator being made operational on the basis of OSPAR eutrophication monitoring and will provide data for IA2017 – indicator technical template spec to be drafted by UK. Trend assessment.
D7 area affect	Extent of area affected – physical	Not needed
D7 habit affect	Spatial extent of habitats affected	Not needed
D7 habit functi	Changes in habitat functions	Not needed
D8 input metal	Inputs of Hg, Cd and Pb via water and air	Discussed by INPUT 2014, technical specification needs to be prepared on the basis of earlier assessment. Will provide data for the IA2017 The quality of the final product will depend upon decent data reporting by the contracting parties.
D8 metals (sedim)	Metal (Hg, Cd, Pb) concentrations in sediment	Common indicator. Will provide data for 2017IA
D8 PCBs (sedim)	PCB concentrations in sediments	Common indicator. Will provide data for IA2017
D8 PAHs (sedim)	PAHs concentrations in sediments	Common indicator. Will provide data for IA2017
D8 Organotin (sedim)	Organotin concentrations in sediments	Common indicator. Will provide data for IA2017
D8 PBDE (sedim.)	PBDE concentrations in sediments	Common indicator. Will provide data for IA2017
D8 HCBD (sedim)	HCBD (hexachlorobutadiene) concentrations in sediments	Not priority candidate indicator
D8 oiled birds	Oiled birds (EcoQO)	Proposed for **deletion**.
D8 fish disease	Externally visible fish diseases	not discussed at MIME 2013
D8 LMS	Lysosomal stability (LMS)	not discussed at MIME 2013

Indicator	Explanation / title	State of play included including likely contribution to IA2017
D8 bile metab	Bile metabolites (of PAHs)	not discussed at MIME 2013
D8 micronuclei	Micronuclei (MN)	not discussed at MIME 2013
D8 EROD	EROD	not discussed at MIME 2013
D10 on beach	Beach litter	Will contribute to IA2017. Full assessment in regions II, III and IV and partial assessment in Region I. Will be an assessment of the quantities, types, sources and **trends** of marine litter, including the impact of litter on the marine environment
D10 on seabed	Litter on the sea floor	Will contribute to IA2017. Full assessment in regions II, III and IV and partial assessment in Region I but does depend on continuing availability of IBTS data and testing in 2015. UK, SE, ES, NL and DE confirmed they would use the indicator NO, IE need to confirm it was included in monitoring plans FR, DK and BE confirmed it was in their consultation on monitoring but need confirmation. Will be an assessment of the quantities, types, sources and **trends** of marine litter, including the impact of litter on the marine environment
D10 microplastic	Microplastics	Not a priority candidate indicator (will not provide information for IA2017)
D11 impulsive	Impulsive noise	NL, ES, IE, DE, BE and UK were all planning to use the indicator FR confirmed it was in their consultation on monitoring but need confirmation NO were to confirm if they were undertaking the indicator. DK need to confirm it was included in monitoring plans. Will produce an assessment for regions II, III and IV and a partial assessment for Region I. Will be an assessment of the **pressure** from underwater noise.
D11 ambient	Ambient noise	EIHA outcome was that this indicator is not ready for adoption as common. Unlikely to contribute to IA in 2017.

Annex 2 Introduction of contaminants

Selection of substances

Several activities (and calamities such as spills) introduce contaminants into the environment. In this study we focus only on hazardous compounds known to pose a threat to marine mammals. Also we disregard calamities in this study, such as oil spills. OSPAR defines hazardous substances as substances which are persistent, liable to bioaccumulate[2] and toxic (PBT substances), or which give rise to an equivalent level of concern as the PBT substances. Due to, a.o. metabolism, some substances do not accumulate in trophic levels higher than fish. Others are known to biomagnify[3] (i.e. increase in concentration in biota at successively higher levels in a food chain). The table below an overview of main substances and an indication of relevance for the marine environment (e.g. OSPAR priority substance) and, if available/found in literature, for marine mammals. OSPAR has identified forty substances and groups of substances as chemicals for priority action of which 26 pose a risk for the marine environment due to their use patterns ('OSPAR priority chemicals'). For the purpose of this study, we identified those substances that are both 'OSPAR priority chemicals' as well as specifically identified as a potential threat to marine mammals. Results are presented in Table A2.1 and described in the text below.

Table A2.1 *Substances selected for this study, based on their identification as an OSPAR priority chemical and a potential threat for marine mammals*

Main group	Substances	Identified as relevant/important for	Reference
Non-synthetics			
Metals	Hg, Cd	OSPAR priority chemicals	OSPAR (2010)
		Elevated levels found in harbour porpoise	Mahfouz et al. (2014)
Synthetics			
Polychlorinated Biphenyls (PCB)	PCBs	Harbour porpoise	OSPAR (2009)
		OSPAR priority chemicals	OSPAR (2010)
		Elevated levels found in harbour porpoise and harbour seal	Weijs et al. (2009)
		Reproductive failure in harbour seals	Reijnders (1986)
Brominated flame retardants	Brominated flame retardants	Harbour porpoise, OSPAR priority chemicals	OSPAR (2009, 2010)
	Polybrominated diphenyl ethers (PBDEs)	OSPAR priority chemicals	OSPAR (2010)
		Elevated levels found in harbour porpoise and harbour seal	Weijs et al. (2009)

PAHs are subjected to metabolic degradation in top predators and their prey (Macdonald & Bewers, 1996; Xinhong & Wen-Xiong, 2006) and were also not listed as main contaminants for harbour porpoise (OSPAR, 2009). Therefore we disregard these substances for this study. We used the same consideration for other hydrocarbons.

(Heavy) metals are known to bioaccumulate in the marine environment (Kahle & Zauke, 2003). The general consensus for metals is that they usually don't biomagnify, but can bioconcentrate (DeForest et al., 2007; Gray, 2002) , as most metals are regulated and excreted. However, some organometals

[2] Bioaccumulation is the intake of a chemical and its concentration in the organism by all possible means, including contact, respiration and ingestion (Alexander, 1999).

[3] Biomagnification occurs when the chemical is passed up the food chain to higher trophic levels, such that in predators it exceeds the concentration to be expected where equilibrium prevails between an organism and its environment (Alexander, 1999).

(e.g., methyl mercury) can biomagnify. Because Hg and Cd are on the OSPAR list of priority substances (OSPAR, 2010) and have been found in elevated levels in stranded harbour porpoise (Mahfouz et al., 2014), we select these two metals as non-synthetics for this study.
PCBs, DDT, brominated flame retardants and polybrominated diphenyl ethers (PBDEs) are substances identified as a threat to marine mammals and/or found in elevated levels in marine mammals (OSPAR, 2009; Weijs et al., 2009; Reijnders, 1986). With the exception of DDT, these substances are also identified as 'OSPAR priority chemicals' (OSPAR, 2010). Half-way through the twentieth century slowly degrading organic contaminants, especially PCBs and pesticides, were responsible for reduced reproduction and mortality of seals (Reijnders, 1980, 1982 & 1986) and possibly also porpoises (Murphy et al., 2010). After a ban on use of these substances, concentrations in marine mammals decreased slowly (ICES 2010). PCBs are considered as the main threat for marine mammals due to toxicity and slow degradability, especially in periods of food shortage and lactation of the first calf (ICES, 2010). Therefore, PCBs and brominated flame retardants (i.e. PBDEs) are selected as synthetic substances for this study.

Spatial distribution
For the selected substances sufficient data is available to assess the distribution and intensity (i.e. concentration). Main sources of data are:

- DOME (Marine Environment). Data portal used by OSPAR, HELCOM, AMAP and Expert Groups in the management of chemical and biological data for regional marine assessments. Including data on e.g. metals and brominated flame retardants in sediment and biota. Available at: http://www.ices.dk/marine-data/data-portals/Pages/DOME.aspx

- EEA database of hazardous substances (e.g. WISE_TCM_Biota.mdb. Available at: http://forum.eionet.europa.eu/etc-icm-consortium/library/subvention-2013/tasks-and-milestones-2013/1.5.1.d-wise-soe-data-flows/milestone-7-2013-reference-databases-wise-soe-data-flows-tcm-tcm-water-quality/index_html).

The magnitude of the introduction of contaminants should ideally be expressed by a metric that:

- Best represents the nature of the pressure;
- Is identical to the unit of the exposure metric;
- Is identical to that used to describe sensitivity.

Addressing the nature of the pressure, i.e. *introduction* of contaminants, the magnitude is best described by the quantity of emission, i.e. load and involves a unit of time. In other words, x amount of chemical is introduced per x unit of time. For example, an oil/gas production platform discharges produced water into the marine environment causing introduction of contaminants with a magnitude of x kg dispersed oil per month per platform. This metric is however not identical to the unit of exposure. Marine mammals are mainly exposed to contaminants via food. Therefore the magnitude of the pressure (i.e. load) needs to be transformed into a concentration in the water column and subsequently concentration in food (i.e. fish). This transformation requires a calculation of the dilution (concentration in water) and bioaccumulation data (concentration in food). Another option would be to use monitoring data to describe the concentration in food/biota, therewith using the best metric concerning exposure but only a proxy of the nature of the pressure. Sensitivity (i.e. effect values) is also based on concentration in food.

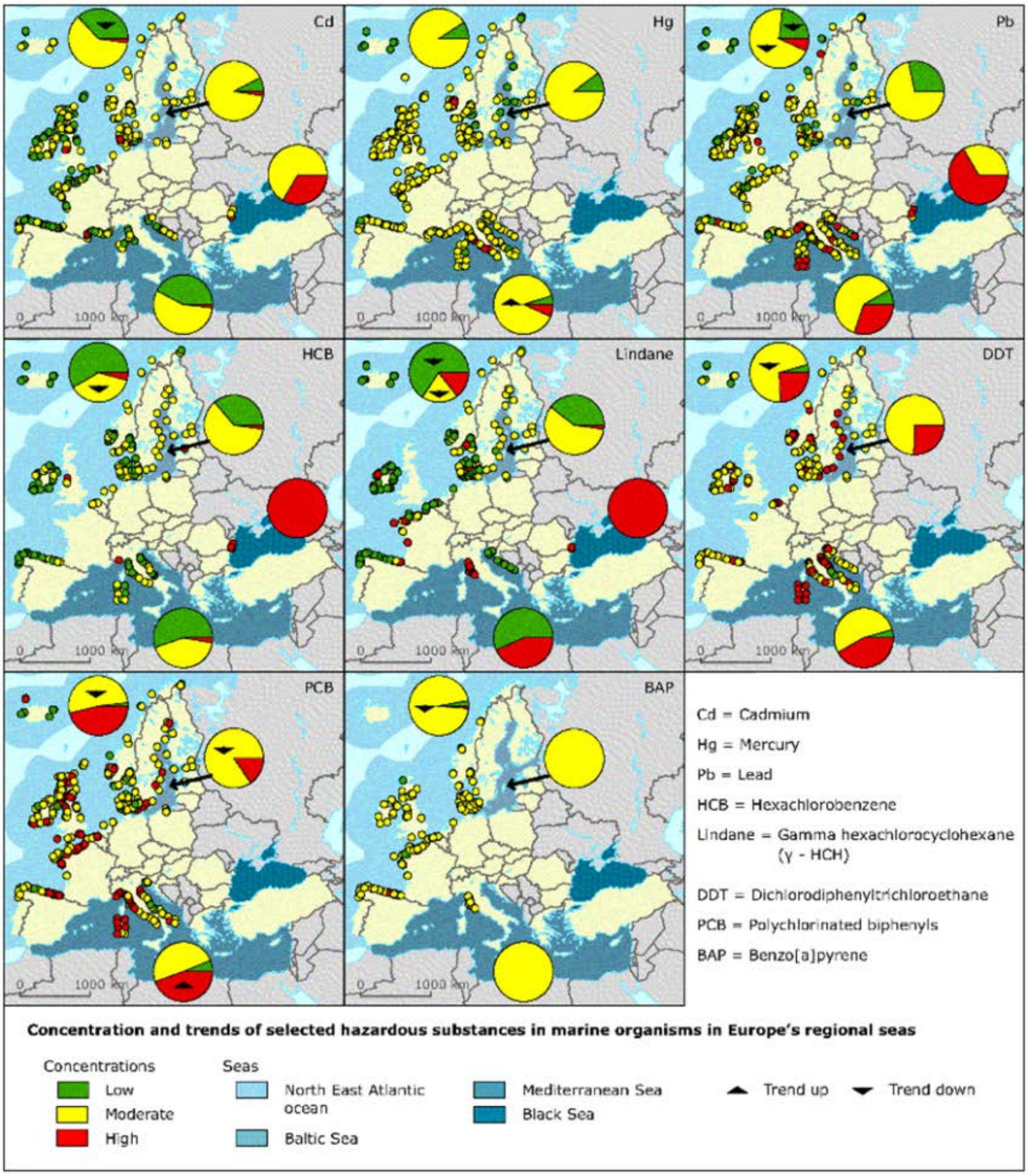


Figure A2.1 *Example of spatial distribution of the pressure 'contaminants' (source: http://www.eea.europa.eu/data-and-maps/figures/aggregated-assessment-of-hazardous-substances-2/19373-mar001-).*

Sensitivity

Potential effects

Marine pollution is a threat to harbour porpoise, for example from toxic substances that bio-accumulate and are known to reduce reproductive fitness (OSPAR, 2009).

A passive monitoring study of stranded animals showed that levels of Hg, Se, Zn, Cd and V appeared to be higher in porpoises that died from infectious diseases compared to healthy porpoises that died from physical trauma, although synergetic effects of metallic contaminants on health status was not elucidated (Mahfouz et al., 2014). The findings indicate that metallic contaminants may influence the health of harbour porpoises and contribute to the increased stranding numbers encountered over the last decade for the population in the southern North Sea.

Persistent organic pollutants (POPs), bio-accumulating in the blubber of harbour porpoises include polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and brominated flame retardants (OSPAR, 2009). Harbour porpoises stocks with relatively high PCB levels were from the southern North Sea (Netherlands and Belgium) and had the lowest reproductive rate (OSPAR, 2009).

Bioaccumulation
Bioconcentration factors (BCFs), bioaccumulation factors (BAF) or biomagnification factors (BMF) are required to calculate concentrations in biota based on concentration in water. For the selected compounds, sufficient data is available to assess bioaccumulation and/or biomagnification (e.g. Table A2.2).

Table A2.2 *Bioaccumulation values available for the selected compounds*

Compound	BCF	logBAF	BMF	Reference
Cd	249			Jak et al. (2000)
Hg	992 (fish)			Jak et al. (2000)
PCBs	3200000 (fish)			Jak et al. (2000)
PBDEs		2.3-7.6 (fish)	0.8-2.4 (porpoise)	Lee and Kim (2015)
			2.0-12.4 (harbour seal)	Jenssen et al. (2007)

Internal effect concentrations and kinetic parameters (required for bioaccumulation modelling) are available to some extent for metals (Vijver en Van Gestel et al. 2004; DeForest et al. 2007; Van Kolck et al. 2008).
Weijs et al. (2009) investigated the accumulation and biomagnification of PCB and PBDE congeners in blubber of harbour seals and harbour porpoises from the Southern North Sea. Harbour seals showed a higher ability to metabolize PCBs and PBDEs compared to harbour porpoises (Weijs et al., 2009).

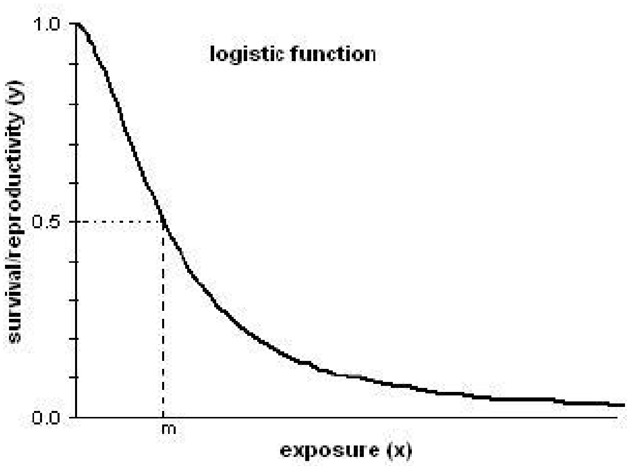
Dose-effect relationship
Marine mammals are exposed to the selected bio-accumulative substances via their food (i.e. fish). The exposure via food can be assessed in three different ways, depending on the available data and purpose of the assessment:

- based on a known (measured) concentration in food (monitoring of concentrations in biota) or;
- by using the bioconcentration factor (BCF) or bioaccumulation factor (BAF) to calculate the concentration in food based on known (measured or calculated) concentrations in water and/or;

If (measured) concentrations in water and/or food are not available the concentration in water can be calculated based on the input of contaminants (i.e. load). This could also be the most appropriate way to assess exposure when a direct link to the activity is required/desired.

The dose-response relationship for contaminants are described by a logistic function (Jak et al., 2000):

$$y = \frac{1}{1+\left(\frac{x}{m}\right)^{c}}$$



With:

m = median intensity of effect, disturbance at which the effect = 50%
c = intensity-effect coefficient, which describes the slope f the function

The variables in the equation are described by y as the effect on survival/ reproduction (fraction between 0 en 1) and x as the disturbance intensity of the potential exposure.

For contaminants the median intensity of effect (m) is defined as the mean EC50 value m (concentration leading to mortality of 50% of the individual) and a value of 2.9 is used for the slope of the function (c).
To correct for intake of food:

$$LC_{50} = \frac{LD_{50}}{F_{int}}$$

With:
LC50 = median lethal concentration in food (mg substance/kg food)
LD50 = median lethal dose, tested in the laboratory on test organisms e.g. rats (mg/kg body weight)
F_{int} = daily food intake (kg food/kg body weight per day), see Table A2.3.

Table A2.3 *Calculated daily food intake (Jak et al., 2000)*

	Body weight		Daily food intake		
	(kg)	Reference	(kg)	Reference	F_{int}
Seal	70	Reijnders (pers.com.)	6	Markussen *et al.* '90	0.09
Porpoise	50	Mohl-Hansen '54	8	Kayes '85	0.16

Effect values (LC50, NOEC) are required for Hg, Cd, PCBs and brominated flame retardants (Table 4). NOECs for Cd, (Methyl-)Mercury and PCBs for seal and porpoise were extrapolated from other species groups by Jak et al. (2000), following the methodology developed by Jongbloed et al. (1995) and were calculated as 1.4, 0.2 and 3.0 mg substance / kg food respectively. These values should be corrected for the caloric value of the different food types and for laboratory-field differences, for which Jak et al. (2000) use a correction value for seal and porpoise of 0.15. This results in NOECs of 0.21 (Cd), 0.03 (methyl-) mercury and 0.45 (PCB) mg/kg food.
A different literature source reports effect values for PCB (Kannan et al., 2000). The no observed adverse effect level (NOAEL) represents the least exposure treatment tested and the lowest observed adverse effect level (LOAEL) represents the greatest exposure. It appears that mink, otter and harbour seals are comparably sensitive to toxic effects of PCBs (Kannan et al., 2000). Daily dose NOAEL for seals exposed to PCBs is reported at 5.2 ug/kg bw/d, daily dose LOAEL at 28.9 ug/kg bw/d, dietary NOAEL at 100 ng/g wet wt and dietary LOEAL at 200 ng/g wet wt (Kannan et al., 2000).

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Annex 3 Marine litter

Data inventory

Inventory of data sources and data quality

Based on the methodology outlined above, an inventory of data for marine litter was done (**Table A3.1**). Important note: It is assumed that the data sources on marine litter in the environment represent the exposure for entanglement as well as ingestion.

Table A3.1 *Inventory of data sources of marine litter, including the spatial and temporal presence in the environment as well as the effects on biota in the North Sea.*

Data type	Exposure route	Area	Policy domain	Size class	Matrix	Data Quality	Type data source	GIS available?	Reference
Presence of ML in the environment	Direct	OSPAR region	EcoQO Marine litter	Macro, meso	Beach	INSPIRE compliant	Online dataset	Yes	http://odims.ospar.org/odims_data_files/ Marine litter beach monitoring
Presence of ML in the environment	Direct	North Sea	MSFD	Macro, meso	Beach	Unknown	Online viewer	No, spatial data are available	http://www.informatiehuismarien.nl/krm/viewer/ Data on request via serge.rotteveel@rws.nl or erik.eggenkamp@rws.nl
Presence of ML in the environment	Direct	OSPAR region	EcoQO Northern Fulmars[4]	Macro, meso, micro	Water surface	INSPIRE compliant	Online dataset	Yes	http://odims.ospar.org/odims_data_files/ Plastic particles in the stomachs of seabirds
Presence of ML in the environment	Direct	OSPAR region	MSFD	Macro	Sea floor	Unknown	Field data in table, figures	No	OSPAR (2007) www.ospar.org/documents?d=7059 Data presented in figures in OSPAR (2009), including other OSPAR countries
Presence of ML in marine mammals	Ingestion of ML by comparable species	North Sea coast	Unknown	Macro, meso and micro	Biota (harbour seals)	Unknown	Scientific article	No	Bravo Robelledo et al. (2013)
Presence of ML in marine mammals	Entanglement and ingesti	Global	Unknown	Macro, meso and micro	Biota (cetaceans)	Unknown	Scientific article(literature review)	No	Baulch & Perry (2014)

[4] This species is used as a proxy for marine litter on the water surface, and does therefore not represent effects on biota, but presence in the environment.

Data type	Exposure route	Area	Policy domain	Size class	Matrix	Data Quality	Type data source	GIS available ?	Reference
	on of ML by target family								
Presence of ML in marine mammals	Ingestion of ML by target family	Dutch coast	Unknown	Micro	Biota (humpback whale)	Unknown	Scientific article	No	Besseling et al. (2015)
Potential effects of ML on marine mammals	Ingestion of comparable species	North Sea coast	Unknown	Macro	Biota (sperm whale)	Unknown	Scientific article	No, but spatial data are available	Unger et al. (2016)
Potential effects of ML on marine mammals	Ingestion of comparable family	Mediterranean Sea	MSFD	Macro	Biota (loggerhead turtles)	Unknown	Scientific article	No	Nicolau et al. (2016)
Potential effects of ML on marine mammals	Ingestion and entanglement of comparable families	Mediterranean Sea	MSFD	Macro	Biota (multiple species)	Unknown	Scientific article	No	Deudero & Aloma (2015)

Collecting the relevant information

The most relevant data sources from the table above were scored on a range of criteria to determine the potential presence and effects on marine mammals to determine which data are of importance to quantify the cause-effect relationship.

Table A3.2 *Representation of the application of criteria to the data sources inTable 38. Y = Yes, N=No, U=Unknown. The scores for the overall importance of data for quantification of cause-effect relationship were based on the following classes: green = ≥4 Y, orange = 3 Y, red = ≤ 2 Y. The more Yes, the more relevant a data source for determining the presence of marine litter in the environment and effects in marina mammals.*

Data type	Reference	Appropriate spatio-temporal coverage	Appropriate Quality	Appropriate Matrix	Appropriate size range	Overlay possibilities with limited efforts	Overall importance of data for quantification of cause-effect relationship
Presence of ML in the environment	http://odims.ospar.org/odims_data_files/ Marine litter beach monitoring	Y	Y	Y	Y	Y	
Presence of ML in the environment	http://odims.ospar.org/odims_data_files/ Plastic particles in the stomachs of Sea birds			Y		N	
Presence of ML in the environment	Delft-3D PART (Deltares transport model)	Y	U	Y	Y	Y	
Presence of ML in the environment	Neumann et al. (2014)	Y	U	Y	U	Y	
Presence of ML in marine mammals	Bravo Robelledo et al. (2013)	N	U	Y	Y	N	
Presence of ML in marine mammals	Baulch & Perry (2014)	N	U	Y	Y	N	
Presence of ML in marine mammals	Besseling et al. (2015)	N	U	Y	N	N	
Potential effects of ML on marine mammals	Unger et al. (2016)	Y	U	Y	Y	N	
Potential effects of ML on marine mammals	Nicolau et al. (2016)[5]	N	U	Y	Y	N	
Potential effects of ML on marine mammals	Deudero & Aloma (2015)	N	U	N	Y	N	

Based on the table above, it is clear that there are three data sources most appropriate data to determine exposure:

- OSPAR Marine Litter Beach Monitoring (as a proxy for large marine litter items in the sea)
- OSPAR Plastic particles in the stomachs of Seabirds (as a proxy for small floating litter on the sea-surface)
- Deltares plastic transport model (Delft-3D PART transport model).

No data sources were found that described the effects of ML on the target species, since no direct relationship between marine litter ingestion and mortality has been described.

Exposure of seals and porpoises to ML

[5] Please note that this article is on logger head turtles, not on marine mammals.

The main conclusion is that very little data are available for the Greater North Sea for the exposure risk of seals and porpoises to ML:

- Spatial and temporal scale: most data are point measurements in space and time rather than areal estimations throughout the year. Also, verified and coordinated datasets among EU Member States are not spatially explicit. For example, the OSPAR marine litter in seabirds' dataset is based on birds that could have eaten the plastics anywhere and are thus not spatially explicit. This makes it difficult to determine hotspots of marine litter based on these data. However, based on the data on exposure there is a chance that marine mammals ingest or get entangled in marine litter items anywhere at sea.
- Matrix: the most spatially explicit dataset is on the beach. Model schematisations are made for areas of the sea surface too, which is helpful and can be a tool in extrapolating data within an area.
- Data quality: Only the OSPAR datasets are INSPIRE compliant and therefore meet the EU meta-data standards, for other data the quality of data is unknown. INSPIRE compliance adds to comparability, availability and quality of the data.

Magnitude of the pressure of ML

- Most data sources look at the amount of particles present in the environment. For the water column, this is expressed in number of particles/m^3 (Deltares model) or, looking at the proxy of litter on the water surface, Northern fulmars, weight of litter items/stomach (OSPAR dataset). For the beach this is expressed in the amount of items/category of litter on a stretch of 100 m of beach (OSPAR Marine Litter Beach Monitoring dataset). For the sea floor this is expressed in number of litter items/km^2 sea floor (for large items), or in particles/m^3 for microplastics.

Sensitivity

- No data were found on the effects of microplastics on marine mammals, only some data are available on the occurrence of microplastics in biota, including fish and other relevant food sources. There are incidence reports on the entanglement of large plastics and choking of seals on large plastics, but there is no dedicated reporting and inventory of locations. There are data from lab studies for the effects of microplastics on lower trophic levels with a potential for food web effects, however these are often carried out with high concentrations of microplastics and are therefore less relevant in the field. Furthermore, these data represent an indirect exposure route, which is less relevant for the target species.
- There are some (citizen science) data available for observations of entanglement of marine mammals washed up on Dutch beaches. Also available are pathological reports and some scientific articles on the occurrence of plastic particles in the stomachs of (washed up) seals and porpoises.
- There are no clear data (dose-response) on the effects of macroplastics and microplastics on the target species. An assumption can be (albeit worst case) that entanglement leads to death. But ingestion does not necessarily lead to decreased survival. Data on effects on survival through direct ingestion of macroplastics or through food-web effects of microplastics are virtually absent. There are no data directly linking the presence of plastics in an organism to death since most animals are found washed up on the beach and were unlikely to have died from ML ingestion.

What assumptions, uncertainty and thus level of confidence

- The main assumptions around this pressure are:
    - That there are no known direct effects of microplastics on the target species.
    - There is a risk of entanglement or ingestion of ML from the seafloor, from beaches (seals only) and floating ML on the sea surface or in the water column. The effect of entanglement or ingestion is not well known.
    - Indirect effects through the food web are largely unknown and cannot be used in the risk assessment.
- The uncertainties around the presence of ML in the environment are high, since the material is very heterogeneously distributed in the environment, and data points on the ML presence are few. For floating litter on the water surface for example, the currents, wind and wave energy

are important processes determining the transport and fate of ML. The most useful data for exposure of seals and porpoises is the data for the North Sea on floating marine litter; this ML can cause choking or entanglement of seals and porpoises leading to direct effects of decreased survival. Currently, results are available that models the distribution of large, floating ML through the North Sea, an important assumption here is that the only source of ML input is from rivers (for more information see Van der Meulen et al., 2016).

Determine Risk of Impact

- The potential risk of the impact of marine litter on the target species is considered too uncertain to assess due to the lack of data on effects. The risk of exposure is thought to be moderate since the amounts of litter items found in the environment can be high locally (i.e. on the beach), however, in looking at floating litter the pressure is so diluted that it is difficult to say anything about the risk of an encounter between ML and the target species. This is also due to the heterogeneous nature of floating litter.

Outlook

- To better quantify the cause-effect relationship between ML and the target species several developments could take place. These should focus on the effect side of the pressure, so the sensitivity of the target species to the pressure.
- For research:
    - Using the presence of ML in fish as a proxy for the distribution of microplastics in the marine environment, and for possible ingestion rates of ML by the target species, which is needed as input in assessing indirect effects
    - Modelling the exposure level of large ML for porpoises and seals
    - Improved reporting and stocktaking of data on entanglement and choking from citizen science platforms such as waarnemingen.nl
    - Improve modelling efforts for the distribution of ML in the marine environment, especially for large ML (macroplastics) since these appear to be the most relevant direct lethal effects on especially seals
    - Set up a national database for ML presence with a focus on the beach and floating litter and agreeing on a standardized method for measuring ML in the marine environment.
    - Increase post-mortal studies on beached porpoises and seals to determine the relative numbers of cases of ML-related deaths.
- For policy makers:
    - To reduce the risk of exposure of the target species to ML the focus should be on reducing the input of macroplastics in the environment. This can be done in several manners, i.e. banning single use plastic bags. This will also aid in the reduction of the amount of secondary microplastics being created as a result of degradation and fragmentation.
    - Maintain the OSPAR monitoring programs, which also make the data comparable with neighbouring countries and agreeing in OSPAR on a targeted approach to the ML issue.
    - Stimulate post-mortem studies, including studies on ML-contaminant levels in marine mammals

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Wageningen Marine Research
T +31 (0)317 48 09 00
E: marine-research@wur.nl
www.wur.eu/marine-research

Visitors' address

- Ankerpark 27 1781 AG Den Helder
- Korringaweg 5, 4401 NT Yerseke
- Haringkade 1, 1976 CP IJmuiden

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