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Uso de Evaluaciones de Servicios Ambientales para Determinar las Compensaciones en el Manejo de Mamíferos Marinos Basado en Ecosistemas

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Palabras clave: biodiversidad marina, compensaciones ambientales, conflicto humano-fauna, perjuicios ambientales ecoturismo, estrategia ecosistémica, IPBES, manejo adaptativo

Resumen. El objetivo del manejo basado en ecosistemas (EBM) es respaldar una estrategia de manejo multisectorial sustentable y holística, objetivo que es reconocido dentro de varias políticas de marcos de trabajo internacional. Sin embargo, todavía desconocemos cómo deben vincularse este objetivo con las evaluaciones y los planes de manejo de la fauna marina, como los mamíferos y las poblaciones ícticas. Actualmente, parece un reto realizar los análisis de las compensaciones de varios usos oceánicos sin un marco de trabajo que integre el conocimiento sobre los beneficios ambientales, sociales y económicos derivados de la fauna marina no estacionaria. Discutimos que este vacío puede completarse con la aplicación de una versión de la estrategia de servicio ambiental a nivel poblacional para la fauna marina. Para impulsar esta idea usamos mamíferos marinos como estudio de caso para demostrar cuáles indicadores podrían poner en práctica evaluaciones relevantes y entregar una base de evidencias para la presencia de servicios y perjuicios ambientales derivados de los mamíferos marinos. Descubrimos indicadores que cubren las categorías de servicios ambientales comunes cuya aplicación es factible; los ejemplos de datos indicadores ya se encuentran disponibles en la literatura para varias de las poblaciones. Alentamos una exploración más profunda de esta estrategia para su aplicación en la fauna marina y el manejo de biodiversidad, bajo advertencia de que las tensiones conceptuales relacionadas con el uso del concepto de servicio ambiental necesitan ser tratadas para asegurar la aceptación por parte de los actores relevantes.

Using ecosystem-services assessments to determine trade-offs in ecosystem-based management of marine mammals

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Keywords

marine biodiversity, ecosystem approach, adaptive management, environmental trade-offs, human-wildlife conflict, ecotourism, ecosystem disservices, IPBES

Running head

Marine mammals

Article Impact Statement

The use of ecosystem service assessments at the stock level can help implement ecosystem-based management of marine biodiversity.

Abstract

The goal of ecosystem-based management (EBM) is to support a sustainable and holistic multisectored management approach, and is recognized in a number of international policy frameworks. However, it remains unknown how these goals should be linked to assessments and management plans for marine fauna, such as mammals and fish stocks. It appears particularly challenging to carry out trade-off analyses of various ocean uses without a framework that integrates knowledge of environmental, social, and economic benefits derived from nonstationary marine fauna. We argue this gap can be filled by applying a version of the ecosystem-service approach at the population level of marine fauna. To advance this idea, we used marine mammals as a case study to demonstrate what indicators could operationalize relevant assessments and deliver an evidence base for the presence of ecosystem services and disservices derived from marine mammals. We found indicators covering common ecosystem service categories feasible to apply; examples of indicator data are already available in the literature for several populations. We encourage further exploration of this approach for application to marina fauna and biodiversity management, with the caveat that conceptual tensions related to the use of the ecosystem service concept itself needs to be addressed to ensure acceptance by relevant stakeholders.

Introduction

Marine ecosystems provide a range of benefits (i.e., ecosystem services) that contribute to human well-being (Costanza 1998; Liquete et al. 2013; MEA 2005). Marine ecosystem services are, however, under pressure across the globe due to unsustainable anthropogenic activities and ineffective ecosystem management (MEA 2005; IPBES 2019). To address this challenge, international and regional policies, such as the Convention for Biodiversity and EU's Marine Strategy Framework Directive, call for integrated management approaches, often called ecosystem

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approaches or ecosystem-based management (EBM), depending on the specific policy (EU 2008, Waylen et al. 2014).

Although professional interpretations of EBM vary (Trochta et al. 2018), there is evidence of a shared understanding (Marshak et al. 2017). The multiinterpretability of EBM is, however, both a strength and a weakness. To avoid ambiguity, considerable research has been dedicated to supporting consistent EBM terminology and its practical application at different management levels (Patrick & Link 2015; Link & Browman 2014). We consider EBM (McLeod et al. 2005) an overarching cross-sectoral approach with the goals of maintaining ecosystem structure, functioning, and services based on a process that accounts “for the interconnectedness within systems”; that integrates “ecological, social, economic, and institutional perspectives”; and that “recogniz[es] their strong interdependences.”

The ability to address trade-offs between sectors and stakeholders is a key focal point in EBM (Marshake et al. 2017). Thus, an important task when implementing EBM is to collect information that enables trade-off analyses of management options. The production of such information is the focus of the ecosystem-service approach and is therefore one of the key steps to achieving successful EBM of marine and coastal ecosystems (e.g., UNEP 2011).

Ecosystem-service terminology and concepts have over the past 2 decades risen in popularity in academic and policy spheres (Constanza et al. 2018, IPBES 2019), specifically regarding marine environments (Beaumont et al. 2007, Börger et al. 2014, Bouwma et al. 2018). Although the concept of using the ecosystem service approach to enhance formalization of trade-offs is well established (Rodríguez 2006), its practical application is less documented.

Many articles provide conceptual critiques and highlight the epistemological challenges of its practical application (Schröter et al. 2014, Beaumont et al. 2017, Chan et al. 2012), pointing to problems related to, for example, the concept's normative anthropocentric perspective, economic framing, vagueness, and lack of accounting for relational and noninstrumental ethical values. The framework provided by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) attempts to address some of the criticism by mainstreaming several types of value that different communities assign to nature, making the concept more inclusive of spheres beyond science (e.g., indigenous knowledge) (Diaz et al. 2018).

The few trade-off applications conducted (Martin Lopez et al. 2014, King et al 2015) show the ecosystem-service framework promotes pluralism and insightful analysis of trade-offs but needs a clear methodological framework to enable consideration of the multidimensional nature of ecosystem services. This framework does not need to be consistent across all applications; flexibility of the framework depending on its application is a strength (Schröter et al. 2014).

Building on Hammerschlag et al. (2019), who suggest adaptive-management plans for marine areas should be informed by socioecological frameworks, which integrate knowledge about ecosystem services of aquatic predators, we suggest extending the scope of present ecosystem service assessments to include analyses at the population or stock level of marine fauna. This application to species groups, rather than areas, would be novel in marine settings, valid, and necessary, given the need to understand trade-offs related to, for example, migratory populations of marine fauna. This should increase the ability to conduct systematic and transparent trade-off analyses and goal setting at the EBM level and provide a link to actions needed at low management levels.

Marine mammals are particularly relevant from an ecosystem-service perspective because of their large ranges; migratory behavior; past histories of exploitation; present iconic status across much of the world; cultural and economic importance for indigenous people; regulating effect on ecosystem structure; and monetary value for tourism (NAMMCO 2017, O'Connor 2009, Pompa et al. 2011, Roman 2013). For example, the climate-regulating ecosystem services provided by marine mammals inspired the International Monetary Fund to consider the benefits of marine mammal conservation (Chami et al. 2019). Similarly, it is striking that the European Commission changed its definition of *bioeconomy*; it now includes all value chains related to marine ecosystem services and thus by default, for example, marine mammal tourism (European Union 2018).

Several marine mammals are and have historically been in conflict with societal interests, which increases the need for understanding of the complex ecosystem-service trade-offs related to their management (Olsen et al. 2018). There are potential management benefits of making the gains and losses associated with marine mammals more explicit. For example can the economic valuation of benefits and problems be used as an evidence base to develop monetary compensation schemes when, for example, new regulations lower the speed of vessels to decrease the risk of ship strikes (Lent 2015). This illustrates how ecosystem-service-inspired approaches can account for multiple stakeholder interests and thus trade-offs when they include identification of direct and indirect ecosystem services and ecosystem disservices (i.e., "functions or properties of ecosystems" that have undesired effects on humans [Lytimäki 2015]).

We suggest ecosystem-service-based assessments advance the complex task of integrating socioecological knowledge of migratory populations in aquatic environments, which has mainly focused on area management (e.g., marine spatial planning [e.g. Beaumont et al. 2007]) rather than spatially transient and culturally significant populations of marine fauna. With the exception of a partial review by Roman et al. (2014) and indirect or unpublished descriptions (e.g., Andersen et al. 2018, NAMMCO 2017, Riisager-Pedersen 2017, Hammerschlag et al. 2019), no comprehensive description and classification of marine mammal ecosystem services has been presented relevant to their management.

To fill this gap, we applied the ecosystem-service approach to marine mammal management by assessing the potential ecosystem services and disservices generated by marine mammal populations and compiled indicators that can be used to quantify ecosystem services and disservices at the population level, where management often focuses (Lavigne 2003, Sveegaard et al. 2015).

Assessment of ecosystem services and disservices from marine mammals

Ecosystem services frameworks available include The Millennium Ecosystem Assessment (MA 2005), the UK's National Ecosystem Assessment Follow-On (UKNEA 2014), The Economics of Ecosystems and Biodiversity (TEEB 2010), the Common International Classification of Ecosystem Services of the European Environment Agency (CICES) Haines-Young & Potschin 2018), and IPBES (Diaz et al. 2015). Because there has been no previous work on the ecosystem services of populations of marine fauna, we drew on this broad literature to develop an assessment of ecosystem services, disservices, and indicators for marine mammals as an example (Tables 1 & 2). Some frameworks, such as CICES, do not include supporting services to avoid double counting if the services are valued monetarily. However, because marine mammals provide a host of substantial supporting services (Supporting information), we maintained this category for communication reasons (Geange et al. 2019) related to EBM objectives. Supporting services should not be valued monetarily; thus, we did not provide indicators for this category. We included services (nature benefits people) and disservices (nature harms people) because these are now frequently included in the literature, such as the recent IPBES framework and concept of nature's contribution to people (UKNEA 2011; Ostfeld & Keesing 2017; IPBES 2019).

To understand and illustrate which ecosystem-service categories should be considered in assessing marine mammal populations, we searched the literature with Web of Science and Google Scholar. Search terms related to common ecosystem service categories in, for example, CICES, TEEB, and Millennium Ecosystem Assessment and marine mammal keywords (e.g., *whales*, *pinnipeds*, *seals*, *seal fisheries*, *conflict*). Because so little has been published about ecosystem services of marine mammals, a systematic review was not feasible. To compensate, we also identified references from publications to reach a reasonable number of example publications that illustrate the potential relevance of marine mammals across common ecosystem service and disservice categories. The examples are therefore not an exhaustive list.

Recommendations for application of marine mammal ecosystem service and disservice assessments

Our assessment is intended to identify trade-offs in EBM options at the population level. It is applicable across a range of scales and stakeholder groups, but should be modified for specific contexts. We recommend the assessment be applied to other species groups, such as sharks, that may provide similar ecosystem services and disservices as marine mammals (Hammerschlag et al. 2019). Irrespective of species, we devised general guidance on the operationalization of the assessment to advance its application in EBM.

Interdisciplinary policy research

The need for data and scientific evidence that can link overall goals for environmental management (including EBM) with ecosystem service frameworks, is likely to increase in the future due to the widespread use of ecosystem-service terminology in marine policies (Bouwma et al. 2018). Given that trade-off analyses are at the heart of EBM, we recommend research determine how the dynamic lives of marine populations can be properly accounted for in ecosystem service-based assessments. This would help ensure fauna management in general does not become a discipline detached from overarching policy agendas, such as EBM. We expect this to be particularly important for marine populations whose ecological roles and values may not be easily understood by the public or policy makers given their lack of visibility and scarcity of data (Beaumont et al. 2007). Marine mammal management provides a good starting point because of the multiple ways they generate services and disservices for stakeholders in various settings (Lavigne 2003, Roman et al. 2014). Interdisciplinary research will be vital, given the need to document the spectrum (Rasmussen et al. 2017) of ecological, social, economic, and noninstrumental services and disservices of marine fauna.

Assessment and Inclusion of Scale

Ecosystem-service assessments of marine fauna must take scale into account to represent the relative significance of, for example, a few stationary porpoises relative to a large population of migratory baleen whales (Morissette et al. 2010). This means assessments must cover the flow and quantity of services and disservices provided along, for example, migratory routes and identify potential beneficiaries. Such assessments would likely have to rely on abundance estimates combined with studies of the fauna's general ecology (Mosbech et al. 2018). Because the extent of and ability to perform such assessments will vary greatly among institutions, we suggest a scoping exercise be performed with inputs from stakeholders and experts on the spatial scales relevant to the fauna in question. Pendleton et al. (2015) found scoping exercises increase the relevance of marine ecosystem-service assessments in general and provide several recommendations.

Indicator Development

Another challenge for the operationalisation of an ecosystem-service assessments at the species or population level is the selection of service and disservice indicators. We suggest that a number of generic examples of indicators and that indicators specific to local contexts or frameworks (e.g., IPBES) be developed to ensure relevance for policies and legitimacy among stakeholders. Criteria for indicator development by Oudenhoven et al. (2018) and on-going work of IPBES be considered for guidance. Further, indicator development could be included in the scoping process, allowing stakeholders to act as cocreators. This would support legitimacy of the results and identification of synergies (e.g., monitoring programs focused on the blue economy).

Some populations and areas may need to discriminate between present and potential future benefits to demonstrate how, for example, whale watching could become a benefit if an industry were to develop (Cisneros-Montemayor et al. 2010). In general, however, there are few data on marine ecosystem services (Townsend et al. 2018). For marine mammals, only the economic benefits of whale watching have been assessed globally (O'Connor et al. 2009). The examples in Table 1 could, therefore, provide a starting point for the populations to which the data relates.

Use of Ecosystem Service Assessments in Trade-Off Analyses

To inform social, economic, and environmental trade-offs in ecosystem management, knowledge is needed about how the provisioning of one ecosystem service may reduce the provisioning of another in space, time, and reversibility (Rodriguez et al 2006), especially because incorrect, partial, or no information about ecosystem interactions can lead to unintended trade-offs and inferior management options (Lester 2013).

In our assessment, we did not aim to prioritize management options. Rather, we suggest that the use of the assessment provides a much-needed basis for transparent discussions with stakeholders about what trade-offs are at stake in management of marine fauna and thus who (equity), how, when (i.e., intra- and intergenerational justice), and where people and the environment will be (nonstandard usage) affected. For example, Guerra (2019) suggests conflicts between humans and marine wildlife is likely to increase globally due to the recovery of marine mammal populations, leading to calls for culling or harvest by stakeholder groups potentially unaware of the associated trade-offs in terms of loss of ecosystem services provided by the same animals.

Structuring information relevant to trade-off discussions is thus a key goal so that relevant knowledge and knowledge gaps can be identified or combined with other types of information relevant to stakeholders. Because interactions between sectors and policies ought to be considered in EBM (Rosenberg & McLeod 2005), other information might include indirect disservices that result in costs associated with marine mammal conservation regulations (e.g., reduced economic activities of private companies);. To reduce bycatch, for example, time-area closures of fisheries are common practice in , for example, Australia, New Zealand, Mexico, United States, and Finland, and displace or reduce fishing efforts (FAO 2018). Similarly, restrictions on the speed of vessels, mandated changes to shipping routes and a ship-reporting system for several areas on the East Coast of the United States protect endangered northern right whales (*Eubalaena glacialis*) (NOAA 2019). Monitoring of bycatch and vessel strikes also costs the responsible institutions and thus the public sector (FAO 2018, Kindt-Larsen et al. 2012).

The benefit of adopting ecosystem-service terminology is thus its ability to advance the integration of a much fuller understanding of the importance of marine fauna in, for example, marine spatial planning and other policy areas focused on addressing environmental, economic, and social trade-offs as part EBM (Beaumont et al. 2007). On a global scale, recent initiatives such as Migratory Connectivity in the Ocean (www.mico.eco/system) could provide a platform for disseminating results to relevant management and policy makers about where trade-offs can be made and where stakeholders may exist (Dunn et al 2019).

Addressing Conceptual Concerns

Operationalization of our proposed assessment requires addressing conceptual concerns in a way that is acceptable to key stakeholders. The ecosystem-service approach does not appeal to all users (McKinley et al 2019); even the terminology can dissuade engagement. One solution could be to supplement the suggested framework with IPBES' terminology, which may be more inclusive of context-specific perspectives and value pluralism (Diaz et al. 2018, Kadykalo et al. 2019). This may be particularly relevant when assessing how indigenous people perceive trade-offs between types of values derived directly or indirectly from nature, including marine mammals (Pasqual et al. 2018).

Some ecosystem services may appear inappropriate to stakeholders. For example, "using marine mammals as sentinels… of anthropogenic pollutants" may be viewed as humans benefiting from marine mammals swimming in polluted waters. This is clearly not the intention, but it illustrates that the practical application of an ecosystem-service framework requires close collaboration with stakeholders to avoid misunderstandings and to empower, not disenfranchise users in the process (Beaumont et al. 2018). Application of the framework should also take into account the reoccurring criticism of the ecosystem-service concept itself and the possible ways of addressing it (Chan et al 2012, Schröter et al. 2014).

The way forward

We believe our approach will improve the ability of managers to communicate the wider socioecological consequences of marine mammal management decisions (e.g., whether to cull, hunt, protect, or use in recreational ways) to stakeholders. This is in line with the ambitions of EBM (i.e. Rosenberg & McLeod 2005) and provides a systematic way to structure discussions related to marine fauna management in general.

Research Initializing research programs focused on untangling the multiple ways fauna provide ecosystem services is a natural step for conservation, and marine mammal populations present particularly interesting candidates. This research is already underway (e.g., Beaumont et al. 2007; Mosbech et al. 2018). A priority is to ensure the absence of evidence for ecosystem-service provisioning from fauna does not become indirect evidence in the eyes of stakeholder of the lack benefits.

Due to criticisms of the ecosystem-service approach (Braat 2018, Chan et al.2012, Schröter et al. 2014) and the challenges of marine ecosystem-service assessments in particular (Townsend et al. 2018), operationalization will demand considerable effort. Nonetheless, we believe it is worthwhile given the urgent need for transformative changes to environmental management (IPBES 2019).

Ecosystem-service assessments at the stock level will become particularly important for marine systems because policies and case studies are increasingly integrating ecosystem-service approaches and terminology in marine spatial planning (Beaumont et al. 2007, Drakou et al. 2018, Rosenberg & McLeod 2005). The pressures and economic development projected for the world's oceans (OECD 2016) means systematic consideration of nonstationary ecosystem service providers, such as migratory marine mammals, should be a key research topic.

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Table 1: Direct ecosystem services provided by marine mammals that can be quantified and accounted for in ecosystem service assessments.*

Ecosystem service category	Description	Evidence for ecosystem service	Potential indicators (spatial scale of available data)
Provisioning services			
food	use of marine mammals for consumption	Organized hunting of marine mammals for food and raw materials takes place in a number of countries, including Canada, Greenland, Norway, Iceland, U.S.A., Russia, Australia, Japan, Indonesia, Malaysia, Tonga, Philippines, Namibia, and Faroe and Solomon Islands (Porter & Lai 2017, Robards & Reeves 2011, Oremus et al. 2015). Unregulated and illegal hunting of marine mammals provide many communities with meat for bait and bush meat in e.g. parts of	landing data measured as biomass (t), potentially estimated from the number of caught animals (NAMMCO 2017; Hattam et al. 2015; local to global scale) kg consumed per household (unknown

		Asia, Africa, and South America (Consentino & Fisher 2016, Porter & Lai 2017, Robards & Reeves 2011) People in 114 countries have consumed one or more of at least 87 species of marine mammals from 1990 to 2009. Active hunting accounts for the largest provisioning of meat; at least 27 countries consume 100s to 1000s of marine mammals annually. Bycatch and salvaging of stranded or trapped animals also provide many communities with substantial amounts of food (Robards & Reeves, 2011). Marine mammal management advice from e.g. NAMMCO already supports the establishment of sustainable catch levels on a population level (NAMMCO 2017). Nongovernmental organizations have demonstrated that at least some black markets in Europe sell dolphin meat to restaurants at a price up to 900 €/kg (WDC 2014)	whether data exist) percentage of diet or protein intake per capita (unknown whether data exist)
raw materials	use of marine mammal material for other	Traditional use of marine mammal raw materials for e.g. medical purposes, trophies, bait, handicrafts, and clothing are	number of animals used and purpose emus et al 2015; Porter & Lai

	activities than consumption	documented from many parts of the world, including the Arctic, Asia, Oceania, West Africa , and South America (Consentino & Fisher 2016, Reeves 1992, Oremus et al. 2015, Porter and Lai 2017) Globally several hundred thousand pinnipeds are harvested for their oil and fur in e.g. Arctic regions and Namibia (Campbell et al. 2011, Fisheries and Oceans Canada, 2018) Several hundred patents exist that include potential ingredients from marine mammals, including make-up, fragrance enhancers, nutraceuticals, and different medical applications (WDC 2014)	2017; National to regional, mainly qualitative data) number of patents with marine mammal ingredients (WDC 2014; National)
Regulating services			
pest control	reduction of abundance of invasive species or other pests	DNA from the invasive round goby has been found in the scat of grey seals in the Baltic Sea in Northern Europe (Scharff-Olsen et al. 2019). In Guyana West Indian manatees are known for and are actively used as aquatic weed control in irrigation and drainage systems. Estimates suggest that 0.5-1.4	consumed biomass of e.g. invasive species (t) (Haigh 1991, Scharff-Olsen et al. 2019; local to regional)

		manatees/ha of water surface can maintain or clear important water ways (Haigh 1991).	
climate regulation	reduction of greenhouse gas concentrations in the atmosphere or oceans	Estimates suggest a recovery of e.g. the Southern Hemisphere blue whale population alone would sequester 3.6×10^6 tons C in living biomass (Pershing et al 2010). Assuming all whale populations could be restored, the annual flux of carbon to the deep sea caused by sinking carcasses would be 160,000 tons C yr^{-1} (Pershing et al 2010). Marine mammals increase primary productivity by recycling both macro- and micronutrients thus affecting carbon fluxes (Roman et al. 2016, Roman & McCarthy 2010, Lavery et al. 2014).	carbon retained in marine mammals biomass (t) (Pershing et al 2010; Regional) carbon export to deep waters in the form of fecal matter and carcasses (t) (Pershing et al 2010; Regional) carbon fixed as a consequence of primary production stimulated by feces from marine mammals (t) (Lavery et al. 2010; Regional)

Cultural services			
scientific use	direct or indirect use of marine mammals in scientific activities	Species such as narwhals have been used to document the long-term warming of the southern Baffin Bay, Greenland, due to their ability to carry data loggers (Laidre et al. 2010).	number of published studies using marine mammals for research (unknown whether quantitative data

		Bathymetry measurements from narwhals have been used in NASA's work on understanding bathymetric changes caused by climate change (Brennan 2017). Researchers can use marine mammals as sentinels of ocean health due to e.g. their long life spans (Bossart 2011, Savery et al 2014).	exist).
educational use	direct or indirect use of marine mammals in educational activities or materials	Marine mammals and their body parts, such as skeletons, are used in public educational in e.g. museum exhibitions, aquariums, and zoos or are depicted in visual medias, such as nature documentaries, where they are often used as ambassador species to frame larger narratives about the value of science, nature, conservation, and management (Forrestrell 2009, Heyning & Mead 2009). Marine-mammal-watching operators occasionally engage in educational activities with their customers (Lück 2015, Lopez & Pearson 2017)	number of educational activities including marine mammals (unknown if data exist) number of participants in marine mammal education activities (unknown if data exist) number of educational media productions, publications, or exhibitions containing marine mammals (unknown if data exist)

			revenue or number of visitors to museums and other public venues (unknown if data exist)
entertainment	Interactions where marine mammals are used directly or indirectly for the sole purpose of entertainment	The U.S. company SeaWorld had approximately 22 million visitors in their marine mammal theme parks in 2016 (SeaWorld 2017). Marine mammals are continuously caught in the wild to provide animals for aquariums and theme parks (Black Sea Commission 2010, Zhang et a. 2012). Marine mammals are popular characters in movies and TV shows (Forrestrell 2009).	revenue from activities related to entertainment activities using marine mammals (SeaWorld 2017; Local) number of people participating in entertainment activities involving marine mammals (SeaWorld 2017; Local) revenue from or number of people watching entertaining media content based on marine mammals (unknown if data exist)
	direct	Global estimates from 2008 found	number of people

experiential use	experience of watching living marine mammals	the whale-watching industry generates US$2.1 billion annually (O'Connor et al. 2009). Pinniped-focused activities in the Southern Hemisphere were in 2003 estimated to attract > 1.3 million participants (Kirkwood et al 2003). In Australia the ticket revenues for whale watching accounted to AU$47 million in 2008 (Knowles & Campbell 2011).	participating in marine-mammal-watching activities (O'Connor et al. 2009; Global) nevenue from marine mammal watching activities (O'Connor et al. 2009; Global)
cultural heritage	importance of marine mammals in cultural traditions and folklore	Hunting of marine mammals have for centuries provided food, clothing, fuel, employment, and wealth for countless coastal societies (Reeves & Smith 2006) Cultural identity connected to e.g. the hunting of marine mammals is still an important cultural activity for many peoples and is supported by , e.g., IWC's designated quotas on otherwise protected marine mammal populations. Inuit communities are especially represented here (IWC 2018) Hunting represents practices tightly linked to the cultural identity and resilience of some communities (Sakakibara 2009, 2017).	number of cultural practices or significant folklore involving marine mammals (Reeves & Smith 2006, IWC 2018, Sakakibara 2009, 2017; Local to regional) number of people participating in cultural practices involving marine mammals (unknown if data exist)

		Nonconsumptive interactions with marine mammals, such as cooperative fishing between fishers and dolphins in Africa, South America, Europe, Australia, and India, are significant cultural heritage in some regions (Neil 2002). In the Northern Hemisphere, examples of historical interactions with marine mammals that have inspired folklore and religious beliefs include tales of sea creatures such as mermaids, carvings on North American Totem poles, or religious stories like Jonah and the whale (Parsons 2015). In the Southern Hemisphere, examples include production of relics made from marine mammal parts symbolizing gods as seen in Tonga and the local name given to the Milky Way, the Road of the Manatee, by indigenous people in South America (Kessler & Harcourt 2012, Khoury 2015).	
aesthetic use	generation of a noticeable emotional response within the individual observer watching	Marine mammals are very popular with the public, and their portrayal in all types of media content could be interpreted as aesthetic appreciation (Forrestrell 2009).	number of people using or accessing artistic material with marine mammals portrayed (unknown if data

	marine mammals or representations of marine mammals		exist) willingness to pay for seascapes with and without marine mammals (unknown if data exist)
spiritual	contribution marine mammals make to formal or informal religious experiences	The Iñupiat in Alaska (U.S.A.) and aboriginal Australians are examples of cultures where storytelling featuring marine mammals form a part of their belief system (Lowenstein 1992, 1993, Neil 2015).	number of formal and informal religious events related to marine mammals (unknown if data exist) number of people participating in formal and informal religious events related to marine mammals (unknown if data exist)
symbolic	use of marine mammals in symbols	In western societies, many implicit values are connected to marine mammals, enabling their portrayal to communicate e.g. political agendas (Kalland 1993, Schirpke 2018). Activities such as marine mammal consumption can in, e.g., Japan symbolize a political allegiance or opinion (Butler-	number of physical symbols portraying marine mammals (unknown if data exist) number of symbolic activities including marine mammals

		Stroud 2016).	(Unknown if data exist)
existence and bequest	intrinsic value of knowing that marine mammals exist in the world and the value attributed to knowing that they can be experienced by future generations	Evidence for a political will to conserve marine mammals are, e.g., the U.S. Marine Mammal Protection Act of 1972 and the IWC's continued regulation of whaling (IWC 2018, NOAA 2015). Lew (2015) found the mean WTP (US$ 2013 values) for manatees ranged from $14 to $28 (Solomon et al. 2004) for Steller sea lions $120-119 (Giraud & Valcic 2004), for different seals $18–202, and for different whales $37–356 (Lew 2015).	policy dedicated to protect marine mammals (IWC 2018, NOAA 2015; Global) people's willingness to pay for conservation measures (Lew 2015; Local) donations made to marine mammal conservation initiatives (unknown if data could become available)

* The categorization of ecosystem services and potential indicators are mainly inspired by, but not limited to, CICES. However, we highly encourage the adaptation of this assessment to the local context to ensure relevance for policies and stakeholders. Attention should be paid to the fact that provisioning of these services will not be evenly distributed in time and space because the same stock of, for example, whales in one area may be used for whale watching and in another area hunted (e.g., Townsend et al. 2018). Many of the suggested categories and their related research fields are characterized by very scarce evidence and would benefit from increased conceptual and empirical research efforts inspired by, for example, IPBES's ongoing work. In general, assessments ought to proceed through the following steps, in a participatory process where feasible: 1, scoping; that is, define species population, threats, stakeholders, and management needs and the spatial and temporal distribution of the population; 2, select ecosystem services and disservices based on evidence, including relevant spatial and temporal scales; 3, define indicators based on data or desired frameworks, such as IPBES or CICES; 4, map and quantify services and disservices; 5, communicate results to stakeholders, including science-policy platforms.

Table 2: Ecosystem disservices of marine mammals that can be quantified and accounted for in ecosystem-service assessments.

Ecosystem service category	Description	Evidence for ecosystem disservice	Potential indicators and spatial scale available
Decrease in food provision	a reduction in available food for human consumption caused by marine mammals	Marine mammal induced mortalities on fish stocks can lower the stock size available for fisheries (Trijoulet et al 2017). Competition is particularly visible when marine mammals exhibit depredation, which is the direct removal and consuming of, e.g., fish caught in nets, on hooks, or placed in aquaculture sea pens before they are retrieved for processing (Cook et al. 2005, Fjälling 2005, Northridge et al. 2013, Königson et al. 2013). In the Baltic Sea grey seals act as the final host of the gastric parasite *Contracaecum osculatum* for which cod is an intermediate host. Infections with *C. osculatum* decrease the size and fitness of cod, ultimately lowering their market value (Harder et al 2014, Horbowy et al. 2016, Mehrdana	biomass (t) of fish consumed by marine mammals in areas where fisheries target the same stocks (Trijoulet et al. 2017; Regional) biomass (t) or cost of fish removed from nets, hooks, or aquaculture sea pens due to depredation (Fjälling 2005; Northridge et al. 2013; Königson et al. 2013; Local to regional) percentage of fish mortality due to parasites known to come from marine mammals (unknown if data

		et al. 2014, Zuo et al. 2017).	exist)
Damage of fishing gear	direct or indirect destruction of gear by marine mammals	Operational interactions between fisheries and marine mammals leading to gear damage have mainly been documented in areas with seals (Fjälling 2005, Kauppinen et al 2005).	monetary cost ($) of repairing or replacing damaged gear (unknown if data exist) monetary cost of forgone fishing opportunities caused by damaged gear (unknown if data exist)
Decrease in recreational experiences	loss of recreational opportunities due to the behavior of marine mammals	Recreational fishing experiences in, e.g. , southern California are negatively affected by California sea lion depredation (Cook et al. 2008).	type of lost recreational opportunity and number of people affected (Cook et al. 2015; Local)
Pest increase and pathogen vectors	the transmission of pathogens from marine mammals to humans	Avian influenzas occur in harbor seal (*phoca vitulina*) colonies in both Europe and North America. In New England (U.S.A.), influenza strain H3N8 caused lethal pneumonia in 163 harbor seals (Anthony et al 2012; Zohari et al 2014).	presence of human pathogens in marine mammal populations (Anthony et al 2012; Local) number of recorded transmissions to, e.g., humans, pets, or lifestock (unknwon if data exist)
Transmission of contaminants	the transmission of harmful pollutants to	Health professionals in the Faroe Islands recommended the public stop eating meat and other products from pilot whales	presence and levels of pollutants in marine mammal products (Avila et

	humans through the consumption of marine mammal products.	becuase of unhealthy levels of, e.g. , PCB and mercury (Weihe & Joensen 2012). Presently 99 species of marine mammals have been found to be affected by pollution (Avila et al. 2018).	al. 2018, Weihe & Joensen 2012; Local). presence of pollutants in people consuming marine mammal products (Weihe & Joensen 2012; Local)