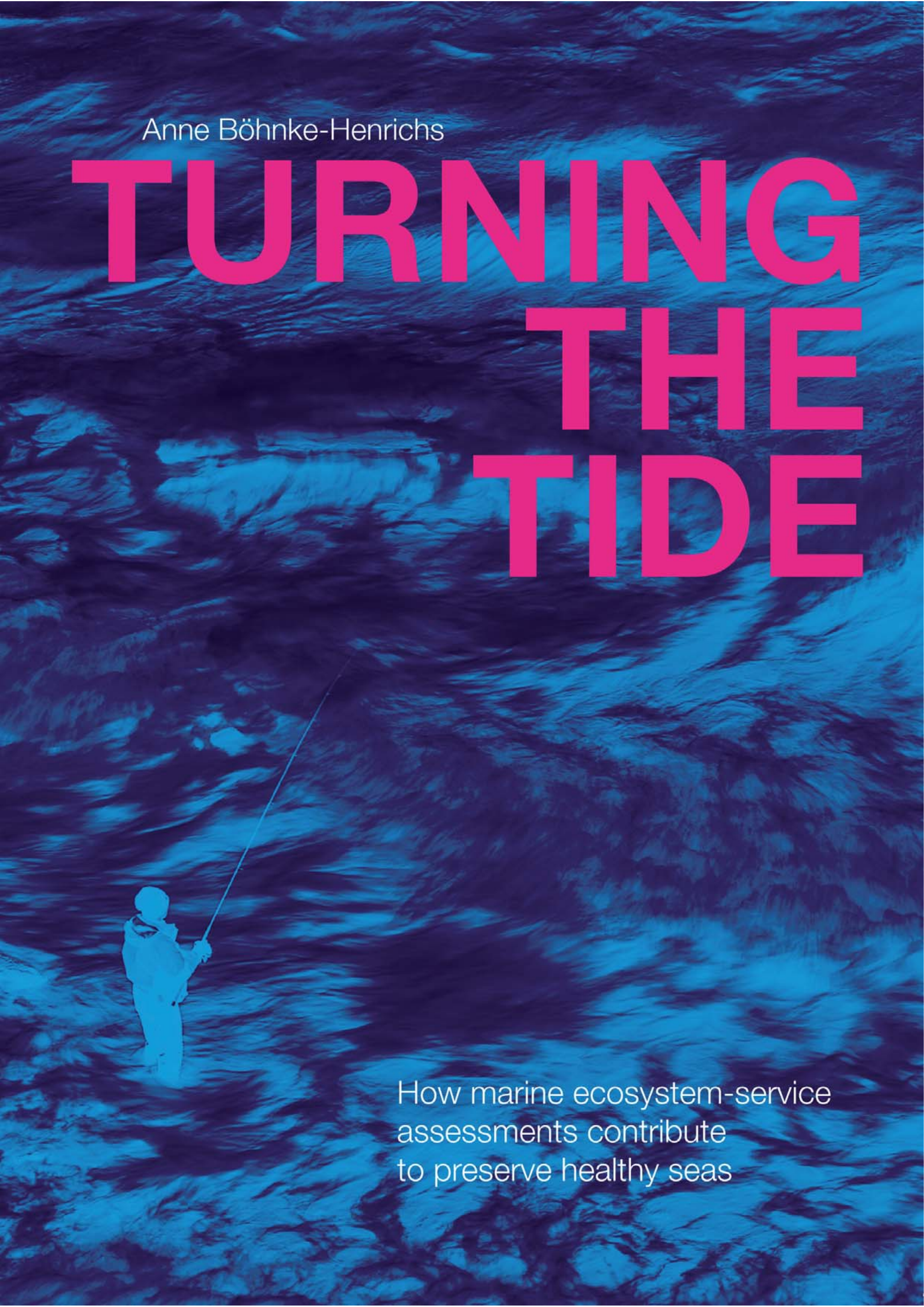
Anne Böhnke-Henrichs

TURNING THE TIDE



How marine ecosystem-service assessments contribute to preserve healthy seas

Propositions

1) Irrespective of which typology is used for nature's contributions to people's wellbeing, the general concept and its applications should be measured by its success in stopping marine ecosystem degradation and biodiversity loss.
(this thesis)

2) Although methods to assess ecosystem services at different scales and in different contexts are available, marine management decisions in Europe still disregard effects on ecosystem services.
(this thesis)

3) Salt marsh restoration is a long-term effort but provides immediate benefits to local residents.

4) As the neoclassical economic paradigm is no law from nature, we, as society, are free to choose other paradigms that are more suitable to sustain future life.

5) The EU's 'Better regulation' agenda undermines the need for strong institutions and effective regulations to manage resources sustainably.

6) The challenge is to be morally good and still live a good life.

Propositions belonging to the thesis, entitled
Turning the tide: How marine ecosystem-service assessments contribute to preserve healthy seas.

Anne Böhnke-Henrichs
Wageningen, 19 May 2020

Turning the tide:

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Turning the tide:

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Anne Böhnke-Henrichs

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To my sons Tore Erik, Maarten El Mar, Jarle Esben.

Children have the right to a clean environment.

UN Convention on the Rights of the Child

Contents

Chapter 1

General Introduction

1.1 Background

Marine ecosystems sustain the livelihoods of millions of people (e.g. FAO 2018), shape traditions and identity of coastal communities, provide food, moderate extreme weather events or mitigate effects of anthropogenic climate change by sequestering and storing carbon dioxide (CO_2). These are only a few examples how vitally marine ecosystems contribute to human well-being. These contributions are currently conceptualized as ecosystem services (ESs). The scientific consensus that these contributions are at risk due to globally degrading marine ecosystems, has recently increased (MA 2005, Worm et al. 2006, IPBES 2019, IPCC 2019). The decline of marine ecosystems health means that internationally agreed targets like the United Nation's Sustainable Development goals or the Aichi Biodiversity Targets set by the Convention on Biological Diversity, will be missed (IPBES 2019, IPCC 2019).

The decline in marine ecosystem health is caused by various cumulative anthropogenic pressures like climate change, destructive fisheries, organic and plastic pollution and coastal infrastructure (Halpern et al. 2007, Halpern et al. 2008, Jambeck et al. 2015). More than forty percent of ocean area is severely impacted by multiple pressures; one-third of global fish stocks are overfished; further sixty percent are fished at the maximum sustainable yield; and about half of all coastal wetlands have been lost during the past century (IPBES 2019, IPCC 2019). The climate crisis exacerbates these negative effects on marine ecosystems: increasing seawater temperatures and decreasing pH values affect, for instance, calcifying species, species distribution, marine habitats and marine food webs (IPCC 2019).

International policies have responded to the decline of the health of marine (and terrestrial) ecosystems. The United Nations' 2030 Agenda for Sustainable Development has been adopted by all United Nations' Member states in 2015 and essentially defines seventeen Sustainable Development Goals (SDGs). Goal 14 focusses on marine systems and aims to "By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans." Similarly but more generally, the Convention on Biological Diversity (CBD) aims to conserve biodiversity, and promote the sustainable use of its components and the fair and equitable sharing of the benefits. However, these aims have not yet been achieved, as the observed marine ecosystem decline illustrates. To reverse this trend, further efforts are required. These should be implemented by applying the Ecosystem Approach (https://www.cbd.int/ecosystem/). This highly ambitious central management concept is developed and adopted by the CBD and has also been adopted by marine policies like the European Marine Strategy Framework Directive (MSFD). The MSFD sets the frame for conserving and sustainably using European seas. In my research, I will focus both spatially and content-wise on this directive. The MSFD aims to achieve a so-called 'Good Environmental Status' of European seas. This means that ecologically diverse and dynamic seas which are clean, healthy and productive, are maintained and restored (MSFD, Article 3).

1.2 Defining ecosystem health

The notion of healthy marine ecosystems is recurring both in the global 2030 Sustainable Development Agenda and in the European MSFD. But what does it mean? Ecosystem health is frequently used as a metaphor that employs the meaning of human health as a desired state of physical, mental and social well-being (WHO 2006). However, Burkhard et al. (2008) emphasize that 'ecosystem health' has a broader, more complex meaning, because it extends beyond a mere ecosystem state and additionally captures social, economic and cultural aspects, as demonstrated by its inclusion in global and regional marine policies. In this regard, healthy marine ecosystems are considered a means to provide ESs and contribute overall to sustainable development (Rapport et al. 1998). Consequently, Burkhard et al. (2008) and Tett et al. (2013) suggest that a healthy ecosystem is resilient and thus maintains its organization under stress (e.g. external human pressures) and that a healthy ecosystem is able to sustainably supply ESs. This suggests that assessing ESs and their trends allows inferences on ecosystem health while management or regulative laws concerning marine ecosystems have to ensure that human pressures do not exceed ecosystem resilience, hence, pressures remain below critical thresholds so that an ecosystem collapse and switch into a different alternative ecosystem state is avoided (Folke et al. 2004). This understanding of ecosystem health acknowledges that also healthy ecosystems are exposed to anthropogenic pressures and thus reflects that today, particularly due to an anthropogenically impacted climate, even remote and hardly accessible ecosystems like the deep sea, are affected by anthropogenic pressures (Smith Jr et al. 2009, Ramirez-Llodra et al. 2011, IPCC 2019).

Box 1.1 Descriptors of Good Environmental Status (Annex 1, MSFD).
Descriptors in bold are addressed in my thesis, respective Chapters are indicated in italics.

Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions. *(Chapters 3, 4 and 5)*

Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems. *(Chapter 5)*

Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock. *(Chapter 3)*

All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.

Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom waters. *(Chapter 3)*

Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.

Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems.

Concentrations of contaminants are at levels not giving rise to pollution effects.

Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.

Properties and quantities of marine litter do not cause harm to the coastal and marine environment.

Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

In my thesis, I adopt the above described ecosystem-health definition proposed by Burkhard et al. (2008). This also coincides with the interpretation of the ecosystem-based approach asked for by the MSFD. This approach applies the dual criteria of ecosystem resilience and the capacity to sustainably provide ESs. My thesis focuses on the ES aspect herein and further specifies ecosystem health according to the eleven descriptors of ‘Good environmental status’ as listed by the MSFD (Box 1.1). These descriptors cover a broad range of different marine ecosystem aspects, including biotic aspects (e.g. biodiversity, non-indigenous species and commercial species), particular habitats (e.g. seafloor), abiotic aspects (e.g. hydrographic conditions) and pollution aspects (e.g. litter, eutrophication and noise). I focus on the first three biotic descriptors and eutrophication (Box 1.1).

1.3 The relation of Ecosystem Services and the Ecosystem Approach

The ecosystem approach is a variously interpreted management concept that emerged since the 1950s and initially attracted only little attention (Waylen et al. 2014). That changed in the 1990s when the United Nations negotiated on the CBD, which entered into force in 1993. During the early implementation process of the Convention, the ecosystem approach has been further developed and adopted as overarching management concept and today is defined as “a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way” (CBD (2004), page 6). The CBD substantially advanced the ecosystem approach particularly by identifying twelve guiding principles (Table 1.1), which are also known as the Malawi Principles, according to the workshop location where they have been developed (CBD 1998). Particularly these guiding principles turned the CBD’s ecosystem approach into a highly ambitious management concept that has not yet been fully implemented (Link and Browman 2017). The concept aims to achieve ecosystem conservation as a result of adaptive, cooperative, and participatory management. The ecosystem approach is thus more comprehensive than related concepts like ecosystem-based management or the ecosystem services approach, which are sometimes used interchangeably (Slocombe 1993, Waylen et al. 2014, Link and Browman 2017). Also the MSFD adopts the ecosystem approach, called ‘ecosystem-based approach’ in the directive’s wording. Despite this differing wording, the underlying management concept clearly aligns with the ecosystem approach and involves links to all twelve Malawi Principles (Table 1.1). How well and how intense these principles are effectively applied depends, however, on the implementation by individual EU member states.

Human activities play a central role within the ecosystem approach: Firstly, they are drivers of change, altering the ecological state of marine systems. Secondly, human activities are regulated by management measures and are thus the entry point for the ecosystem approach since human activities are managed, not the ecosystems themselves. Thirdly, human activities are affected by a changing ecosystem state. These three aspects are also captured by the ES concept. ESs are defined as the “direct and indirect contributions of ecosystems to human well-being” (de Groot et al. 2010). These contributions (i.e. the supply of ESs) depend on the ecosystems’ state that in turn is affected by anthropogenic pressures. ES assessments can reveal how these pressures eventually affect human well-being. This illustrates the complexity of the ecosystem approach. Implementing the approach requires to understand biophysical changes in the marine environment and to acknowledge that these changes affect human well-being.

Table 1.1 Malawi Principles of the Ecosystem Approach in relation to the MSFD and ES assessments

Malawi principles/CBD	MSFD management requirements	Relation to ES assessments
Principle 1:The objectives of management of land, water and living resources are a matter of societal choices.	Public consultation with all interested parties required (Article 19)	Societal ESs demand can inform management objectives
Principle 2: Management should be decentralized to the lowest appropriate level.	Management responsibility at member state level; management should be specific to sub-regions (recitals #10, 11; Article 5)	
Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.	Management strategies prepared for national level should consider and reflect management perspective of the entire region; member states should cooperate and coordinate management (recitals #13, Articles 5, 6); impact assessment of measures required (Article 13)	ES assessments at the entire regional sea level can reveal effects beyond the national level
Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context.	Adoption of the precautionary principle and polluter pays principle (recitals #27); incentives as measures to achieve MSFD objectives (Annex VI); cost-benefit analyses of measures (Article 13); incentives to achieve Directive's aims (Annex VI)	Estimate ES gains and losses related to management effects and thus contribute to more inclusive cost-benefit-analyses
Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.	priority is to be given to conservation and restoration (recitals #8, Article 1)	Understand the relationship between ecosystem structure and functioning; monitor changes in ESs
Principle 6: Ecosystem must be managed within the limits of their functioning.	Precautionary principle (recitals #27, Article 1)	
Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.	Time scales are defined at member state level (Annex IV); transboundary management effects should be considered (Article 11); coherent protected areas are intended (Article 13)	Understanding at which scales ESs are obtained and used can inform appropriate scale choice
Principle 8: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.	Exceptions recognize that achieving MSFD objectives may be delayed due to time lag in improving natural conditions (Article 14)	
Principle 9: Management must recognize the change is inevitable.	Flexible and Adaptive management required (recitals no. 34, Article 3); updating of management required (Article 17); Monitoring required; MSFD is to be evaluated and updated if required (Articles 5 and 11)	
Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.	Sustainable use of ES is enabled while priority is to be given to conservation and restoration (recitals #8, Article 1)	ESs assessments estimate biodiversity use and can reveal what further benefits are gained from conservation
Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.	Public consultation with all interested parties required (Article 19)	ESs concept facilitates communication of management implications for human well-being and thus can stimulate the integration of local knowledge
Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.	Consideration of social and economic concerns when environmental targets are set (Annex IV)	Integrate biological knowledge on biophysical ES changes and societal preferences

The ES concept and the ecosystem approach are interlinked, notwithstanding that clear differences have to be noted. While the ecosystem approach is a complex management concept that structures a management process, the ES concept can rather be considered a tool applicable at several stages within that management process (Table 1.1). For instance, societal preferences for ESs (Chapters 4 and 5) can be used for developing management objectives; impacts of management measures can be assessed or pre-estimated using the ES concept and effects can be expressed in ES changes (Chapter 3); ongoing observation of ES changes can be used to monitor effects of management implementation and assists in evaluating management outcomes. To apply the ES concept in this way, various approaches and methods are available which are briefly described in the following section, next to several challenges involved herein.

1.4 Ecosystem Service definitions, assessment approaches and their application in marine management contexts

The definition, conceptualization and framing of ESs is still in progress (Braat 2018, Díaz et al. 2018, Kenter 2018, Peterson et al. 2018) and scientific literature disagrees whether a generally agreed definition and classification of ESs is appropriate and required (Costanza 2008, Fisher and Kerry Turner 2008, Nahlik et al. 2012). The ESs core concept has been mainstreamed in the scientific literature more than two decades ago and has been established in the policy arena shortly after (Gómez-Baggethun et al. 2010). Since then, three major international initiatives at the science-policy interface, involving more than one thousand scientists each, shaped the ESs concept. First, the Millennium Ecosystem Assessment defined ESs as the benefits people obtain from ecosystems and distinguished four different ES categories: ‘provisioning’, ‘regulating’, ‘cultural’ and ‘supporting’ ESs (MA 2003). Particularly its broad ESs definition and including the supporting ES category have been criticized for confusing ESs and their related benefits and risks double counting when both the supporting ESs and the other ESs are valued (Boyd and Banzhaf 2007). A second major initiative, the TEEB study addressed these issues and defined ESs as the direct and indirect contributions of ecosystems to human well-being and removed the supporting ES category and added ‘habitat provision’ as a separate category to allow for including the service of ecosystems to maintain in situ biodiversity (de Groot et al. 2010). More recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) further developed the concept and introduced the term ‘nature’s contributions to people’ which Díaz et al. (2018, p. 270) defined as “all the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to people’s quality of life”.

When I started my PhD research in 2011, I adopted the, at that time most recent, TEEB definition and classification of ESs. The reason for choosing the TEEB classification was that I expected it to become a widely used, commonly agreed definition. Aligning my work with it offered the chance that my results would be (better) comparable with other assessments and thus could better contribute to the body of literature expected to emerge in response to the TEEB study and its guidance on ES assessments. Next to this pragmatic consideration, I also adapted the conceptual advancements offered by TEEB compared to preceding definitions. TEEB distinguishes 22 general ES types without defining each of them too narrow to keep the typology open to interpretation and flexible to adaptation to specific assessment contexts. This involves the challenge for each assessment to develop its own typology of specific (sub) services. I addressed this challenge by developing an ES typology specific to marine ecosystems. This typology forms a conceptual basis of all case studies that are part of my thesis.

Assessment frameworks are frequently used to structure and analyse complex systems (Ostrom 2009). An example is the concept of socio-ecological systems, which are conceived as interwoven complexes of ecosystems and human societies and are characterized by various mutual flows of material and information and by human activities and institutions. Within such socio-ecological systems, ESs can be considered a connector that intertwines societies and ecosystems. For structuring the complexity of socio-ecological systems from an ES perspective, the so-called 'ES cascade' is frequently used as a framework (Figure 1.1). The cascade describes the steps to be followed for understanding how an ecosystem aspect (i.e. biological structure or process) becomes an ES that contributes to human well-being). The cascade steps are influenced by three main feedback loops that depend on institutions and societal preferences. The cascade depicts ESs as the central conjunction between the two sides, ecosystems and human well-being. These two sides suggest that ESs can be assessed from two different perspectives, i.e. from an ecosystem (left-hand side of the cascade) and from a human well-being (right-hand side of the cascade) perspective (Figure 1.1) (Spangenberg et al. 2014). The ecosystem perspective allows analysing the supply of ESs (i.e. the materials or information that are provided by the ecosystem as ESs). The human well-being perspective analyses the demand for ESs (i.e. how much of which ES is desired and used by society). A combined analysis of ES supply and demand is a relevant basis for ecosystem management (Burkhard et al. 2012, Schröter et al. 2012). Societal ES demand that exceeds sustainable ES supply indicates a conflict within the socio-ecological system. To respond to that conflict, management complying with the ecosystem approach can either increase ES supply or decrease societal demand (Villamagna et al. 2013). Unsustainable management, however, tends to exploit ESs beyond their sustainable use and thus risks their long-term supply and the supply of other ESs as well (Braat et al. 2008, de Groot et al. 2010). ES supply depends on the ecosystems' capacity for providing that ES. This capacity can, for example, be increased by reducing human pressures or restoring habitats (de Groot et al. 2010, Villamagna et al. 2013). Societal demand can be influenced by information, education or participatory management approaches (Chapter 4). Where societal demand cannot be successfully influenced, institutions or regulative laws can restrict the use or appropriation of ESs (National Research Council 2002, Ostrom 2010). For instance, extraction licenses can limit provisioning ESs' appropriation; restrictions for emissions or pollutants help to maintain regulating ESs; access rights can control cultural ESs use.

The assessment of supply and demand requires differing methods (Burkhard et al. 2012, Hattam et al. 2015b). The supply of ESs is frequently assessed using an indicator approach that applies indicators at the first three cascade steps to describe management effects on ESs (van Oudenhoven et al. 2012, Hattam et al. 2015a). The approach recognizes that indicators, that are used to characterize one cascade step, control indicators of a subsequent cascade step. In principle, this approach provides only insights into what ecosystems potentially contribute to human well-being, because it does not involve an assessment of what is actually used (or whether an ESs is used at all) (Burkhard et al. 2012). This is an important constraint to consider.

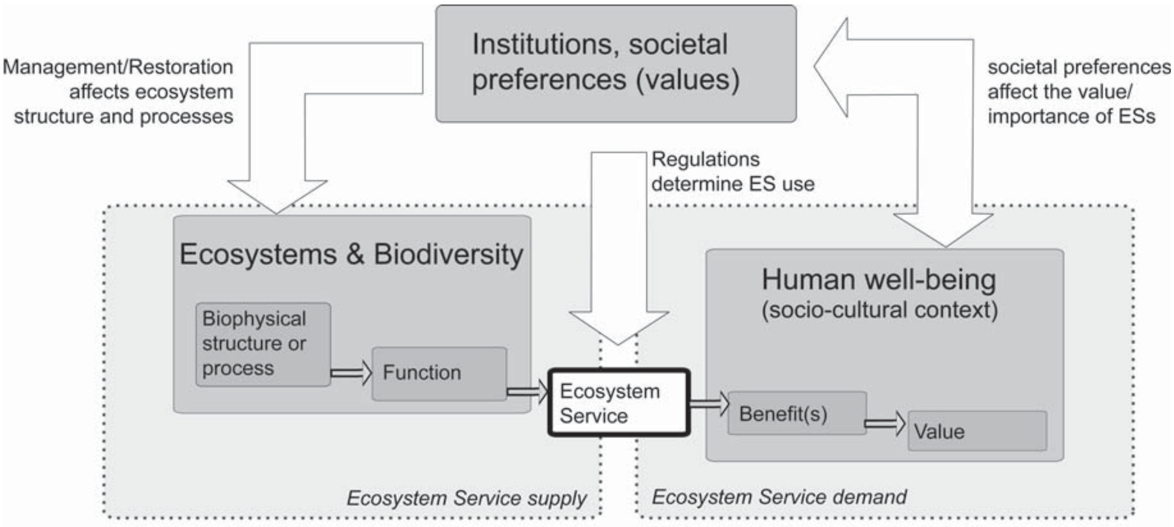

Figure 1.1 The ES cascade as a framework for structuring the complexity of socio-ecological systems. The cascade has been adapted here to emphasize that ES can be assessed from two perspectives, this is their supply and demand (adapted from de Groot et al. 2010)

The demand for ESs can be assessed by stated or revealed preference methods (Scholte et al. 2015, Schmidt et al. 2016). Just as ES supply, also societal demand is variable over time (Chapter 4) and assessments face the challenge to capture such changes. A second challenge is to integrate assessments of ES supply and demand, because this requires to integrate varying methods that differ in several aspects: (1) Definition: where technical ES definitions applied in biophysical studies are usually ill-suited for interaction with a lay audience involved in stated preference studies (Thompson et al. 2016), adapted ES descriptions for a lay audience can hamper transferability into technical ES typologies; (2) Units of measurement: where ES supply assessments use biophysical units (e.g. amount of an ES per unit of area per unit of time) stated preference studies often apply a scoring or ranking of ESs (Hattam et al. 2015, Scholte et al. 2015); (3) Management scenarios: ES supply assessments can deal with complex management scenarios while stated preference methods require a translation and reduction in complexity to be comprehensible by respondents (Hattam et al. 2015a, Börger et al. 2018).

A third challenge is to include several ESs in marine ES assessments. The assessments are considered particularly beneficial to management decisions in case a broad range of different ESs is analysed. Such analysis facilitates the comprehensive consideration of several different management implications or ES changes and helps to avoid negative management effects (Bennett et al. 2009, de Groot et al. 2010). Marine ES assessments, however, in most cases analyse only a single ES while only approximately every tenth assessment analyses more than five ESs (Liquete et al. 2013). This suggests that the full potential of marine ES assessments is not yet tapped and that the many single ES assessments increase the risk to negatively affect many other ESs (de Groot et al. 2010). My thesis addresses this issue by aiming for comprehensive ES assessments with a broad range of ESs.

1.5 Objective

International and the European marine policy agendas face the challenge to conserve and restore marine ecosystems. This challenge is to be addressed by applying an ecosystem approach that aims, inter alia, to ensure the sustainable provision of ESs. Developing, adapting and applying ES assessments towards this policy goal to achieve healthy seas is thus the major objective of my thesis. This objective is addressed by interdisciplinary research that is guided by the following research questions (RQs):

RQ 1 Which marine ESs can be identified and which indicators can be used to quantify them?

RQ 2 How can changes in marine ES supply, as a consequence of various management activities, be determined?

RQ 3 How can stakeholder involvement and analysing ES demand inform marine ecosystem managers?

RQ 4 How can different methods to analyse marine ESs be integrated and what is the added value of such integration?

RQ 5 How do marine ecosystem-service assessments contribute to preserving healthy marine ecosystems?

These RQs were addressed by different case studies in the Black Sea, the Mediterranean Sea and the North Sea. These three case studies applied a joint marine ES typology at different spatial scales to assess marine ESs in the context of current marine management challenges.

Black Sea case study

The Black Sea is located between Europe and Asia and extends to about 460,000 square kilometers and a maximum depth of about 2,200 meters (Goncharov et al. 2018). It is enclosed by the coasts of Bulgaria, Romania, Turkey, Georgia, Russia and Ukraine. Three of which are either European Union members or candidate member States (Turkey). The Black Sea is thus subject to the EU's MSFD. The MSFD's policy goal of 'Good Environmental Status' currently failed for the Black Sea, due to, amongst others, a heavily disturbed food web (Yunev et al. 2017). Restoration of the impaired food web is thus crucial to achieve a good environmental status in the Black Sea region and, accordingly, two related human pressures (eutrophication and fisheries) have been selected as management focus of this study (Chapter 2). My study compared three different management scenarios that combine fishing at maximum sustainable yield with different levels of primary production (reflecting the Black Sea's eutrophication status). The study aimed to reveal trends of marine ES supply under the three management scenarios at the scale of the entire Black Sea. Therefore, the study developed a set of indicators for ecosystem processes, functions and ESs and maps, how these indicators are interlinked in ES supply. The study further explored how fisheries and eutrophication targeted management interact and cumulatively affect ES supply.

Mediterranean Sea case study

The Mediterranean Sea case study area was located at the northern Adriatic coast in the northern Venice Lagoon. The lagoon is a UNESCO World Heritage site and protected under the

EU's MSFD, the Habitats Directive and the Birds Directive. Salt marshes are protected habitats in the lagoon and their conservation is a current management challenge. About seventy percent of salt marshes were lost during the past century due to erosion. Salt-marsh erosion in this case study was addressed by local restoration and conservation measures that are imbedded in a participatory conservation project, LIFE VIMINE (http://www.lifevimine.eu/, Barausse et al. 2015). The case study aimed to understand local resident's demand for salt marsh ESs and explored what preferences residents have towards salt-marsh management. This case study further aimed to understand how these values and preferences changed in the context of the participatory project LIFE VIMINE. To achieve these aims, the study surveyed local residents twice during the project's lifetime.

North Sea Case Study

The North Sea case study area was the Dogger Bank, which is a large submerged sandbank in the southern North Sea. It extends to about 19,000 km^2 to the Exclusive Economic Zones of the United Kingdom, The Netherlands, Germany and Denmark. The Dogger Bank is subject to the MSFD and is protected under the EU's Habitats Directive but faces pressures from fisheries and current offshore wind farm developments. The wind farms introduce hard substrate in the soft bottom, sandy environment. This alters the sandbanks' characteristics and causes a shift in species composition. Underwater noise emissions during wind farm construction (pile driving) and operation (intensive service vessel traffic) are in conflict with marine mammal conservation. The case study was split into three parts to analyse ESs supply and demand and management preferences with three different methods. The overall aim was to synthesize findings, analyse potential conflicts or synergies between ES supply and demand and thus to contribute to better informed marine management decisions.

1.6 Outline

The three case studies of my thesis cover three different spatial scales (a regional sea, a sub-regional sandbank, a local salt marsh) and three different aspects of ES assessments: ES supply, ES demand and the integration of supply and demand. Each of the three aspects is dedicated a separate Chapter of my thesis. The three case studies are based on a joint marine ES typology that is developed in Chapter 2, following this introduction. Chapter 3 analyses ES supply and develops a set of indicators to link ecosystem management and ES changes. Such an indicator approach faces the following challenges: (1) suitable indicators are required at each cascade level and they need to be responsive to the management changes intended to be assessed; (2) understanding is required of how the indicators of different cascade levels are connected; (3) lack of suitable data that confines marine assessments much more than terrestrial equivalents (Beaumont et al. 2017, Drakou et al. 2017). This lack of data is even aggravated at the spatial scale of an entire region at which good environmental status should be determined (Busch et al. 2013), according to the MSFD. These challenges are addressed in Chapter 3 in a case study on nutrient and fisheries management in the Black Sea. Chapter 4 analyses societal demand for ESs and management preferences based on surveys and applying a contingent valuation approach. Since societal demand and management preferences can be variable over time, I addressed the challenge to capture this variability in a case study of a local salt marsh conservation project in the Venice Lagoon. Chapter 5 adopts a mixed-methods approach in which ES supply and societal ES demand and management preferences are initially assessed with separate methods and subsequently integrated for a more comprehensive assessment that covers the entire ES cascade. Challenges related to the integration of different methods, such as different ES definitions, units of measurement and management scenarios are addressed. Chapter 6 discusses insights obtained in previous chapters and draws general conclusions on how ESs assessment can contribute to achieving the policy goal of healthy seas (see Figure 1.2 for an overview).

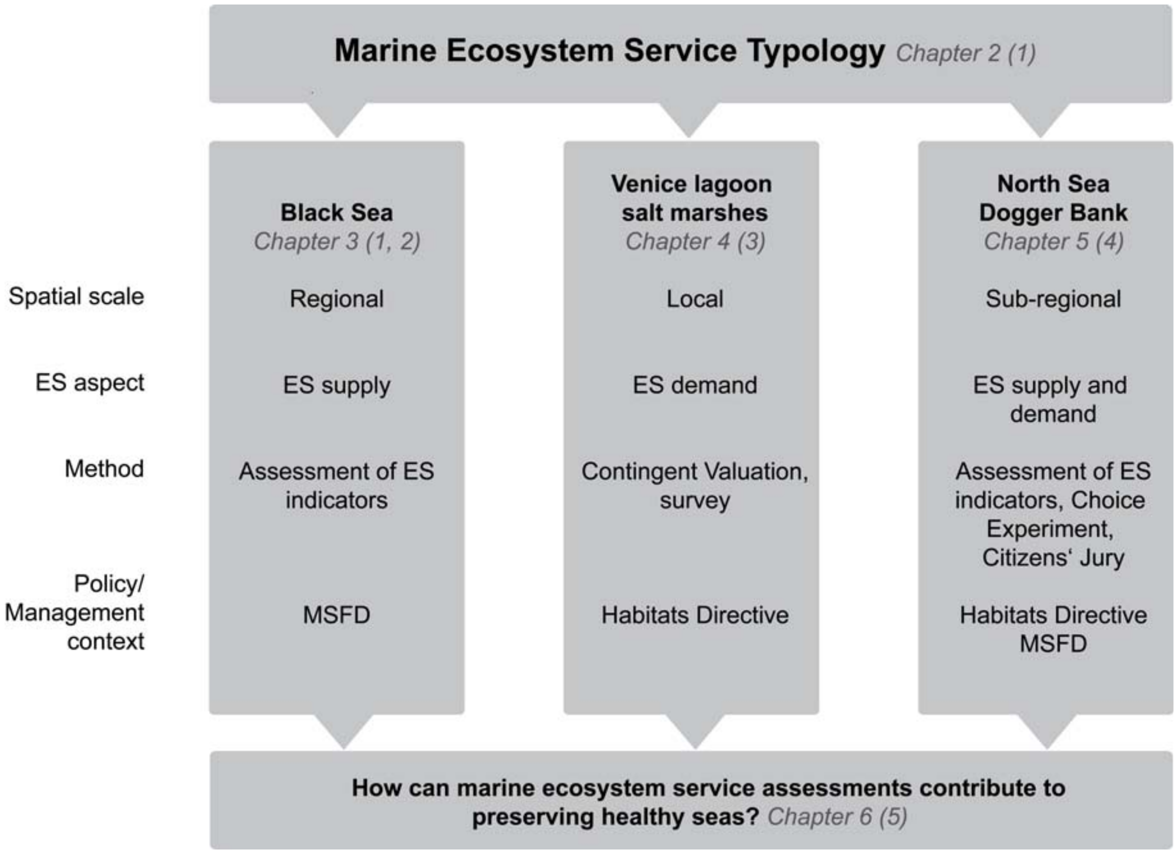

Figure 1.2 Outline of this thesis that provides an overview of included Chapters in relation to addressed research questions (numbers in brackets).

Chapter 2

Typology and indicators of ecosystem services for marine spatial planning and management

The ecosystem services concept provides both an analytical and communicative tool to identify and quantify the link between human welfare and the environment, and thus to evaluate the ramifications of management interventions. Marine spatial planning (MSP) and Ecosystem-based Management (EBM) are a form of management intervention that has become increasingly popular and important globally. The ecosystem service concept is rarely applied in marine planning and management to date which we argue is due to the lack of a well-structured, systematic classification and assessment of marine ecosystem services. In this paper we not only develop such a typology but also provide guidance to select appropriate indicators for all relevant ecosystem services. We apply this marine-specific ecosystem service typology to MSP and EBM. We thus provide not only a novel theoretical construct but also show how the ecosystem services concept can be used in marine planning and management.

Based on: Böhnke-Henrichs, A., C. Baulcomb, R. Koss, S. S. Hussain & R. S. de Groot. 2013. Typology and indicators of ecosystem services for marine spatial planning and management. Journal of Environmental Management. 130, 135-145.

2.1 Introduction

The increasing human pressure on marine resources, and the failure to date of single-sector marine policies to achieve sustainable resource use, has resulted in recent policy shifts towards the adoption of ecosystem-based management (EBM). This adoption of EBM intends to facilitate protection, recovery, and sustainable use of marine environments (Directive 2008/56/EC of the European Parliament and of the Council, The White House Council on Environmental Quality 2010, The White House Office of the Press Secretary 2010). Worldwide, EBM examples can be found. Australia, for instance, has focused on sustainable multiple use management since 1997 (Sainsbury et al. 1997). Similarly, Canada adopted EBM and has developed a suite of objectives and indicators to meet the principles of sustainable development and integrated management of ocean resources (Canadian Science Advisory Secretariat 2001). Likewise, the USA adopted the National Oceans Policy in 2010, which emphasizes the EBM approach in its coastal and marine zones (The White House Council on Environmental Quality 2010, The White House Office of the Press Secretary 2010).

The European Union (EU) has also developed a comprehensive Maritime Policy, which includes the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC of the European Parliament and of the Council 2008) and the recently proposed Maritime Spatial Planning Directive (pMSPD) (European Commission 2013). This Maritime Policy adopts EBM to support environmentally and socially sustainable development, in addition to improving the quality of Europe's regional seas (Directive 2000/60/EC of the European Parliament and of the Council, European Commission 2006, 2007, Directive 2008/56/EC of the European Parliament and of the Council). Moreover, the co-existence of conflicting marine sector activities must be facilitated (European Commission 2013). Both MSFD and pMSPD explicitly link marine planning and management with the ecosystem services[1] (ES) concept. According to the MSFD, the marine strategies adopted by the EU member states in the future must enable the sustainable use of ESs (Article 1). The MSFD emphasizes the importance of healthy ecosystems as a prerequisite for ESs to be provided (Directive 2008/56/EC of the European Parliament and of the Council). Similarly, the pMSPD aims to "halt the (...) degradation of ecosystem services" (Article 5) and requires member states to consider ESs in their coastal management strategies (Article 8).

This illustrates the importance of the ES concept for marine planning and management. This connection, unfortunately, has not gained much attention as yet in the literature. For instance, while several publications identify and discuss required advances in MSP (Ehler and Douvere 2010, Flannery and Ó Cinnéide 2012, Halpern et al. 2012, Jay et al. 2012), the integration of ESs in assisting the MSP process is largely unexplored. This lacking consideration of ESs in marine management and planning to date may be contributing to the continued absence of an integrative approach in marine management. Consequently, single sector development plans are still dominating which involves largely unresolved conflicts among different coastal user groups, and continued unsustainable resources use (European Commission 2011).

We argue that the ES concept can be embedded in the application of MSP and EBM in order to facilitate the consideration of multiple uses and impacts, as well as the analysis of use conflicts and trade-offs implied by different management and development options. This way, the integration of ESs can advance EBM and MSP beyond commonly used single sector management.

[1] See Section 2.3 for the definition of ecosystem services adopted by the authors of this paper.

The assessment of ESs helps to bridge the conceptual gap between the natural and social sciences (i.e. between marine ecosystems and human preferences) by linking the state of ecosystems (i.e. their processes and functions) with human well-being and activities, even (or perhaps especially) when formal markets are incapable of doing so (MA 2005, TEEB 2010). This potential of the ES concept is important given that there is a tendency within decision-making to ignore social welfare changes that are not directly quantified through market-based measures, and that humanity's ultimate reliance is on well-functioning ecosystems (Brown et al. 2007, Beaumont et al. 2008, Boyd 2008).

This paper aims to make the potential of the ES concept for marine planning and management accessible, by:

1. Providing a clearly structured, internally consistent and operational ES typology that is adapted for use in marine ecosystems and associated management approaches, for example, EBM and MSP.
2. Providing guidance on the application of the typology by (i) linking the typology to a set of possible indicators to quantify the provision of ESs; (ii) identifying related benefits; (iii) identifying services which can be enjoyed directly and those which require other forms of capital before they can be enjoyed.
3. Discussing and illustrating the application of the typology in MSP and EBM.

To address these aims, this paper is organized as follows: In Section 2.2, we present an overview of extant ES classifications and use the extant literature as a starting point to define our requirements for a new EBM/MSP oriented ES typology. In Section 2.3, we both present and elaborate on our novel marine-focused ES typology and in Section 2.4 provide guidance for operationalizing the ES typology (through indicators, required capital input and the identification of benefits). In Section 2.5, it is explained how the ES typology and related outcomes of this paper can be applied for EBM. Together, the various components of this paper illustrate the need for a new marine ES typology that identifies and addresses the gap in the ES field and its application in MSP and EBM.

2.2 Existing terrestrial and marine ecosystem services classifications

Early comprehensive classifications of ESs and their applications originate in the 1990's (de Groot 1992, Costanza et al. 1997, Daily 1997) where they provided guidance to classify natural ecosystems' contributions to human well-being. These early typologies allowed ES research to diversify, generating several different ES classifications (e.g. MA 2005, Farber et al. 2006, Beaumont et al. 2007, Boyd and Banzhaf 2007, Wallace 2007, de Groot et al. 2010, Atkins et al. 2011).

The existing typologies have been reviewed against the following criteria:

a. ES definition: Does the applied definition distinguish between ecosystem processes, ecosystem services, related benefits and values? This is important, because this cascade allows to translate a change in ecosystem state (as induced, for instance, by planning or management) into related implications for human well-being.

b. ES categories: Which categories (e.g. provisioning or supporting services) of ES are applied?

c. Specific ESs considered. Which service types are included and are these capable of reflecting changes in ecosystem state? The latter question is crucial for applying this typology in EBM or MSP, where different management options or spatial scenarios influence the state of an ecosystem.

The review against the above criteria yielded the following results:

2.2.1 ES definitions in existing typologies

Recent typologies present definitional limitations wherein ESs are frequently defined to be the benefits people obtain from ecosystems (MA 2005, Farber et al. 2006, Beaumont et al. 2007, Wallace 2007). Although this definition is generally accepted, de Groot et al. (2010), Boyd and Banzhaf (2007) and Atkins et al. (2011) point out that benefits and services need to be independently distinguished, stressing that one service can deliver multiple benefits, which can be economically valued. ES definitions, which confuse different levels of the ES cascade (i.e. processes – functions – services – benefits – values; see Figure 2.1), are considered inappropriate here, because they interrupt this cascade and thus impede the smooth translation of ecosystem state changes (as introduced, for instance, through marine planning and management) into implications for human well-being.

This applies also for the two existing marine-focused ES typologies. Beaumont et al. (2007), for example, considered ES to be synonymous with benefits, while Atkins et al. (2011) equated ES with ecosystem processes. This implies that the existing marine ES typologies are based on problematic definitions, because they fail to make appropriate distinctions between processes, which provide the services, and the magnitude of the benefits derived from the services.

2.2.2 Classification of ES in existing typologies into ES Categories:

The majority of ES typologies mentioned above (MA 2005, Farber et al. 2006, Beaumont et al. 2007, Wallace 2007, de Groot et al. 2010, Atkins et al. 2011) aim to contribute to EBM-focused decision-making and all include the provisioning, regulating, and cultural services categories. However, five of them also include the supporting service category[2] (termed fundamental services in one case) within the typology itself. Although this category was introduced by the Millennium Ecosystem Assessment (MA 2005), its inclusion in a typology intended for application in a context where economic trade-offs must be analysed is problematic, because it substantially increases the risk of double counting when aggregating valuations across service

[2] Other than the ES definition applied by these typologies (i.e. *benefits people obtain from ecosystems*) suggests, supporting services are not directly beneficial to people. They are rather a prerequisite for other services being provided and that way *support* these actual services.

categories[3]. As was the case with the ES definitional issues, the two explicitly marine focused typologies identified (Beaumont et al. 2007, Atkins et al. 2011) include the supporting (or fundamental) service category. This limits their suitability for economic valuation.

2.2.3 Specific ES included in existing typologies:

For applying the ES concept within MSP or EBM, the specific ESs included within typologies and the specific service definitions used are also important to consider. For instance, Farber et al. (2006) define the service Raw Material as "building and manufacturing, fuel and energy, soil and fertilizer". This definition suggests that both wind energy and non-renewable energy would be considered to be an ES within this particular typology. This, in turn, limits the ability of this service to reflect changes in ecosystem state. Indeed, only the examples reveal the biological focus of this service while the typology itself is not explicit about this issue – a feature of this typology that undermines its usability in the context of EBM and MSP.

Individual ES definitions can also be problematic if they fail to maintain the aforementioned distinctions between services, benefits, and values. Beaumont et al. (2007) include as a service type Option Use Value, with the corresponding specific service of Future Unknown and Speculative Benefits. However, in the often used Total Economic Value framework[4], value types (such as option value) are not considered to be separate services, but are instead considered to be subsets of the Total Economic Value of an ecosystem service that, in turn, reflects the importance of services to people. This is a key distinction to make – between services and humankind's perception of their importance. We agree that the option use value of ecosystem services deserves attention in decision-making, but its inclusion as a separate service is problematic and can both confuse and undermine the valuation process.

The above analysis of ES typologies reveals the weaknesses of existing marine-focused typologies. This suggests that their application is problematic in the context of EBM and MSP and it implies that in the absence of an improved marine-specific typology the terrestrially-focused typologies must be adapted for use in marine systems on a case-by-case basis. In turn, this may have a number of consequences that undermine the effectiveness of MSP or EBM-focused measures. For example, different marine management initiatives or spatial planning units rather likely use different, and potentially fundamentally contradictory, service definitions. Consequently, this may cause inconsistencies between different (neighboring) planning or management units. Additionally, using different and inconsistent ES typologies would likely complicate comparisons between different EBM approaches and MSP case studies. This would inhibit the transfer of experiences and lessons learnt between different case study

[3] Double counting occurs when the value of an ecosystem service is counted more than once which causes distortions in the valuation results. Double counting can be caused, for instance, by insufficiently delineated services or by valuing a service and additionally its underlying processes (as such included in the supporting services category). For example, if all marine organisms extracted from the sea are valued (including those used as fodder in aquaculture) and additionally, aquaculture products themselves are valued as well, this involves double counting the portion of marine organisms used as fodder, because the value of the final aquaculture product contains/subsumes the value of the inputs, including that of the fodder. In an application-oriented ecosystem service typology – i.e. one that can be used for monetary valuation in EBM or MSP processes – double counting must be avoided. For the purpose of the typology proposed here, therefore, the supporting services category is considered not appropriate.

[4] For more details on the Total Economic Value framework see, for instance, Pascual, U., R. Muradian, L. Brander, E. Gómez-Baggethun, B. Martín-Lopez & M. Verma. 2010. The economics of valuing ecosystem services and biodiversity. 5 In: P. Kumar, The Economics of Ecosystems and Biodiversity (TEEB): Ecological and Economic Foundations, pp. 183-256. Earthscan, London, Washington

sites. A third issue that could arise from case-by-case adapted terrestrially-focused typologies relates to the economic valuation of ESs via the benefit transfer[5] approach. Where different valuation studies use different ES definitions, the ability of the analyst to justify transferring value estimates from one case study to another is severely undermined.

2.2.4 Synthesis

Considering the extant ES classifications, there are three main reasons for developing a new typology specific to EBM and Spatial Planning for a marine context: (i) ES typologies developed with a terrestrial focus cannot be smoothly transferred to applications in marine ecosystems; (ii) the use of extant typologies is problematic for economic valuation; and (iii) several specific ES types and definitions found within existing typologies are not capable of reflecting changes in the state of the marine ecosystem. Given the absence in the literature of a typology that meets all these requirements, we propose in the following section a marine ecosystem services typology.

2.3 Typology of marine ecosystem services for Ecosystem-Based Management and Marine Spatial Planning

The typology presented in this paper addresses the issues raised above while being consistent with The Economics of Ecosystems and Biodiversity framework (TEEB 2010). This framework distinguishes between ecosystem processes, services, benefits and values (Figure 2.1). In the context of MSP and EBM, this separation of the different ES cascade levels is critical and recognizes that the ES definition and/or typology needs to facilitate the analysis of trade-offs implied by human actions and environmental management strategies.

In the TEEB framework, biophysical structures and processes interact and generate ecological functions. In turn, these ecological functions generate ESs that are definable and measurable entities. Humans derive benefits from these services. These are the social preferences, which may be quantified and explicitly included in economic analyses for decision-making (see Figure 2.1). In the case of coastal wetlands, for example, the TEEB framework recognizes that coastal wetlands are formed by biophysical processes that enhance sedimentation. Therefore, the wetlands function ecologically as natural buffers during storms. This function is described as providing the ecosystem service of Disturbance Prevention where human infrastructure is protected from naturally occurring impacts such as wave surges or storms originating from the ocean. The individuals to whom this service is provided benefit from this service.[6] Depending on their understanding of their relationship to the marine ecosystem and their personal preferences[7], these individuals may or may not value the benefit derived from the service.

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[5] Valuation studies on ecosystem services can be quite time and money consuming. A quicker and cheaper option is the benefit transfer approach, because it is based on data available from existing valuation studies. These original value estimates are transferred to value ecosystem services in a new study area.

[6] As their lives, property and livelihoods would experience increased threats in the absence of the services

[7] Value may, for example, be expressed through actions designed to protect the relevant ecosystem. Failing to value the ecosystem service may result in decisions that undermine the provision of the service and increase risk to life and property, which may, in this example, result in people incurring damage and replacement costs after storms/extreme events.

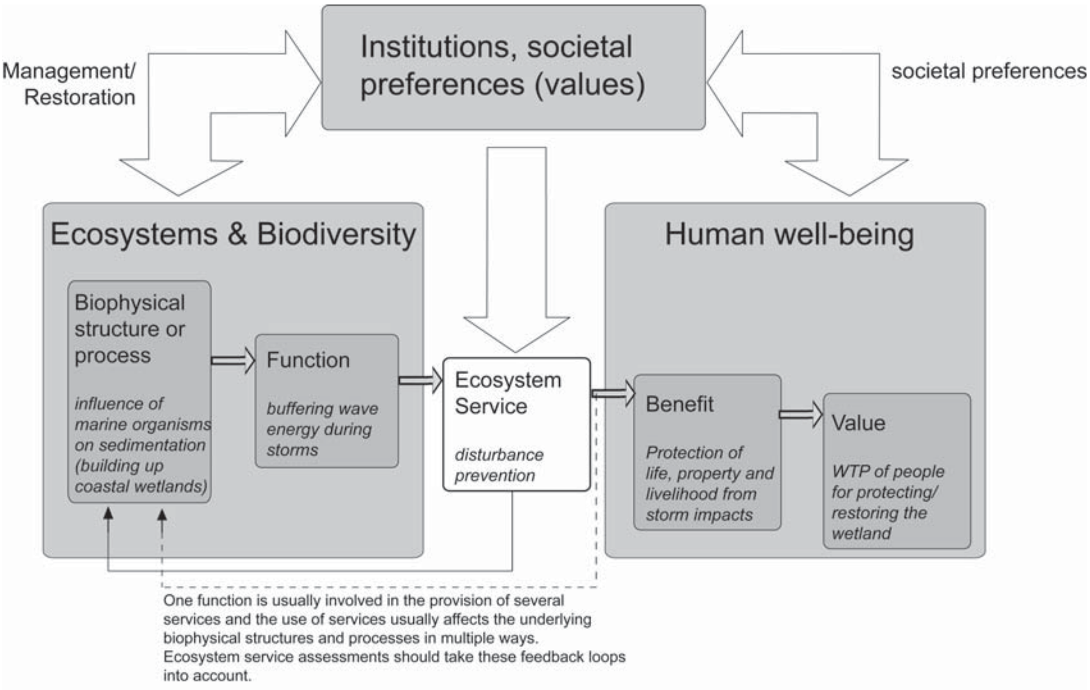

Figure 2.1 Linking ecosystem structure and processes to human well-being applying the example of the service Disturbance Prevention or Moderation in the marine environment (adapted from De Groot et al. (2010), based on Haines-Young and Potschin 2010).

2.3.1 Definition of ES within the proposed typology

In order to facilitate the separation of the different levels of the ES cascade (Figure 2.1) we use the following definition of ESs (de Groot et al. 2010):[8] "ecosystem services are the direct and indirect contributions of ecosystems to human well-being"

In addition to maintaining this type of separation between functions, processes, services, benefits, and values, our typology strives to be internally consistent, meaning that there is consistency between the generic definition of 'ES' used and the specific descriptions, definitions, and examples of the specific services provided in the typology. The proposed typology therefore addresses one of the main critiques of existing ES typologies as described in Section 2.2, and should help to alleviate one of the major constraints to the adoption and operational use of the ES typologies published to date (Boyd and Banzhaf 2007). An internally consistent typology facilitates the consideration of explicit links between the ecological processes that are responsible for providing ES and the economic valuation of the benefits that those services provide (Chapman 2008, Fisher et al. 2009). Hence, this will be crucial for the utility of ES assessments in the context of trying to improve marine management.

In order to achieve internal consistency, each ES was assessed for compliance to the generic service definition (shown above) prior to inclusion in the typology (Table 2.1). Additionally, every ES that was defined and included within the typology was explicitly constrained in terms

[8] This definition implies that ecosystem services contribute to human welfare through the creation of benefits which people may/may not recognize and value. In our interpretation of this definition, by 'direct,' we mean that the services generate benefits for humanity directly and without needing to be paired with other forms of capital. By 'indirect,' we mean that the services generate benefits through their pairing with other forms of capital. 'Direct' and 'indirect' should not, therefore, be construed as being equivalent to the label of 'final' or 'intermediate,' respectively, when it comes to describing services (for examples see Table 2.2).

of scope so as to avoid overlap with the other ES identified. Creating the typology in this way required a combination of both minor, largely semantic adjustments to existing service characterizations (for example, include the following: 'Food' is adapted and restricted to Seafood, Erosion Prevention is restricted to Coastal Erosion Prevention, and Biological Control is redefined to focus on marine pest and disease control), as well as, more substantively, the creation of specific definitions for each service included in the typology. These are included in sufficient detail to make the boundaries between each of the services explicit and therefore to facilitate its application in management or spatial planning.

Table 2.1 Typology of marine ecosystem services.

Ecosystem services	Definition	Examples
Provisioning Services		
Seafood	All available marine fauna and flora extracted from coastal/marine environments for the specific purpose of human consumption as food (i.e. excluding for consumption as supplements)[2]	Fish, shell fish, seaweed
Sea Water	Marine water in oceans, seas and inland seas that is through biological processes maintained at appropriate quality and extracted for use in industry and economic activity	Seawater used in shipping, industrial cooling, desalinization
Raw Materials	Biotic material extracted from coastal/marine environments, excluding those included in Ornamental Resources	Algae (non-food), sand, salt
Genetic Resources	Genetic material from marine flora and fauna extracted for use in non-medicinal contexts, excluding the research value on Genetic Resources that is covered by ES Information for Cognitive Development	The use of marine flora/fauna-derived genetic material to improve crop resistance to saline conditions
Medicinal Resources	Any biotic material that is extracted from the coastal/marine environment for its ability to provide medicinal benefits, excluding the research value on Medicinal Resources which is covered by ES Information for Cognitive Development	Marine-derived pharmaceuticals; marine/coastal-derived salt-water used for health purposes
Ornamental Resources	Any biotic material extracted for use in decoration, fashion, handicrafts, souvenirs, etc.	Shells, aquarium fish, pearls, coral
Regulating Services		
Air Purification	Removal of air pollutants by coastal/marine ecosystems	The removal from the air of pollutants like fine dust and particular matter, sulphur dioxide, carbon dioxide, etc.
Climate Regulation	The contribution of the biotic elements of a coastal/marine ecosystem to the maintenance of a favourable climate	The production, consumption and use by marine organisms of gases such as carbon dioxide, water vapour, nitrous oxides, methane, and dimethyl sulphide
Disturbance Prevention or Moderation	The contribution of biotic marine ecosystem structures to the dampening of the intensity of environmental disturbances such as storm floods, tsunamis, and hurricanes	The reduction in the intensity of and/or damage caused by environmental disturbances resulting directly from marine ecosystem structures like salt marshes, sea grass beds, and mangroves
Regulation of Water Flows	The contribution of biotic marine ecosystem structures to the maintenance of localized coastal current structures	The effect of macro algae on localized current intensity; The maintenance of deep channels by coastal currents which are used for shipping
Waste Treatment	Storage, burial, and biochemical recycling of pollutants by coastal/marine ecosystems	The breakdown of chemical pollutants by marine microorganisms; The filtering of coastal water by shell fish
Coastal Erosion Prevention	The contribution of coastal/marine ecosystems to Coastal Erosion Prevention, excluding what is covered by Regulation of Water Flows	The maintenance of coastal dunes by coastal vegetation; The reduction in scouring potential that results from near-shore macro-algae forests
Biological Control	The contribution of marine/coastal ecosystems to the maintenance of natural healthy population dynamics to support ecosystem resilience through maintaining food web structure and flows.	The support of reef ecosystems by herbivorous fish that keep algae populations in check; the role that top predators play in limiting the population sizes of opportunistic species like jellyfish and squid

Table 2.1 (continued)

Ecosystem services	Definition	Examples
Habitat Services		
Lifecycle Maintenance	provision of essential habitat for reproduction, juvenile maturation, resting or wintering of migratory species	The reproduction habitat of commercially valuable species that are harvested elsewhere
Gene Pool Protection	The contribution of marine habitats to the maintenance of viable gene pools through natural selection/evolutionary processes	Inter- and Intra-specific genetic diversity that is supported by marine ecosystems which enhances adaptability of species to environmental changes
Cultural and Amenity Services		
Recreation and Leisure	The provision of opportunities for Recreation and Leisure that depend on a particular state of marine/coastal ecosystems	Bird-/whale-/...watching, beachcombing, sailing, recreational fishing, SCUBA diving, etc.
Aesthetic Information	The contribution of coastal/marine ecosystems to surface or subsurface coastal and marine sea-/landscapes that generate a noticeable emotional response within the individual observer. This includes informal Spiritual Experiences but excludes that which is covered by other cultural ESs	The particular visual facets of a 'sea-scape' (like open 'blue' water), a 'reef-scape' (with abundant and colourful marine life), a 'beach-scape' (with open sand), etc. that emotionally resonate with individual observers
Inspiration for Culture, Art and Design	The contribution of coastal/marine ecosystems that inspire elements of culture, art, and/or design. This excludes that which is covered by Ornamental Resources, and other cultural ESs.	The use of a marine landscape as a motif in paintings; The use of marine environmental features (like waves) in jewellery; The construction of buildings according to a marine-inspired theme; the use of marine organisms or marine ecosystems in films (including Jaws and Finding Nemo)
Spiritual Experience	The contribution that coastal/marine ecosystems make to formal religious experiences.	Several Greek and Roman gods were connected to the sea; A prominent Christian symbol is the fish; Marine organisms (such as whales and salmon) sometimes play important roles in various indigenous communities' religion
Information for Cognitive Development	The contribution that a coastal/marine ecosystem makes to education, research, etc. This includes the contributions of coastal/marine ecosystems makes to bionic design and biomimetic and to research on applications of marine Genetic Resources and pharmaceuticals.	The environmental education of children and adults; The development of surfaces to reduce marine biofouling based on similar surfaces found in marine environments; the application of hydrodynamic flow analysis to marine animals for ship design; Utilization of marine animal swimming mechanisms in engineering design[9]
Cultural Heritage and Identity	The contribution that a coastal/marine ecosystem makes to Cultural Heritage and Identity (excluding aesthetic and formal religious experiences). This includes the contribution of marine/coastal ecosystems in cultural traditions and folklore. This covers the appreciation of a coastal community for local coastal/marine environments and ecosystems (e.g. for a particular coastline or cliff formation) or identity related to sea dependent practices (e.g. identity as a fishing community)	The Wadden Sea is listed as UNESCO World Heritage site

Typology adapted from de Groot et al. (2002), Beaumont et al. (2006), de Groot et al. (2010)

2.3.2 The proposed ES typology in context of MSP and EBM

Consistently defined and explicitly delineated ESs are still interdependent (i.e. in that the use of one may affect the provision of others), because they are the products of complex ecological systems. These interdependencies are important to consider, for instance, in EBM or MSP when assessing trade-offs or other implications of management measures or planning alternatives. They are multifaceted and depend on site-specific characteristics (see Box 2.1 for a subset of possible examples and Appendix 1 for examples for each ES considered in this typology) and may reflect both positive and negative feedback loops.

[9] For example see the AirPenguin, AirJelly, and Air_ray created by Festo Robotics (Deutschland). Available at: http://www.festo.com/cms/de_corp/9780.htm, http://www.festo.com/cms/de_corp/9647.htm, and http://www.festo.com/cms/de_corp/9789.htm

Box 2.1 Examples of relationships where changes in ESs drive changes in other ESs within the typology

The Sea Water quality can influence the services Seafood, Recreation and Leisure, Aesthetic Information: if as a consequence of water extraction (e.g. for ballast water) invasive species were brought to a new location, this could change 1) availability of Seafood 2) suitability for recreational activities (impact of occurrence of jelly fish on beach tourism) 3) Aesthetic Information of a location.

Carbon Sequestration in oceans is driving research and education (Information for Cognitive Development) and can also influence on Seafood provision: Ocean acidification due to uptake of atmospheric CO_2 may influence the availability of Seafood like shell fish, especially in the future.

Lifecycle Maintenance can influence on Seafood provision, Biological Control, and Recreation and Leisure: Changes to nurseries can impact on the availability of Seafood harvestable in an area, on the food web, and on recreational activities related to observation of nurseries.

The Aesthetic Information of an area might influence services related to human perception of an area, such as Recreation and Leisure, Inspiration for Culture, Art and Design, and Spiritual Experience. The interdependency with Cultural Heritage & Identity may be connected to the aesthetics of a place, because changes in Aesthetic Information can influence the sense of place feeling.

Another key feature of the proposed typology is the ability of each ES within the typology to reflect ecosystem state changes driven by changes in management or spatial planning. Both management and spatial planning target the state of an ecosystem, that is, its processes and functions, and therefore the ecological characteristics that ultimately provide ESs and the associated benefits for human well-being.

Although the treatment of ESs as being ecosystem state-dependent means explicitly excluding from the typology any uses of marine ecosystems that are independent of ecosystem state (e.g. oil and gas, renewable energy, transportation/shipping), this does not mean that such related activities should be neglected in EBM and MSP. They are, or course, important drivers of marine change (Halpern et al. 2008) and carry a value to people. Rather, distinguishing between state-dependent ESs and state-independent activities means that trade-offs between the pursuit of those activities and environmental protection can be more easily assessed.

A third issue crucial in this context is to consider the direct or indirect nature of ESs. Prior to benefits being realized, some ESs need to be coupled with other forms of capital, i.e. they contribute indirectly to human well-being (e.g. in the case of Seafood, fishing gear, vessel, and fuel is required to catch fish; moreover, specific knowledge is needed, for instance, which Seafood can be harvested where and when). The nature of Ornamental Resources and Recreation and Leisure is context-specific in this regard. Table 2.2 illustrates this link between services and benefits by specifying for each ES those required other capital forms and by identifying services which can be directly enjoyed.

The aspect of direct and indirect services is relevant to spatial planning, management and decision making where the implications of different management measures are evaluated. In case of a management measure resulting in changes of ecosystem service provision, these changes are experienced directly in case of the directly enjoyed services. However, in case of the indirectly enjoyed services, these changes are moderated through the other types of capital required which can obscure the actual changes in service provision. For example, if a certain management measure reduces Seafood availability, an increase in fishing effort can mask this reduction (by increasing the amount of other capital required). In contrast, a reduction in Air Purification is perceived directly by people who are affected by reduced air quality.

Consideration of these aspects can assist in trade-off analyses. Understanding the direct and indirect effects of changes in ES provision also has implications for the ES value perception by related economic sectors as well as consumers. For instance, a decrease of an indirect service (like Seafood) may be perceived differently (especially if subsidies compensate for the required increase of other capital forms) than a decrease in a direct service (like Air Purification) where the losses cannot be mitigated by technical measures.

A further aspect relevant for applying the ES concept in the context of spatial planning is to distinguish the scale (and location) at which ESs are provided and the scale (and location) at which benefits are enjoyed. It is important to consider that these scales very much depend on site specific conditions and that they can exceed the actual scale of a planning area. Hein et al. (2006), for instance, explore this issue in more detail. An illustrative example of this issue in the marine context is Seafood. While a spawning habitat of a species may be situated in one country's Exclusive Economic Zone (EEZ), its nursery area may be located in a second country and finally this species may be caught in a range of different countries' EEZs. The fisheries in these different countries however, consciously or unconsciously, heavily depend on the situation and ecosystem state in the spawning and nursery areas. In contrast to this, the service Disturbance Prevention or Moderation is rather 'stationary' with regard to the location of service provision and related beneficiaries. At a coast where, for instance, sea grass meadows buffer wave energy, thus mitigating storm impacts, only residents located at the coast adjacent to this ecosystem are benefitting. An 'export' of benefits (as seen in case of Seafood) is rather unlikely for this service.

Changes in ecosystem state impact on the capacity of ecosystems to provide services. Since the proposed typology is sensitive to ecosystem state changes, this facilitates linking the scale and location of ecosystem state changes with scale and location of ES provision changes. For linking the ESs of this typology with the scale at which benefits are enjoyed, Table 2.2 lists relevant benefits for each ES. Subsequently, the spatial scale of these benefits can be determined individually for case study specific conditions.

2.4 Operationalizing the marine ecosystem services typology: Indicators and human benefits

2.4.1 Quantifying ES through indicators

This paper links the marine typology shown in Table 2.1 to a number of indicators that can be used to quantify service provision (see Table 2.2). This quantification is an important step in the consideration of ESs in EBM and MSP, because it can provide an indication of the service importance in an area and it constitutes an important reference point for the monetary value of a marine ES which can be affected by planning and management.

The indicators presented here were derived from an extensive literature review of marine valuation studies. This literature review used valuation and ecosystem service-focused keyword searches in the ISI Web of Knowledge database through the end of 2011 and yielded more than 145 studies of note. For some services there seems to be a consensus on the indicator to use (such as is the case with Seafood, Raw Materials, and Climate Regulation), for other services the measures applied to date appear rather diverse, (as is the case, for example, with Waste Treatment and Coastal Erosion Prevention). Studies on Recreation and Leisure have generated the greatest variety of indicators. The most frequently used measures are number of trips (e.g. angling, diving, boating and beach visit) (Agnello 1989, Curtis 2003, Blackwell 2007, Rees et al. 2010, Souza and Ramos e Silva 2011), number of tourists in an area (involved with particular activity, such as whale watching) (Beaumont et al. 2006, Ruijgrok et al. 2006, Ovetz 2007, Lange and Jiddawi 2009, Souza and Ramos e Silva 2011) and number of beach days or tourist days[10] (Bell and Leeworthy 1986, Brandolini 2006, Moksness et al. 2011). Other measures included number of hotel rooms, catch rate of target fish species (for recreational fishing) or annual access days.

In order to apply this typology in the context of EBM and MSP, the importance of reflecting ecosystem state has been emphasized earlier. However, these above examples reveal that not all indicators used in the extant literature are actually sensitive to changes in ecosystem state, but rather refer only to human activities that, in turn, may have some lag in their sensitivity to ecosystem state change. For example, decline in the marine fauna observed by divers, or the fish species targeted by anglers may not be noticed by people immediately, but instead may only be noticed after several years (at which point a decline in target species would influence the number of trips taken). This means it is possible for there to be a temporal disconnect between preferences, human behavior and state change. Similarly, in the case of beach recreation (number of beach days), it is unclear whether this indicator is linked to ecosystem state at all unless it is possible to explain what visitors appreciate during their visits. This can be either the physical characteristics only (sand, waves, water) or biological features (e.g. collecting sea shells) and the opportunity to spot marine fauna or the cleanliness of water (without algal or jelly fish blooms) as well. These observations based on recreation and leisure indicators apply to other cultural services as well and have been indicated in Table 2.2 since it may be crucial to be aware of this issue when applying indicators of this type.

Indicators were lacking in the reviewed literature for eight ecosystem services including: Sea Water, Genetic Resources, Ornamental Resources, Biological Control, Inspiration for Culture, Art and Design, Spiritual Experience, Information for Cognitive Development. To address this gap, possible units are proposed here (Table 2.2). The identification of appropriate biophysical units of measure for each ES included in our typology is an important contribution to the usability of this typology.

[10] Bell and Leeworthy (1986) assessed bundled services Coastal Erosion Prevention, Recreation and Leisure, Aesthetic Information

Table 2.2 Operationalizing the marine ecosystem service typology: indicators, required capital input and human benefits.

ES	Indicators [a]	Other capital input required?	Direct benefits: Examples
Seafood	Amount of fish landed [b] (Beaumont et al. 2006, Lange and Jiddawi 2009, Hunsicker et al. 2010) Amount of Seafood harvested/year [b] (Kasperski and Wieland 2009, O'Higgins et al. 2010) Amount of fish harvested/ha or km^2/year [b] (Cesar 1996; Ruijgrok et al. 2006)	Yes, e.g. fishing gear, fishing vessel, fuel	Nutrition, protein source, livelihood, pleasure: enjoy the taste
Sea Water	Number of days sea water is of insufficient quality for desired application Amount of Sea Water extracted per year per area [c]	Yes, e.g. desalinization plant, ship	Drinking water, health, safety (ballast water for shipping, cooling water for nuclear power plants), relaxation (recreation, leisure)
Raw Materials	Amount of fuel wood and amount of timer used from mangroves [b] (kg/household/year) (Hussain and Badola 2008) Amount of raw material extracted[b] (m^3/year) (Beaumont et al. 2006; Ruijgrok et al. 2006) Amount of seaweed grown per year [c] (Lange and Jiddawi 2009)	Yes, e.g. labor, dredger, other extraction gear	Inputs to industrial processes, construction material for infrastructure, employment,
Genetic Resources	# of Genes utilized per year per area [b]	Yes, e.g. genetic engineering lab/facility	Industry products, nutrition, livelihood,
Medicinal Resources	# of undiscovered oncological drugs (Erwin et al. 2010)	Yes, e.g. lab, facilities to process pharmaceuticals	Health
Ornamental Resources	Amount of Ornamental Resources (tons) used per year per area [b]	Depends: for personal use: directly beneficial, for commercial use indirect: labour, extraction gear, transportation	Pleasure (interior decoration – symbolic or other, use for fashion, jewellery), livelihood
Air Purification	Amount of fine dust/NO_x or SO_2 captured (kg/ha/year) (Ruijgrok et al. 2006)	No	health (via clean air)
Climate Regulation	Amount of CO_2 sequestered (Beaumont et al. 2006, Ruijgrok et al. 2006, Jialin et al. 2009, Wang et al. 2010)	No	Favourable living conditions, health and well-being
Disturbance Prevention or Moderation	# of freshwater wells or amount of drinking water protected from tsunami impacts (Sanford 2009)	No	Safety (protection of human life, coastal infrastructure, property, livelihood), (mental) health and well-being of coastal citizens
Regulation of Water Flows	Amount of sediment prevented from sedimentation in natural channels used for shipping (m^3/year) (Ruijgrok et al. 2006)	No	Maintenance of natural shipping lanes, Safety, livelihood (shipping sector)
Waste Treatment	Biochemical degradation capacity of COD (g/m^3/day) (Wang et al. 2010) Amount of N and P stored (kg/ha/year) (Souza and Ramos e Silva 2011)	No	Health (via clean Sea Water)
Coastal Erosion Prevention	Length of natural coast line (Wang et al. 2010) Amount of sediment prevented from erosion per ha of an ecosystem per year (Ruijgrok et al. 2006)	No	Protection of property and land (e.g. used for recreation, coastal protection, agriculture, industry), protection of land/ seascape, mental and physical health and well-being of coastal citizens
Biological Control	# of species (Species richness) (Beaumont et al. 2006)	No	Mental and physical health

Table 2.2 (continued)

ES	Indicators [a]	Other capital input required?	Direct benefits: Examples
Lifecycle Maintenance	Amount of fish caught outside an area [b] (Hussain and Badola 2008)	Yes, e.g. fishing gear, labour, fishing vessel	Nutrition (via Seafood), health, livelihood, Warm glow (existence value satisfaction)
Gene Pool Protection	Genetic diversity per population	No	Warm glow (representing the existence value)
Recreation and Leisure	For most frequently used indicators please refer to Section 2.4 # of visits of an area[c] (Dehghani et al. 2010) # of trips per site per year[c] (Gao and Hailu 2011) # of days used for particular activity per person [c] (Tapsuwan and Asafu-Adjaye 2008) # of day trips per year and # of overnight stays[c] (Ruijgrok et al. 2006) # of hotel rooms in a region[c] (Lange and Jiddawi 2009) Square feet of beach/beach day[d] (Bell 1986) Amount or Catch rate of target fish species (Cameron and James 1987, Bockstael et al. 1989) # of visitors per season[c]; # of boats involved in trips[c]; # of dive operators offering trips[c] (Dicken 2010) Annual access days[c] (Cameron 1988)	Depends: e.g. yes for SCUBA diving (equipment); no for beach recreation	Feelings of relaxation, pleasure and enjoyment, health and well-being, happiness, rejuvenation, employment
Aesthetic Information	Square feet of beach/beach day[b] (Bell 1986) Beach day [c,b] (Bell and Leeworthy 1986)	No	Pleasure, feelings of stimulation, relaxation, rejuvenation, and enjoyment.
Inspiration for Culture, Art and Design	Amount of time (# or person days) dedicated to creation of culture, art and design per area per year[c]	No	Inspiration and the promotion of creativity, enjoyment, satisfaction, livelihood
Spiritual Experience	Amount of time (# of person days) dedicated for formal religious ceremonies that involve coastal/marine environments per area per year[c]	No	Feelings of spirituality, the ability to perform religious ceremonies
Information for Cognitive Development	Amount of time (# of person days) spent in education about, research regarding, or individual learning about an ecosystem/species/ etc. per area per year[c]	Yes, e.g. any tools to study marine organisms	Intellectual inspiration to pursue knowledge, satisfaction of curiosity, education
Cultural Heritage and Identity	# of households that consider an area or aspects of an area as cultural heritage[c] (Ruijgrok et al. 2006)	No	Cultural practices which define the heritage, sense of community, sense of place, belonging, health and well-being.

[a] Cells shaded grey: no indicator could be obtained from literature; indicators proposed here are considered to represent the ecosystem service in question as good as possible. However, depending on data availability for specific case studies these indicators may need to be adjusted.
[b] This indicator is directly linked with the state of the ecosystem. However, due to the indirect nature of this service, a change in human effort of using it may disguise these ecosystem state changes. For instance, increasing fishing effort can mask a reduction of fish stocks.
[c] This indicator is not or indirectly linked with the state of the ecosystem and rather reflects human activities.
[d] This Study assessed bundled services Coastal Erosion Prevention, Recreation and Leisure, Aesthetic Information.

The reviewed literature interestingly revealed that several studies, which valued ESs in monetary terms, described ESs qualitatively but did not apply respective indicators and were not explicit on the amount of a service provided (and valued). Without this quantification, an important reference point for the monetary value of an ES is missing and changes in ecosystem state cannot be (smoothly) translated into changes of benefits and values. Additionally, this complicates the use of such monetary values for benefit transfer. We address this gap in several ways: (i) Designing the typology, only those ESs have been included whose provision is sensitive to ecosystem state (Section 2.2). (ii) For measuring changes in ESs, suitable indicators have been compiled (Table 2.2). (iii) For facilitating to identify further indicators, crucial issues are highlighted above (i.e. ecosystem state sensitivity, possible time lag in responding to ecosystem state).

This assists in linking ecosystem state changes with implications for human well-being and enables valuation study results for benefit transfer.

2.4.2 Linking ecosystem functions, ES and related benefits

The analyses presented in Sections 2.2 and 2.3 have been integrated into one comprehensive table (Table 2.2). This table provides for each ES the details essential to apply the proposed typology in EBM and MSP contexts (and beyond) and links consistently three different levels of the ESs cascade (Figure 2.1), i.e. functions, services and benefits.

Starting at the function level, the indicators compiled (Table 2.2) assist in assessing the linkages between the ecosystem functions and services, and therefore between functions and quantity of ESs provided. For EBM and MSP contexts, these indicators help to translate the expected or observed changes in ecosystem state into changes in ES quantity and consequently, to estimate the impacts on human well-being (see Figure 2.2).

The benefits derived from the ESs are identified in a further column of Table 2.2. This reveals that one ES can be associated with several related benefits which in turn can be valued. In the case of Seafood, the benefits comprise for instance, nutrition, livelihood and the pleasure when enjoying its taste.

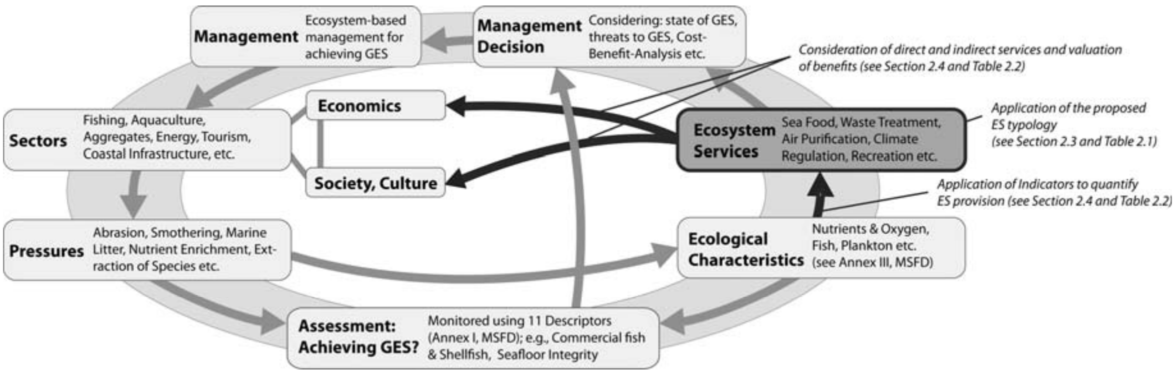

Figure 2.2 ES assessments (dark grey box and arrows) within the management cycle for implementing the MSFD (Figure adapted from Koss et al. (2011)). Text in italics indicates how this chapter contributes to this management cycle.

2.5 The application of the ecosystem services typology in ecosystem-based management and marine spatial planning

As discussed in Section 2.1, global marine policies are adopting EBM in order to achieve the improvement, restoration, or protection of coastal and marine ecosystems and their resources. This management approach often legislates for substantial ecological data collection and monitoring, and evaluates the achievement of environmental improvement in the context of ecological indicators. Simultaneously, the feasibility of individual management options, new policies, or other forms of human intervention in the environment is evaluated in relation to the financial input required and its impact on human welfare. This dichotomy often results in a fundamental disconnect between the overall goals of this type of legislation (i.e. environmental improvement/protection as assessed via ecological indicators) and the way in which individual efforts aiming to contribute to these goals are evaluated (i.e. through economic assessments of social welfare).

An illustrative example of this type of legislation is the EU's MSFD (Directive 2008/56/EC of the European Parliament and of the Council) (for an example of a management cycle according to the MSFD see Figure 2.2). Its objective is measured by the achievement of Good Environmental Status (GES) in Europe's regional seas for 11 high-level qualitative descriptors and measured by 17 ecological characteristics and 18 pressures and impacts (see Annexes I and III of Directive 2008/56/EC). This in turn must be evaluated (and monitored) according to a series of criteria, indicators, and attributes (European Commission 2010). The actions required to achieve ecologically-defined GES are largely left to member states to determine, but the MSFD mandates that proposed actions be subject to social and economic analysis. This legislation therefore demands dual decision-making based on both ecological and socio-economic analysis without giving clear priority to either, or based on an explicit link between them. The integration of ecosystem services in the MSFD implementation process can provide this link (see Figure 2.2). As ecosystem services are grounded in ecology, they can be defined and measured using ecologically relevant units (see, for example, Luck et al. (2009) and Kontogianni et al. (2010)), and the proposed indicators in Table 2.2. The impact of sustainable management measures can be traced via changes in the ecological characteristics used for the assessment of GES through accompanying changes in the provision of ecosystem services as ecological entities. ESs are however also inherently economic in nature where changes in the ecological delivery of the ESs influences the benefits (i.e. welfare) received by society.

The marine ES typology proposed in this paper is a tool that facilitates several steps within this management cycle (Figure 2.2, dark grey box and arrows). Therefore, it facilitates the dual decision making required to assist in achieving marine EBM and in implementing the MSFD in EU Member States.

2.6 Discussion and Conclusions

The field of marine ESs is currently rapidly emerging. Our brief review of existing ES classifications (Section 2.2) reveals that an appropriately designed and marine-focused typology is lacking.

This paper develops an ES typology and highlights several aspects crucial for its application in EBM and MSP: The ESs considered here are clearly defined and delineated and they are sensitive to ecosystem state for allowing any meaningful assessment in context of EBM and MSP (Sections 2.2 and 2.3). When applying our proposed typology, attention must be paid on the direct and indirect nature of ESs since this may mask ongoing changes in ecosystem state (Section 2.3). Last, ESs are, just like different components of ecosystems, interconnected. These interdependencies (Box 2.1, Appendix 1) are important to consider in ES assessments.

A further pre-requisite to marine ESs being effectively utilised in EBM and MSP-based decision-making is the quantification and valuation of marine ESs via a set of indicators that relates to human benefits. Our analysis found that the extant literature is patchy in this regard. Further research is therefore needed to better understand the nature of those ES that have so far received little formal attention by researchers. Absent this, it will be difficult to better forecast impacts on human well-being due to changes in ecosystem state.

Of interest is the review of several studies that valued ES in monetary terms without being explicit about how much of a particular service has been valued. Without this quantification, an important reference point for monetary value of a marine ES is missing, and the linkages between ecosystems and ESs are broken. Consequently, changes in ecosystem quality cannot be translated into changes of benefits and values, something that complicates the use of such monetary values for benefit transfer. Hence, identifying and testing suitable ES indicators, as well as their consistent application in valuation studies, requires attention in future marine ES research.

While some consider a comprehensive typology inappropriate, and instead favour individually created, context sensitive typologies (Fisher et al. 2009), we believe a common and comprehensive typology as proposed in this paper is both beneficial for, and appropriate in the context of EBM and MSP. A comprehensive typology can be seen as a reference list from which services relevant in an area can be selected for further assessment in MSP. A common typology can also facilitate comparisons between different EBM approaches and MSP case studies to improve the transferability of experiences and lessons learnt. Similarly, a common typology will also facilitate the primary economic valuation of ESs, and by extension, the improved valuation of ESs using the benefits transfer approach. In turn, this is important as benefits transfer is frequently applied in practice and is especially valuable when time and/or money are scarce. Additionally, policy makers often prefer benefits transfer over primary valuation due of resource constraints. In the absence of a common marine ES typology, each project developing its own typology with individual service definitions creates a situation in which benefits transfer is complicated or even unfeasible. Based on this rationale, the application of a common and agreed typology, with uniform ES definitions, is essential for large-scale EBM and MSP. This allows for consistency in the management and planning approaches across all involved nations and regions and reducing inconsistencies across the borders of different planning units.

The applications of integrated ecosystem assessments are increasing, specifically for countries where legislation stipulates the implementation of EBM to the management of marine ecosystems to mitigate degradation to our oceans and seas. As the field of ES research continues to grow and facilitate the link between the natural science, social and economics, governments are starting to recognize the importance and benefits of integrating ES in spatial planning and national environmental and economic accounting. This requires a consistent marine ES typology, indicators and tools for assessment at different spatial scales.

The typology proposed in this paper is comprehensive, consistent and application-oriented, and can serve as a framework for marine EBM and MSP (c.f. Sections 2.3 and 2.5).

Acknowledgements

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Chapter 3

How does the management of nutrients and fisheries affect marine ecosystem services in the Black Sea?

The Black Sea, located between Europe and Asia, faces severe anthropogenic environmental pressures, such as eutrophication and unsustainable fishing. This is in conflict with the EU's Marine Strategy Framework Directive which aims to achieve 'Good Environmental Status' by 2020 in all European seas and to enable sustainable use of marine ecosystem services (ESs). We assess how the management of fisheries and nutrients affects marine ESs at the Black Sea scale and also aim to understand cumulative management effects. Our assessment is based on management scenarios that combine fisheries' maximum sustainable yield with two different levels of ecosystem productivity. The effects of these management scenarios are analysed through indicators and by determining trends of ES supply changes. Results suggest that sustainable fisheries management is most favourable from an ES perspective, but this result is rather tentative due to existing knowledge gaps, particularly regarding nutrient management effects. Our study concludes with recommendations for ES assessments in the context of the Marine Strategy Framework Directive and beyond: (1) To deal with knowledge gaps, marine ES assessments should combine qualitative and quantitative methods and an interdisciplinary team that includes several regional sea experts is crucial; (2) to split up ESs into several sub-ESs increases the specificity of the assessment; (3) to consider management regulation effects is very useful for revealing management effects that potentially remain undetected otherwise within the ESs framework; (4) to analyse cumulative management effects is relevant for identifying synergies and useful antagonistic effects. Combining such synergistic and antagonistic effects smartly can assist in alleviating negative management outcomes.

Based on: Anne Böhnke-Henrichs, Corinne Baulcomb, Rebecca Koss, Ekin Akoglu, Tanya Churilova, Snejana Moncheva, Temel Oguz, Laura Boicenco, Florin Timofte, Olga Kryvenko, Kremena Stefanova, Helen Bloomfield, Leonie Robinson. How does the management of nutrients and fisheries affect marine ecosystem services in the Black Sea? (Manuscript)

3.1 Introduction

With its Marine Strategy Framework Directive the European Union adopted a highly ambitious Ecosystem Approach to marine management that is to be implemented by all Member States and is characterized by balancing marine conservation and the societal demands for using an ecosystem (CBD 2004). The directive aims to achieve a 'Good Environmental Status' by 2020, but that target will most likely be missed. The directive measures 'Good Environmental Status' by eleven Descriptors, including the maintenance of biodiversity, healthy stocks of commercial species or reduction of marine litter. Marine environmental data on these descriptors indicate that there are still challenges to overcome to achieve the Directive's aims. For instance, almost 40% of European marine species for which sufficient data are available are threatened (Gubbay et al. 2016), in the Mediterranean and the Black Sea more than 85% of fish stocks do not meet any of the 'Good Environmental Status'-criteria (EEA 2019) and marine litter is a widespread problem that despite some efforts not yet decreases (EEA 2018, Maes et al. 2018). These figures exemplify how human pressures affect European seas. The MSFD requires to manage these pressures to improve the environmental status and to enable the sustainable use of ecosystem services.

Ecosystem services (ESs) are defined as the direct and indirect contributions of ecosystems to human well-being (de Groot et al. 2010) and their assessment in marine ecosystems is usually confronted with a couple of challenges. For instance, substantial data are frequently required to estimate how marine management alters ES availability (UNEP-WCMC 2011, Turner et al. 2015). Yet, marine ES assessments frequently face the challenge of data scarcity, especially in comparison to their terrestrial equivalents and they often only take a very limited number of ES into account (Liquete et al. 2013, Rodrigues et al. 2017, Dailianis et al. 2018). However, marine management requires to consider a wide range of different ESs to avoid undesired management outcomes (Rosenberg and McLeod 2005, Bennett et al. 2009). This leads to the main objective of our paper, to understand how marine management affects ES supply and how this can be assessed for multiple ES. A further challenge in this context is to understand how different management measures interact and cumulatively affect ES provision (Willsteed et al. 2018). This objective and these challenges are addressed in our Black Sea assessment. Black Sea ESs and their management effects so far received only little attention in the peer-reviewed literature, except for few cultural ES studies.

The Black Sea faces anthropogenic pressures like high nutrient loads, unsustainable fishing and introduction of non-indigenous species. These pressures are associated with regime shifts of the Black Sea food web towards a degraded state that is characterized, for instance, by collapsed fish stocks, outbreaks of jellyfish and algal blooms (Oguz and Velikova 2010, Daskalov et al. 2017). This degraded state involves considerable losses for the fishing sector (Knowler 2005) and is in conflict with the policy goals of the European Commission's Marine Strategy Framework Directive (MSFD) (BSC 2019). Thus, to achieve the MSFD's policy goal constitutes a current management challenge. Consequently, our study focuses on two food web related management aspects, nutrient and fisheries management and explores, (1) which ES changes are caused by eutrophication and fisheries management; and (2) how eutrophication and fisheries management interact cumulatively. Our study responds to these questions by using three different management scenarios for which ES changes are assessed. By comparing these scenario outcomes, our study aims to answer the question, (3) which scenario is most favourable regarding its effect on a broad range of marine ESs.

The paper is organized as follows. Section 3.2 introduces the study area and explains the methods while Section 3.3 presents the results. In Section 3.4 we discuss these results and implications that arise from our assessment approach and explore management trade-offs. We conclude with recommendations for ES assessments in the context of the MSFD and beyond (Section 3.5).

3.2 Methods

3.2.1 Study area

The Black Sea is located between Europe and Asia, with access to the Mediterranean Sea via the Bosporus Strait and the Sea of Marmara. The Black Sea extends to 423,000 km^2, with a maximum depth of 2,200 meters. Europe's second and third-largest rivers, the Danube and Dnieper, enter at the northwestern coast. The Black Sea's huge basin, six times larger than the sea area, increases its sensitivity to human activities even if they occur far away (Humborg and Kölle 1999, Ludwig et al. 2009, BSC 2019). The Black Sea is enclosed by the coasts of Bulgaria, Romania, Turkey, Georgia, Russia, and Ukraine. Since three of which are either European Union members or candidate member States (Turkey) the Black Sea is subject to the MSFD, whose objective of a 'Good Environmental Status' is not yet achieved. According to this regional sea-scale policy context, the spatial scale of our study is the entire Black Sea. Moreover, this scale is considered appropriate since fisheries and nutrient management are expected to have cross-border effects.

The Black Sea faces several human pressures, including eutrophication (Zaitsev 1992, BSC 2019), unsustainable fishing (Daskalov 2002, Llope et al. 2011), introduction of nonindigenous species (Kamburska et al. 2006, Oguz et al. 2008) and litter (Mureșan et al. 2017, Simeonova et al. 2017, Simeonova and Chuturkova 2019, Oztekin et al. 2020). These pressures result in deteriorated habitats, biodiversity changes, and in a heavily disturbed food web (Oguz and Velikova 2010, Daskalov et al. 2017, Yunev et al. 2017). This disturbance is reflected by an altered phytoplankton community structure, jellyfish outbreaks and changed fish stocks (Berdnikov et al. 1999, Daskalov et al. 2012, Akoglu et al. 2014). Restoration of the impaired food web is thus crucial for achieving a good environmental status in the Black Sea region (Breen et al. 2012) and accordingly, two related human pressures (eutrophication and fisheries) have been selected as management focus of this study. This management focus is also in line with the Black Sea Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea (BS SAP 2009). The Strategic Action Plan is a multi-lateral agreement between six countries adjoining the Black Sea, and two out of four major transboundary problems are related to eutrophication and fisheries.

3.2.2 Management scenarios

The assessment is based on three management scenarios that combine different levels of nutrient management with sustainable fisheries management (Table 3.1). Across all scenarios, fishing mortality was determined at the maximum sustainable yield. Changes in nutrient management are reflected as different primary production values. All other aspects of Black Sea management and related pressures, such as destruction of habitats or introduction of non-indigenous species, were considered constant across the scenarios.

Table 3.1 Overview of applied management scenarios

Management scenario	Description
Sustainable Fishing	Fishing mortality is set to the maximum sustainable yield while primary production level is considered constant
Clear Water	Fishing mortality is set to the maximum sustainable yield and primary production decreases by 50%.
Agricultural Intensification	Fishing mortality is set to the maximum sustainable yield and primary production increases by 50%.

3.2.3 Assessment Framework

To structure the complex interactions of marine management and ESs, the ES cascade model is used as a framework for analyzing ES changes (Haines-Young and Potschin 2010). This framework is widely acknowledged and has been applied to various contexts, demonstrating its flexibility. The ES cascade (Figure 3.1) basically consists of five different cascade steps and conceptualizes how ecosystem changes (that are caused, e.g. by marine management measures) translate into ES changes and eventually into human well-being changes. ES as the middle step can be considered the connector between ecosystems and human well-being. The cascade suggests that management measures affect ecosystem structures or processes that in turn determine various functions of the ecosystem. If these functions contribute to human well-being, they are considered ESs. At each cascade step indicators can serve to describe management effects (van Oudenhoven et al. 2012, Hattam et al. 2015a). The basic concept is that indicators of an earlier cascade step control indicators of the following cascade step. Such an indicator-based approach is applied here. The major focus of our study is on the first three cascade steps, i.e. to understand how marine management affects ESs supply. Next to these ES supply effects (Figure 3.1), marine management can also change the availability of ESs by enforcing regulations on marine ES use. Such management regulation effects bypass the cascade and become immediately effective once a management measure is implemented (Figure 3.1). For example, fishing quotas limit the amount of seafood to be caught. Consequently, we define management regulation effects as changes in the appropriation or use of ESs due to management regulations.

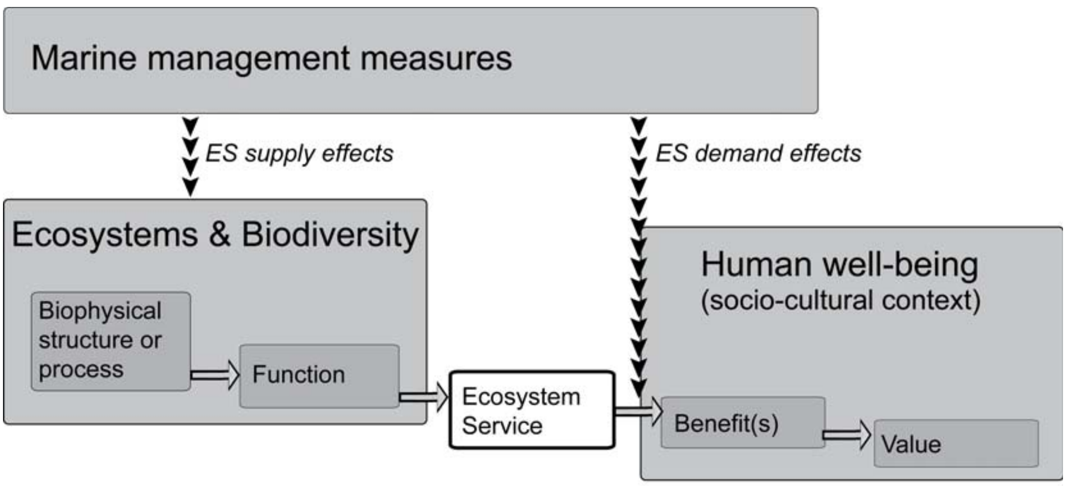

Figure 3.1 ES supply and management regulation effects as analysed in our study in relation to the ES cascade with its five steps: (1) ecosystem structure, (2) function, (3) ES, (4) benefits and (5) values (adapted from Haines-Young and Potschin 2010).

3.2.4 Assessment process

To translate marine management changes into ES changes was a complex endeavour and required an interdisciplinary research team consisting of eleven Black Sea experts from Ukraine, Bulgaria, Romania, and Turkey, next to ES experts. We conducted two workshops with the research team to tailor a marine ES typology (Böhnke-Henrichs et al. 2013) to the Black Sea environment, to explore data availability for each ES and to estimate direction of ES changes. The ESs and sub-services that were included in the assessment are listed in Figure 3.2 (middle column). In case of lacking data, the workshops applied an expert-based approach to estimate ES changes under the three management scenarios.

ES supply effects

The effects of management measures on ESs are analysed using indicators for the ES cascade steps (1) ecosystem structure and processes and (2) ecosystem functions and (3) services. Due to data scarcity, this assessment was predominantly qualitative and combined published data, peer-reviewed findings, grey literature and expert judgment. Where specific Black Sea data were missing, published insights from other seas were used. The role of expert judgment in this qualitative assessment was to integrate and interpret available data and to apply it to the specific study context. The expert-based approach required two workshops during which the entire research team shared available data and discussed ES changes until consensus was achieved. The ESs “Seafood (fish)” and “Climate Regulation (carbon sequestration)” were the only ESs with sufficient data for a quantitative assessment. To assess changes in fish biomass, a time-dynamic trophic Ecopath with Ecosim (Christensen et al. 2005) model of the Black Sea was set up and was based on a modified model version by Akoglu et al. (2014). The fish species whiting, turbot, anchovy and sprat were included in the model. These are among the most valuable commercial species in the Black Sea. The estimated changes in carbon sequestration were based on primary production rates of coccolithophores which are considered one of the main drivers of the biological carbon pump (Thierstein and Young 2004). The detailed methodologies and results are described in Appendix 2.

Management regulation effects

Management regulation effects result from the immediate implications of management enforcement. Accordingly, for each management focus (nutrients and fisheries) we explored whether it involves institutional or regulatory or other changes that affect ES use or appropriation directly. For fisheries management, introducing FMSY is clearly related to the regulation of total allowable catches. Thus, implementing these regulations affects the amount of Seafood that is allowed to extract. This not only affects Seafood but also other ESs that depend on fish catches (Table 3.6). For nutrient management a literature search was performed to understand the main nutrient sources and to infer whether regulation affects Black Sea ES use or appropriation.

3.3 Results

This section summarizes assessment results while all underlying data, the justification for expert judgment and references are comprehensively documented in the Appendix 2.

3.3.1 ES supply effects

The assessment developed a set of indicators and mapped indicator linkages to analyse ES changes under different fisheries and nutrient management regimes (Figure 3.2). The indicators relate to 15 different ESs and a greater number of sub-services. The mapping of indicator linkages shows that a single ES can be affected by either one or both management aspects. In the latter case, nutrient and fisheries management can interact either synergistically (by affecting an ES in the same direction) or interact antagonistically (by affecting an ES in opposing directions).

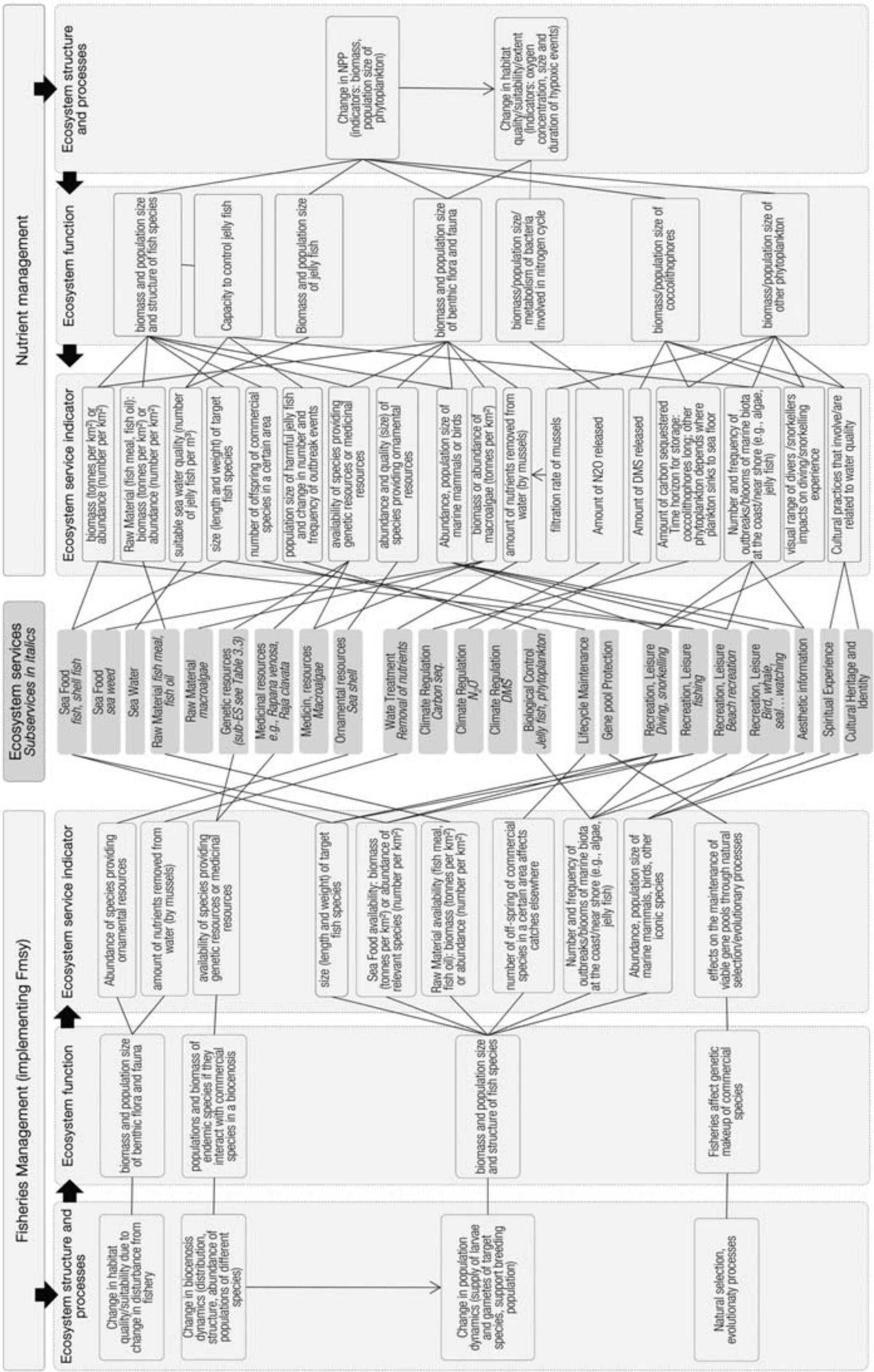

Figure 3.2 Overview of indicators and their linkages used to assess nutrient and fisheries management implications. Indicators that influence each other or depend on each other are connected by lines (i.e. indicators linkages). Indicators used for assessing fisheries management effects are shown on the left-hand side and indicators for assessing nutrient management effects are shown on the right-hand side. Indicators have been separated for the cascade steps (1) ecosystem structure, (2) function, (3) ES. Where an ES shows links to both sides, cumulative management effects are expected.

Table 3.2 indicates whether cumulative effects are synergistic or antagonistic. Nutrient and fisheries management changes are represented by white and black arrows respectively. A white and black arrow next to each other indicates a cumulative effect. The effect is synergistic where both arrows point in the same direction and antagonistic where both arrows point in different directions. Direction of change has been assessed by using the above indicators, expert judgment and data and literature as documented in the Appendix 2.

Table3.2 Summarized results of ES supply changes for each management scenario

ES	Sub-ES	Direction of change for ES supply			Key references (for all references and explanation refer to the Supplementary material)
		Sustainable Fishing	Clear Water	Agricultural Intensification	
Seafood	Fish	↑	↑⇩	⇧↑	
Seafood	seaweed	⇨	⇧	⇩	Berov et al. (2012)
Seawater	water for desalinization, ballast water, water for industrial cooling	⇨	⇧	⇩	Bilefsky (2013)
Raw Materials	fish meal; fish oil	↑	↑⇩	⇧↑	
Raw Materials	macroalgae	⇨	⇧	⇩	Negreanu-Pîrjol et al. (2011), Berov et al. (2012)
Genetic Resources	Tursiops truncatus ponticus, Delphinus delphis	↑	↑⇩	⇧↑	IUCN (2013)
Genetic Resources	Acipenser gueldenstaedti, Acipenser nudiventris, Acipenser ruthenus, Acipenser stellatus, Acipenser sturio, Huso huso	⇨→	⇨→	⇨→	IUCN (2013), CITES (1998)
Genetic Resources	Alosa caspia, Alosa maeotica, Alosa immaculata	↑	↑⇩	⇧↑	IUCN (2013), BSC (2008)
Genetic Resources	Clupeonella cultriventis	↑	↑⇩	⇧↑	IUCN (2013)
Medicinal Resources	Rapana venosa	⇨	?	?	Badiu et al. (2008), Badiu et al. (2010), Rodica et al. (2017), Leontowicz et al. (2015)
Medicinal Resources	Squalus acanthias	↑	↑⇩?	⇧↑	Compagno (1984), Zasloff et al. (2011), Newman and Cragg (2004), Brunel et al. (2005)
Medicinal Resources	Macroalgae: Coccotylus truncatus (Phyllophora brodiaei), Cystoseira barbat	⇨	⇧	⇩	Vitalie (1986), Dumont (1999), (Milchakova et al. 2013)
Medicinal Resources	Mytilus galloprovincialis, Molgula euprocta, Botryllus schlosseri	no relationship	no relationship	no relationship	http://bipolan.com.ua/, Rinehart (2000), Dalekaya (2010)
Ornamental Resources	Rapana venosa, Mytilus galloprovincialis	⇨	?	?	Beukema and Cadée (1991), Wolowicz et al. (2006), Diaz and Rosenberg (1995), Al-Dabbas and McManus (1987)
Air Purification	Capturing fine dust (PM10), NO_x and SO_2	no relationship	no relationship	no relationship	
Climate Regulation	Carbon sequestration	⇨	⇩	⇧	
Climate Regulation	Capturing N_2O	⇨	⇧	⇩	Walter et al. (2006), Babbin et al. (2015)
Climate Regulation	DMS release	?	?	?	Moncheva et al. (2006), Mikaelyan et al. (2011)

Table3.2 (continued)

ES	Sub-ES	Direction of change for ES supply			Key references
		Sustainable Fishing	Clear Water	Agricult. Intensific.	
Waste Treatment	removal of nutrients	▷	△	?	Grégoire and Friedrich (2004), Grégoire and Beckers (2004), Pérez Camacho et al. (2000), Clausen and Riisgård (1996), Bat et al. (2012), Oros and Gomoiu (2010)
Biological Control	limit population size of harmful jellyfish (effects on fishing gear likely affect well-being. Effects on recreation or seawater are indirect and considered under the respective ESs)	▲	△▲	▲▽	Salihoglu et al. (2011), Kamburska et al. (2006), Mihneva (2011), Purcell et al. (2007), Konsulov (1989), Gucu (2002), Daskalov (2002), Knowler (2005)
Biological Control	limit population size of phytoplankton	no relationship	no relationship[1]	no relationship	
Lifecycle Maintenance	Contribution of a study area to commercial catches elsewhere	?	?	?	Ivanov and Beverton (1985) and Niermann et al. (1994) in Daskalov et al. (2012)
Gene Pool Protection	maintenance of viable gene pools through natural selection/evolutionary processes	?	?	?	Garcia et al. (2003), Hard et al. (2008)
Recreation and Leisure	Recreational fishing, SCUBA Diving (both related to the abundance of target/iconic fish species)	▲	▲▽	△▲	(Brown (1996) cited by Knowler (2008), Taylor and Longo (2010)
Recreation and Leisure	SCUBA Diving and beach recreation (related to phytoplankton concentration and thus visual range and attractiveness)	▶	△	▽	
Recreation and Leisure	SCUBA Diving and beach recreation (related to jellyfish abundance and thus attractiveness)	▶	△▲	▲▽	
Recreation and Leisure	Observation of species (e.g. Bird/whale/seal watching)	▲	▲▽	△▲	
Spiritual experience		?	?	?	
Cognitive development		no relationship	no relationship	no relationship	
Cultural heritage and identity		▲	▲▽	△▲	Fletcher et al. (2014)

△▽▷ Direction of ES change related to nutrient management (increase, decrease, constant); ▲▼▶ Direction of ES change related to fisheries management (increase, decrease, constant); thicker arrows indicate stronger effects; ? Direction of change unknown; synergistic effects: both arrows point in the same direction; antagonistic effects: both arrows point in opposing directions.

[1]At the scale of assessment, management measures are not specified in sufficient detail. For certain measures to achieve scenario targets (e.g. restoration of coastal wetlands to reduce nutrient loads) changes in ES provision are considered possible.

Quantitative ES changes were estimated for the ESs Seafood and Carbon Sequestration. The Seafood changes are based on modeling results and provide relative biomass changes of four target fish species (Table 3.3). The model output further included biomass changes of phytoplankton and zooplankton that allow inferences on water quality dependent ESs (e.g. recreation). For further details, see Appendix 2. Due to the lower productivity, the Clear Water scenario shows the strongest decreases in fish biomass whereas the Agricultural Intensification scenario shows the strongest increases.

Table 3.3 Relative changes in selected fish species and plankton as obtained from Ecopath with Ecosim modeling (see Appendix 2).

	Sustainable fishing	Clear Water	Agricultural Intensification
Anchovy	1.3%	-85%	66%
Sprat	4.8%	-86%	73%
Turbot	32%	-85%	135%
Whiting	26%	-83%	110%
Zooplankton	~0%	-85%	64%
Phytoplankton	~0%	-90%	90%

The Carbon Sequestration changes (Table 3.4) were estimated based on the primary productivity of coccolithophores (see Appendix 2). Just as for Seafood, the strongest decrease in this ES is expected for the Clear Water scenario due to its strongly reduced productivity.

Table 3.4 Change in Carbon Sequestration under different management scenarios

	Sustainable Fishing	Clear Water	Agricultural Intensification
Change in C Sequestration (Entire Black Sea)	No change	-2163 kt C y-1	2163 kt C y-1
Change in C Sequestration (Northwestern shelf)	No change	-192 to -240 kt C y-1	192 to -240 kt C y-1

An overall comparison regarding ES changes under the three assessed management scenarios reveals for the sustainable fishing scenario the most positive and least negative changes (Table 3.5). The Clear Water scenario involves the most positive changes but nine negative changes. The Agricultural Intensification scenario appears as least favourable, because it involves the largest number of negative ES changes.

Table 3.5 Summary of ES changes for assessed management scenarios

	Sustainable fishing	Clear water	Agricultural intensification
# of increasing ES	10	11	10
# of constant ES	14	1	1
# of decreasing ES	0	9	10
# of ?	4	7	7

3.3.2 Management regulation effects

For fisheries management, regulation effects on four ESs were identified Table 3.6). All effects are related to reduced allowable catches according to a fishing mortality at the maximum sustainable yield and thus apply to all three management scenarios. For nutrient management, no regulation effects were identified. The main anthropogenic nutrient sources in the Black Sea are land-based: agriculture, households, industry and tourism (Zessner and Van Gils 2002, Shtereva et al. 2015). Agricultural and sewage management offer the opportunity to reduce nutrient inputs considerably (Strokal et al. 2014). This suggests that management regulations affect rather land-based activities directly but not marine ES use.

Table 3.6 Management regulation effects on ES availability

Ecosystem Service	Direct consequences of fisheries management – fishing mortality at the maximum sustainable yield
Seafood (fish)	Change in allowable catch rates implies a reduction in the amount of fish caught (i.e. Seafood availability).
Raw Materials (fish meal, fish oil)	Change in allowable catch rates implies a reduction in the amount of fish caught (i.e. raw material availability).
Ornamental resources	Change in fishing intensity reduces the amount of by-catch that is usable as ornamental resources.
Recreation and leisure (recreational fishing)	Adjustment of catch limitations for commercial fisheries may involve higher catch rates for recreational fishermen.

3.4 Discussion

3.4.1 Limitations of assessment methods

Our assessment adopts an ES indicator approach (van Oudenhoven et al. 2012, Hattam et al. 2015a) and applies it to assess the cumulative effects of fisheries and nutrient management. As frequently reported in the literature (e.g. Liquete et al. 2013, Bertram et al. 2014, Hattam et al. 2015a) a lack of suitable data also affects our assessment and allows us to estimate most ESs changes only qualitatively. Thus, only the direction of ES change is determined while the magnitude of that change remains unknown. This limits the comparability of assessment results regarding their ES effects, because it remains unknown whether an ES increase under one scenario is comparable to an increase under another scenario. Any ranking or comparison of management scenarios needs to acknowledge this constraint.

To deal with the lack of data, Bertram et al. (2014) recommend combining qualitative and quantitative approaches, as we have done in our study. We further highlight the need for an interdisciplinary research team with several regional sea experts. This proved successful in our assessment to deal with data scarcity. Moreover, to clearly specify assessed sub-ESs helps to understand more precisely existing knowledge gaps to be addressed in future research. Most important, knowledge gaps should not prevent sustainable management measures to be implemented, but requires adaptive management and a precautionary approach to be able to respond timely to unforeseen effects (Curtin and Prellezo 2010).

A further constraint to our study is its focus on the first three steps of the ES cascade, i.e. ecosystem structure and processes, ecosystem functions and ESs. While this focus is characteristic for an understanding of ES supply, it fails to understand actual human well-being effects related to ESs. This is, however, a prerequisite for an ES. Our assessment is thus restricted to analyse what the Black Sea ecosystem potentially contributes to human well-being. Whether these potential contributions are actually ESs that support human well-being depends on whether and how much of an ESs is actually used and how important it is to society.

Our assessment scale extends to the entire Black Sea to align with the Marine Strategy Framework Directive as the relevant policy context. Furthermore, nutrient and fisheries management respond to transboundary phenomena that can be appropriately addressed only at the scale of the entire Black Sea. A consistent regional sea scale is considered crucial to assess management consequences towards the goal of ‘Good Environmental Status’ (Busch et al. 2013). Such a large assessment scale, however, limits the level of detail at which management scenarios are determined and consequently limits the level of detail for identifying ES changes. For example, a reduction in nutrient input from land-based sources could be achieved either by land-use change, through coastal wetland restoration or through technical improvements of water treatment plants. The choice of actually implemented measures determines which ES changes would realize. Coastal wetland restoration, for instance, would improve the ESs 'Coastal Erosion Control' or 'Disturbance Prevention and Moderation' or offers recreation opportunities. Consequently, a range of further positive ES outcomes becomes possible once specific measures are determined. Since the regional sea scale does not allow for this level of detail, assessment results obtained at the regional sea scale as presented in this study likely underestimate ES changes and should only be transferred with caution to more local or sub-regional sea scales. However, the above examples illustrate that carefully selected specific management measures at the local scale can increase the number of positively affected ES and thus allows for some flexibility to align desired management implications with local stakeholder's preferences.

3.4.2 Mapping of ES indicator linkages and cumulative effects

The mapping of indicator linkages (Figure 3.2) reveals that the majority of ESs are affected by the interaction of both nutrient and fisheries management. Consequently, various synergistic or antagonistic effects need to be considered when planning, implementing and evaluating respective management measures. For the Clear Water scenario, for example, a synergistic effect can be observed for Biological Control (limit biomass of jellyfish): The nutrient management results in a reduced phytoplankton biomass that exerts a bottom-up control on jellyfish biomass. Additionally, sustainable fisheries management supports food competitors and thus limits jellyfish biomass. Antagonistic effects for the Clear Water scenario are expected, for instance, for the ES Recreation and Leisure (recreational fishing and scuba diving). While the fisheries management positively affects iconic species and target fish species, the strongly reduced primary production causes an overall decrease in those species. Simultaneously, however, scuba diving benefits from the overall improved water quality. This leads to a mixed picture for this ES. This example also illustrates that it is crucial to distinguish sub-ES. Though both, recreational fishing and scuba diving, belong to the ES Recreation and Leisure, scenario outcomes for the sub-ES differ. For interpreting management outcomes and identifying affected stakeholders it is thus essential to specify precisely analysed sub-ES.

The mapping of indicator linkages (Figure 3.2) demonstrates the complexity involved in translating management into ES changes and is in line with the mapping proposed by Bertram and Rehdanz (2012). To keep the level of complexity manageable during our expert-based approach, cumulative effects are merely analysed at the ES level while they remained unconsidered at other levels (e.g. ecosystem structure and processes). For example, both nutrient and fisheries management affect the indicator 'habitat suitability' at the level of ecosystem structure and processes. This suggests that further cumulative effects are plausible that were beyond the scope of our assessment.

The linkage mapping further shows that linkages do not always follow a linear progression from one cascade step to the other. In fact, there can be several interdependencies within a single cascade step (Bertram et al. 2014) and a single ecosystem function can affect several different ESs (Figure 3.2). This complexity is not particularly surprising since (marine) ecosystems are complex systems with many non-linear relationships (Hagstrom and Levin 2017).

While our set of indicators and their linkages is specific to fisheries and nutrient management in general, it is generic regarding its usability for other seas or policy contexts. This qualifies the indicators not only as a result of this study but also as a tool for further ES assessments.

3.4.3 Distinguishing ES supply and management regulation effects

Here we analyse effects on ES supply next to management regulation effects. Effects on ES supply occur when management affects ecosystem structure, processes and functions. Such an ecosystem response to management usually takes longer. Management regulations, in contrast, affect ES availability as soon as regulations are enforced. This means, both effects occur at different time scales and thus should not be added up. For instance, sustainable fisheries management is expected to recover fish stocks and thus to increase the availability of Seafood in the future. However, to achieve this management outcome, regulations need to reduce fishing mortality to the maximum sustainable yield. Consequently, in the short term, less fish can be landed and Seafood availability is reduced. This shows that ES availability can decline (at least for a certain time period) even while the ecosystem state is improving until management yields desired outcomes. Analyzing both ES supply and management regulation effects allows revealing those contradicting time scales. They are crucial for understanding and communicating management implications to affected stakeholder groups.

3.4.4 Trade-offs and comparison of management scenarios

The assessment results allow a comparison of three fisheries and nutrient management scenarios that are compared and discussed here regarding their effect on 23 different ESs, including sub-ESs. The scenario Sustainable Fishing involves the least negative ES changes, Clear Water shows the most positive and Agricultural Intensification the most negative ES changes. However, the comparison of scenario outcomes needs to recognize existing knowledge gaps, because the direction of change for seven ESs under the scenarios Clear Water and Agricultural Intensification could not be determined, which was also the case for the direction of change for four ESs under the scenario Sustainable Fishing. Consequently, a scenario comparison has to be interpreted with caution and results potentially change once knowledge gaps are filled.

The scenario's ES effects reveal multiple trade-offs. While Sustainable Fishing so far appears to be the most desirable scenario because it involves the most positive and only few negative ES changes, it leaves the management challenge of eutrophication unaddressed. The Agricultural Intensification scenario, in contrast, is characterized by a strong increase in productivity. That also increases other ESs such as carbon sequestration, whereas increasing phytoplankton biomass degrades water quality and declines related ESs. Although the overall status of the ecosystem is degrading under this scenario, the concomitant basin-wide adoption of a fishing mortality at the maximum sustainable yield results in larger fish biomass. Under the Clear Water scenario, the ecosystem state improves but due to the strongly reduced productivity several ESs decrease, but some positive ES effects are expected to occur faster than under Sustainable Fishing due to the synergistic fisheries and nutrient management. As Clear Water combines improvements in both fisheries and nutrient management, it is the most ambitious of the three analysed scenarios. Particularly the Clear Water scenario shows that fisheries management complements nutrient management: While negative ES trends are caused by reduced productivity, the simultaneously applied fisheries management involves an antagonistic positive effect on the same ESs, thus, alleviating some negative nutrient management effects (Table 3.2). This exemplifies how management can utilize the antagonistic effects of different management aspects.

3.5 Conclusion

This ES assessment addresses the challenge to understand the cumulative effects of fisheries and nutrient management on a wide range of different ESs. Management scenario comparison shows several different ES changes. So far, the Sustainable Fishing scenario appears as the most favourable scenario from an ES perspective, but this is a rather tentative result due to existing knowledge gaps particularly regarding nutrient management effects on ES supply.

Our study leads to the following inferences and recommendations for ES assessments in the context of the MSFD and more generally in the context of marine ecosystem-based approaches to management:

- To address knowledge gaps, an interdisciplinary research team with several marine experts who are very familiar with the study area is crucial for compiling and interpreting available data to obtain qualitative and quantitative ES estimates.
- To include management regulation effects in the analysis proved very useful for revealing management effects that had remained undetected otherwise.
- To distinguish sub-ESs increases the specificity of the assessment.

Results highlight that it is particularly relevant to analyse cumulative management effects and to understand synergistic and antagonistic effects. To combine such different effects smartly can assist in alleviating negative management outcomes and thus can generate greater management acceptance.

This greater management acceptance is urgently required since the EU MSFD aims to achieve ‘Good Environmental Status’ of all European Seas by 2020. This most likely will be missed, because several human pressures, including unsustainable fishing and eutrophication, pose a risk to European seas. Our study shows that this risk also expands to the people who depend on ESs provided by seas. It also demonstrates that people can benefit from nutrient and fisheries management that increases several ESs.

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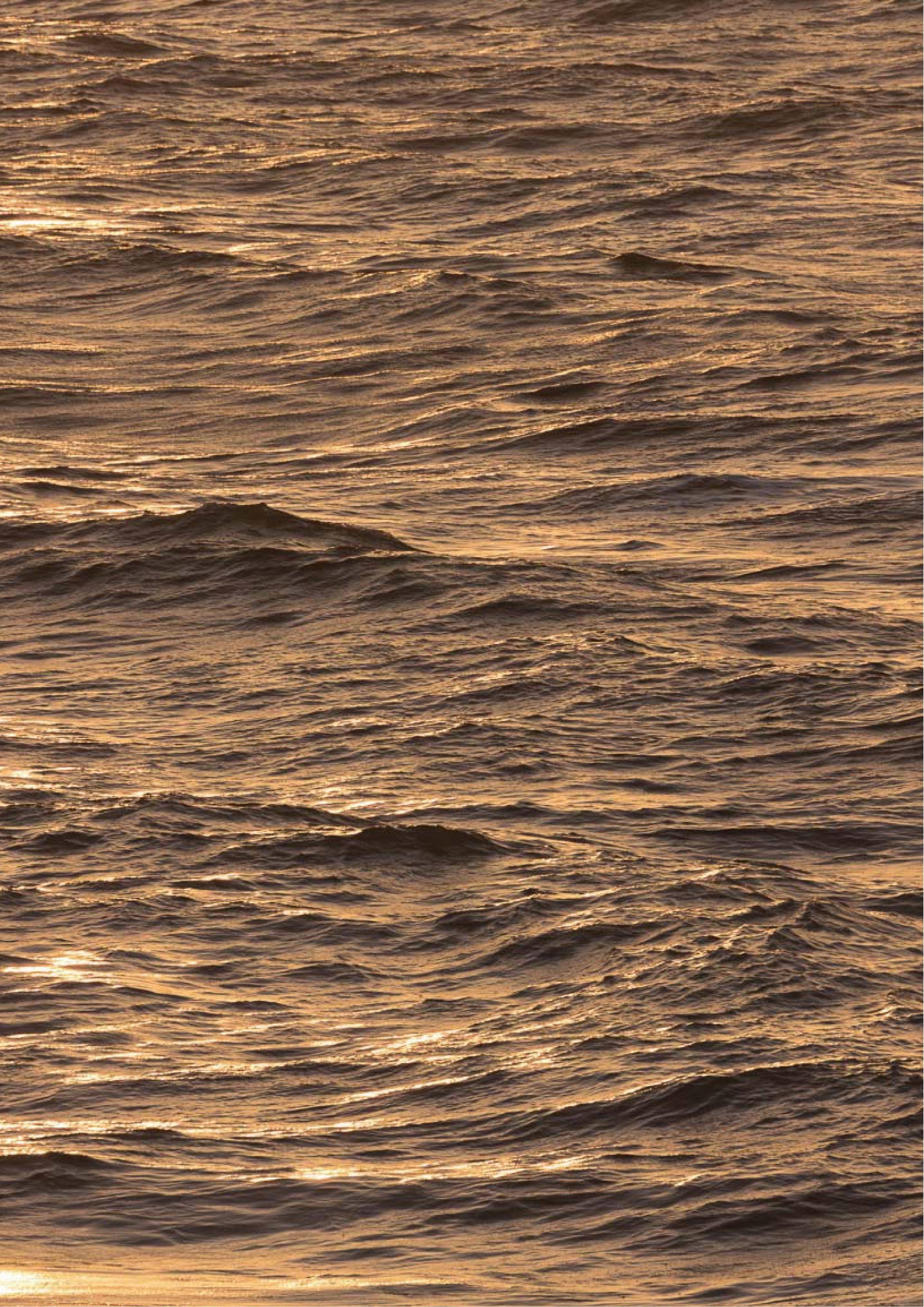

Chapter 4

How does salt marsh conservation affect management preferences and ecosystem-service values of local residents?

The Venice Lagoon faces several severe environmental problems, including widespread erosion of salt marshes. Such intense erosion is caused by shipping and other human activities, like large scale hydro-engineering projects, despite legal obligations to protect them. This situation can be improved by involving local stakeholders in salt-marsh management. Our study analyses how a participatory salt-marsh restoration approach adopted by the EU-funded project LIFE VIMINE affects local residents' appreciation of salt marshes and their support for conservation. Our study surveyed local residents twice at an early and at the final stage of the project and compared the results of both surveys. Results show that salt marshes are widely appreciated in the Venice-Lagoon region and that they are associated with both nature conservation and a range of different ecosystem services, lagoon uses and social benefits. This appreciation is measured in multiple complementary dimensions through a rating of ecosystem services and social benefits, salt marsh-use preferences, willingness-to-pay and willingness-to-volunteer estimates. These ratings provide detailed insights into local residents' various salt-marsh management preferences and also allow to analyse conflicts between different management preferences, though most respondents desire salt-marsh restoration. Crucial to salt marsh conservation in Venice Lagoon is the involvement of local stakeholders, whose appreciation of salt marshes and their restoration support clearly increased during LIFE VIMINE.

Based on: Anne Böhnke-Henrichs, Laura Grechi, Alberto Barausse, Rudolf S. de Groot: How does a salt marsh conservation project affect management preferences and ecosystem-service values of local residents? (accepted with minor revisions in Ocean and Coastal Management)

4.1 Introduction

Intertidal wetlands, such as salt marshes, are among the most threatened marine ecosystems globally (Halpern et al. 2007). Also in Europe these habitats are being lost due to urbanization, coastal infrastructure construction and sea-level rise (Adam 2002, Newton et al. 2013). Further losses are caused by erosion, which is particularly relevant to salt marshes in Venice Lagoon where more than two thirds of this habitat eroded during the past century (Barausse et al. 2015). This severe decline poses a major conservation challenge.

Venice Lagoon is not only a world-famous UNESCO World Heritage site, but is also protected under several European and Italian environmental protection policies. These policies comprise the Water Framework Directive (2000/60/EC), the Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC). Particularly the latter two aim at biodiversity protection and require achieving or maintaining a favourable conservation status of certain species and habitats, including lagoons and salt marshes.

Irrespective of these protection schemes, the ecological and environmental status of Venice Lagoon is poor to moderate (Micheletti et al. 2011, Gabellini et al. 2016) and protected salt marshes and tidal flats have been strongly eroded over the past decades (D'Alpaos 2010, Sarretta et al. 2010). In general, erosion is typical for lagoons, being dynamically shaped by natural variations in hydrology, sedimentation, erosion, water exchange with the sea, and other environmental processes (e.g. Barausse et al. (2015), Ghezzo et al. (2010), Deheyn and Shaffer (2007)). This is also true for Venice Lagoon, where, however, environmental changes have already for centuries been driven mainly by human pressures rather than by natural dynamics. The intense erosion of protected habitats like salt marshes is mainly caused by the anthropogenically altered hydrodynamics and morphology of the lagoon. Initially, several large rivers entered the lagoon and nourished with their sediments the salt marshes. From the 15th to the 17th century main rivers' courses were relocated to bypass the lagoon (Ravera 2000, D'Alpaos 2010), causing a lack of sediment input. Sediment loads were further reduced when in the 19th and 20th century natural lagoon inlets were modified by constructing jetties which increased water exchange with the sea and prevents marine fine sediments from entering the lagoon (Ravera 2000). In the 20th century, large shipping channels were dredged for connecting the Adriatic Sea with port Marghera on the lagoon's mainland coast. All these past changes together with current human impacts such as sediment resuspension by mechanized clam fishing and increased erosion by motorboat generated waves (D'Alpaos 2010), turned the lagoon's sediment budget negative. Thus, sediment input from rivers and the Adriatic Sea cannot compensate the increased sediment loss to the sea. The resulting disappearance of salt marshes is in conflict with salt marshes' protection status according to European environmental policies and therefore requires conservation and restoration efforts to prevent a continued decline.

Our study is part of LIFE VIMINE, an EU-funded salt-marsh conservation and restoration project, LIFE VIMINE (http://www.lifevimine.eu/, Barausse et al. (2015)). The project area covers about 1650 hectares in the northern lagoon of Venice (Figure 4.1) which is protected under the Birds and Habitats Directive. The project area includes inhabited islands (Burano, Mazzorbo, and Torcello) and hosts salt marshes, mudflats, tidal creeks and channels, located along the Dese channel and enclosing the Laghi wetland. In terms of their morphological and ecological quality, the salt marshes found in the study area are among the best preserved in the entire lagoon, notwithstanding that widespread erosion can be recognized here as well.

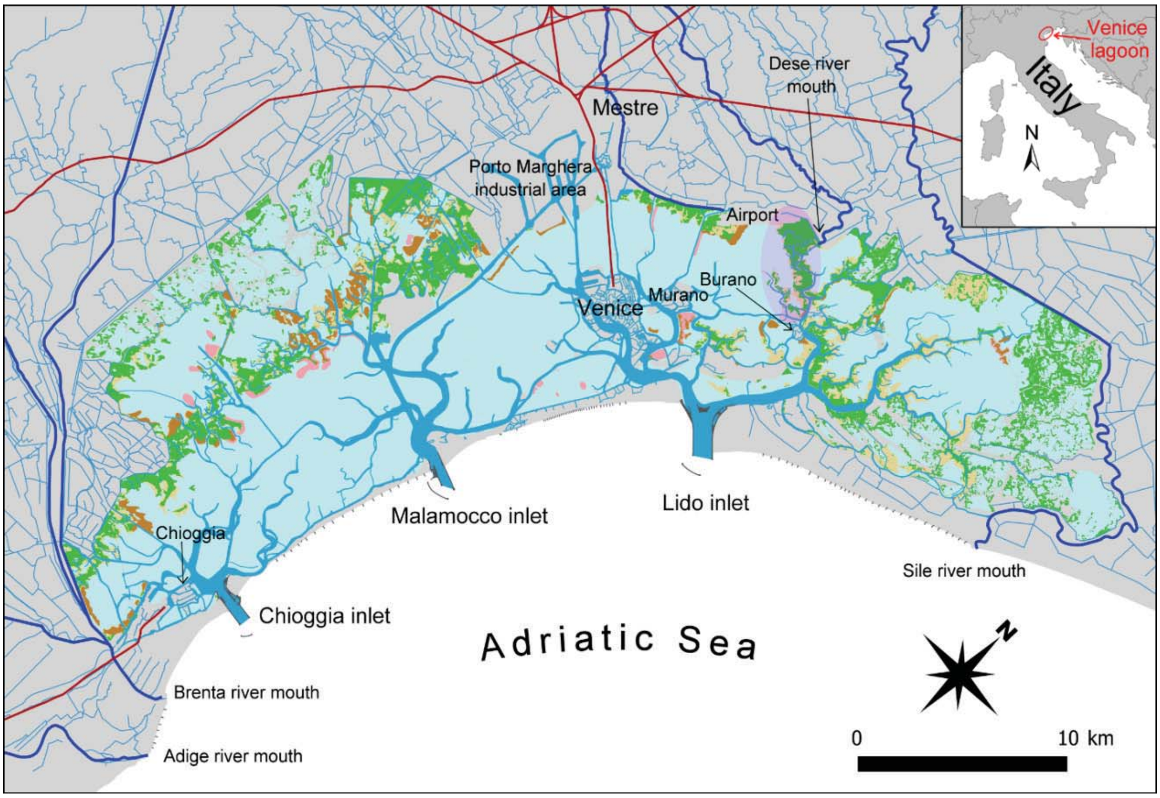

Figure 4.1 Lagoon of Venice and its network of channels , islands and wetlands. Natural salt marshes and tidal flats are depicted in green and yellow, respectively, while artificial salt marshes and tidal flats are in brown and pink, respectively. Lagoon channels are in blue. LIFE VIMINE project works were located in the Northern Lagoon between the airport and the island of Burano (purple oval). Map data are from www.atlantedellalaguna.it.

Next to implementing substantial salt marsh conservation and restoration actions through nature based solutions (Barausse et al. 2015, Grechi et al. 2017), several participation and communication activities addressed the wider public and fostering local stakeholder's and communities' involvement in the project, including (1) information about salt marshes, their erosion and projects aims and actions targeting the general public via online and printed media, press releases, conferences, articles, and information boards, (2) information targeting boat owners (printed material, meetings in exhibitions, a short movie, participatory meetings) since navigating along salt marshes in high speed is an important erosion cause, (3) presentations at conferences, public meetings, workshops and events (targeted at the scientific community, institutions managing the territory, policy- and decision makers, or the general public), (4) technical guidelines (Grechi et al. 2017) and scientific publications, (5) education measures in local schools (lectures, teacher training, creation and distribution of an education book) and lectures in local universities, (6) a smartphone app allowing salt marsh visitors to report newly occurring erosion spots or presence of litter to enable conservation works to respond promptly, (7) creation of a participatory network of local businesses dealing with sustainable lagoon tourism (the "Chart of the sustainable tourism in the Northern lagoon of Venice"), (8) a working group consisting of representatives of local stakeholder groups (public and private) and LIFE-VIMINE representatives, (9) co-design of protection works with local communities, and

(10) creation of local green jobs through the employment of lagoon residents (such as local fishermen, e.g. from the Burano Island) to implement the nature-based conservation measures.

Public information, participation and raising awareness for environmental issues would frequently generate the public's understanding and appreciation of and compliance with restoration and conservation goals and thus would be crucial for restoration success (Turnhout et al. 2010, Arnold et al. 2012, Druschke and Hychka 2015, Metcalf et al. 2017, Sterling et al. 2017). However, how far this can be achieved within a conservation project with a rather short lifetime of only few years is largely unexplored. Studies exploring the impact of stakeholder involvement frequently apply ex-post surveys or interviews (Druschke and Hychka 2015, Dick et al. 2018). Studies drawing on data obtained during the participation process (Turnhout et al. 2010) remain so far underrepresented and our study on Venice lagoon contributes to closing this gap by surveying twice at an early and late stage of the conservation project.

To analyse how local residents benefit from salt marshes, the ecosystem services (ESs) concept was applied. ESs are the contributions of ecosystems to human well-being (de Groot et al. 2010). Here the concept is used in multiple ways: to understand respondent's perception and knowledge about the ESs provided by salt marshes, to understand respondent's prospective ES demand/preferences, and to reveal salt marsh associated values.

For Venice Lagoon Rova et al. (2015) highlighted salt marshes as particularly relevant for regulating (e.g. erosion control) and cultural ESs (aesthetic information and recreation). Other ESs often associated with salt marshes are raw materials and food, carbon sequestration, nutrient uptake and water quality improvements, coastal protection and opportunities for education and research (Barbier et al. 2011, Himes-Cornell et al. 2018). A valuation of these salt marsh benefits so far received relatively little attention. For instance, in their review covering a time period since 2007, Himes-Cornell et al. (2018) identified only 15 salt marsh valuation studies in total, none of which performed in the Mediterranean Sea. Our study adds to this narrow body of literature and aims to contribute to better understanding salt marsh ES values.

To understand peoples' salt marsh appreciation, our study focuses on three different aspects and explores (1) what local residents know about and how they perceive environmental changes in the lagoon and how that changed during LIFE VIMINE; (2) what preferences they have regarding future salt marsh management and related future ecosystem service provision and (3) how they value the salt marshes and how this changed between the two surveys.

This paper is organized as follows. Survey methodology and data analysis are explained in Section 4.2. Insights on lagoon and salt marsh knowledge, salt marsh management preferences and values are presented in Section 4.3 and discussed in Section 4.4. The paper concludes in Section 4.5 with recommendations for future salt-marsh management in Venice Lagoon.

4.2 Methods

4.2.1 Data collection and analysis

Data were collected using a questionnaire (Appendix 3.A). Most questions were multiple choice questions, rating or scoring questions. Where appropriate, these questions offered an open answer option to allow responses beyond pre-defined answers. The sequence of answer options was randomized for each question to remediate survey bias. One entirely open-ended question addressed salt marsh erosion reasons.

The survey avoided technical terms as far as possible. Also the term 'ecosystem services' was avoided and replaced by 'salt marsh benefits' instead. We are aware of the scientific debate of mixing up services and benefits, but our pre-test showed that 'benefits' communicated much better. In the survey we also described these so-called benefits with clear examples of local relevance (Table 4.1).

The questionnaire was tested by about 25 people comprising the LIFE-VIMINE staff (including fishermen employed in the project), some economists and sociologists and lagoon residents. The pre-test aimed to (i) ensure appropriate survey length; (ii) check that questions are comprehensible; (iii) eliminate potential tendentious questions. Subsequently, the survey was slightly adapted. More substantially, a salt marsh restoration tax as payment vehicle was rejected and replaced by a voluntary donation. Especially during a period of Italy's economic crisis, further taxation was perceived a sensitive issue, which was even aggravated by a corruption scandal in the Venice Lagoon concerning the large scale flood-control project MOSE. In this particular context a voluntary payment vehicle was considered more appropriate. Notwithstanding, voluntary payment mechanisms tend to overestimate actual donations when respondents actually desire a public good (and therefore indicate a high donation), but hope to free ride later on once the good is provided (Carson et al. 2001, Carson 2012). However, for assessing changes in willingness to pay (WTP) estimates at two different stages of our restoration project, this bias is less relevant since it should affect estimates of both samples similarly.

Survey responses were collected at an early and at a late stage of the project intervention, from March to September 2015 and from March to April 2017. The survey was distributed online via mail lists, social networks and published on the project's website. The online survey link was also published in Lagunario newsletter on Venice lagoon and ViviVenezia (a newsletter substituting Lagunario in 2017). Two other EU LIFE projects active in the area, LIFE GHOST and LIFE SERESTO, also distributed the survey through their own networks (e.g. social media). The applied convenience or self-selected sampling involves that we possibly did not obtain a representative sample, thus, upscaling or aggregating results must be interpreted with caution.

In 2015 responses were additionally collected face-to-face by an interviewer asking randomly selected people in Burano, in the center of Venice and on water buses. Further surveys were distributed during two governance and environment related master courses at the University of Padua and during LIFE-VIMINE meetings with local stakeholders. Even if we refer to this group as "face to face interviews", respondents were simply handed out the questionnaire instead of having an actual question-answer interview. This way, we established as far a possible a situation similar to those of the online respondents and assume to avoid (as far as possible) interviewer and response bias in the data that are caused by the social interaction between interviewer and interviewee. Only in very few exceptional cases, for example with the elderly, a question-answer interview was carried out.

Prior to the second survey phase the questionnaire was marginally adapted based on experiences made during the first survey phase. Modifications involved removing/clarifying questions and limiting answer options for further reducing response time needed.

166 responses and 423 responses were collected during the first and second survey respectively, out of which local resident's responses had to be selected for the purpose of our study. The participatory approach of LIFE VIMINE targeted rather local residents who are also frequently considered crucial for environmental management success (Reed 2008, Young et al. 2013, Sterling et al. 2017). We defined local residents to live in no more than 30 kilometers distance (i.e. not more than half an hour travel time) from Venice lagoon as detecting restoration project effects required respondents who were for a longer period of time frequently exposed to project activities and who were familiar with the lagoon and its environmental issues (e.g. due to frequent or even everyday experience, local media or social interaction). After selecting only respondents living within the 30 kilometers corridor, we yielded 109 and 236 responses from the 2015 and 2017 survey respectively.

We use descriptive statistics to describe and compare the two datasets. Furthermore, we tested the significance of differences between both surveys by applying Welch's two sample t-test for cardinal response variables and two-sided Fischer's exact test for categorical response variables.

4.2.2 Questionnaire structure and coding

4.2.2.1 Perception and knowledge of lagoon and salt marsh change

Two questions addressed respondent's perception of environmental change in the lagoon of Venice and their salt marsh erosion knowledge. Respondents were asked to indicate whether they perceive particular environmental processes and components of the lagoon having increased, decreased or remained constant within the past 10 years. Answers have been compared with scientific evidence on those changes (Appendix 3.B). It has been tested whether the rates of correct responses changed significantly between 2015 and 2017.

An open-ended question asked respondents about reasons for salt marsh erosion. For analysis, responses have been coded (Appendix 3.C) by three of the authors independently and results have been subsequently compared for validation. In very few cases the codings differed and were discussed among the three involved authors until consensus was achieved. Coded responses were analysed for the three major salt marsh erosion causes communicated by LIFE VIMINE that are particularly relevant in Venice Lagoon (D'Alpaos 2010, Sarretta et al. 2010, Solidoro et al. 2010): (1) the altered **sediment budget**; (2) the **changed lagoon hydrodynamics**; (3) **motorboat-generated waves**. Other erosion causes that do not affect salt marshes directly, like clam fishing or seagrass disappearance, remained unconsidered. For each respondent it has been determined how many of the major erosion causes were mentioned and it has been tested whether this changed significantly between the 2015 and 2017 survey.

4.2.2.2 Management preferences for salt marshes

Four aspects have been selected for understanding respondent's management preferences for lagoon salt marshes: (1) ESs associated with salt marshes and a rating of their importance, (2) respondents' use preferences of the salt marshes, (3) the preferred appearance of salt marshes visualized as management scenarios and (4) the reasons motivating respondent's management scenario selection.

(1) ESs associated with salt marshes and rating of their importance

Respondents were presented an ESs list (Table 4.1) which intentionally avoided technical terminology and included an explanation to minimize misinterpretations.

Table 4.1 Salt marshes benefits – Terminology used in survey

Food **(for example fish, mollusks, birds)**
Filtering the air (thus, preventing health risks)
Capturing greenhouse gases (thus, local contribution against global warming)
Filtering the water (thus, preventing health risks)
Capturing sediments (thus, reduction of the amount of sediments affecting navigation)
Preventing erosion of protected habitats (thus, saving money/efforts required for habitat protection and restoration)
Reducing the open water areas in the lagoon thus, reducing wave energy, and protecting shores
Supporting future availability of food due to the presence of areas where fish and birds reproduce
Nature conservation, in relation to the variety of habitats and species typical of the salt marshes
Opportunities for recreation (mooring close to salt marshes, observing flora and fauna, fishing, hunting, excursions)
Inspiration for artists (paintings, music, design, other)
Opportunities for education (environmental education)
Contribution to the beauty and attractiveness of the lagoon
Contribution to local communities' traditions (thus, contribution to the social well-being)
Importance for local religious congregations and their spiritual traditions

Respondents were asked to select up to six ESs they consider being provided by salt marshes and rate the ES importance on a scale from 1 (= not important) to 5 (=very important). Boxplots diagrams were used to compare ES rates in 2015 and 2017. Where an ES had not been selected by a respondent, the rate was set to zero as an unselected ES represents the lowest preference level.

(2) Salt marsh use preferences

A question on future salt marsh use preferences allowed respondents to select up to three use types or activities. Distributions of selected use types are compared for 2015 and 2017.

(3) Preferred salt marshes appearance visualized as management scenarios

We developed four different salt marsh scenarios for visualizing photo-realistically salt marsh management implications (Figure 4.2). The scenario images combined different levels of salt marsh extent, fishing activities (visualized as number of nets and fishing boats), recreational activities (visualized as number of pleasure boats) and habitat suitability for species/suitability for nature observation (visualized as number of birds). Pleasure boats were distinguished in rowing and motor boats as the latter cause waves that erode salt marshes and are thus considered not compatible with salt marsh restoration, as the scenario images suggest. The visualized scenarios included a 'current situation' image which is fictitious as well, but created a baseline among the scenario images that respondents can relate to when selecting whether they prefer a particular scenario aspect to increase, decrease or remain unchanged.

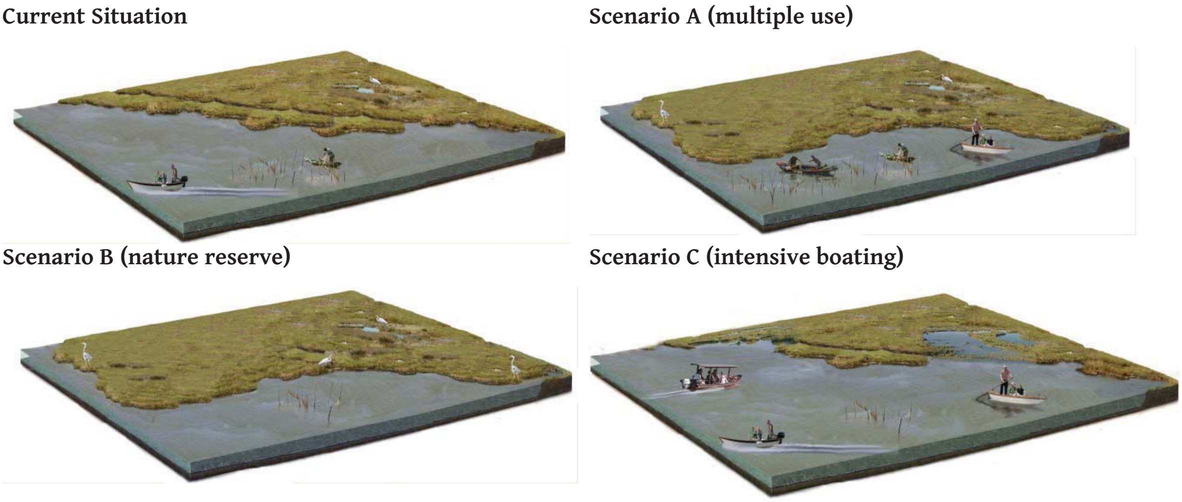

Figure 4.2 Salt marsh management scenarios as presented in the survey. Note: The "Current situation" was labelled as such in the survey. Other scenarios were labelled only by letters A to C to avoid influencing respondents by scenario names. The scenario names shown in parentheses are used only for reference in this paper.

Before selecting their preferred scenario, respondents were told that salt marshes can change as a result of erosion and protection actions and they were asked to include in their decision the ESs they obtain from the salt marshes as well as the way they intend to use the salt marshes in the future.

(4) Motivation of management scenario selection

A multiple choice question explored why a particular scenario has been chosen. Choice options included various ES-related reasons but also 'nature protection', 'local traditions' and the 'support of the local economy'. Distributions of selected reasons were compared for 2015 and 2017

4.2.2.3 Valuation of salt marshes and their ecosystem services

Respondents were surveyed regarding (1) their willingness to pay and to volunteer for salt marsh restoration and (2) their social values associated with salt marshes.

(1) Willingness to pay and to volunteer for salt marsh restoration

The value of ecosystems or biodiversity consists of various different value types, including direct use and indirect use values and existence or bequest values, for instance (for more details see, for example, Pascual et al. (2010). Salt marshes in the lagoon of Venice are associated here with three different value types. Their **direct use value** is, for example, associated with recreation activities like boating near salt marshes. **Indirect use values** characteristic to salt marshes are reported by Liquete et al. (2013) and are associated with climate regulation, waste treatment (nutrient removal) and reduction of wave energy during extreme weather conditions. The **existence value** might be expressed by the salt marshes' conservation status. For eliciting the values people hold in the context of these various value types, a contingent valuation approach has been chosen (Pascual et al. 2010). This is a stated preference method and discloses people's WTP for a public good or for a specified environmental change in a survey setting.

The WTP question was designed as multinomial choice question containing eight pre-defined annual donation amounts ranging from 5 to 90 Euros and alternatively an open answer option where people could define their donation themselves. A zero donation was not included since respondents have been asked previously whether they are willingly to contribute to salt marsh donations. Only those who affirmed were shown the WTP question. The annual donation amounts were additionally presented as monthly amounts to allow people relating their choice better to other expenditures.

Next to the WTP question we included a 'Willingness-To-Volunteer' question (WTV) which was motivated by the participatory restoration approach followed by LIFE VIMINE. Furthermore, results of Garcia-Llorente et al. (2011) suggest that an WTV option is preferred by respondents in a restoration or conservation context and that an WTV option may help to reduce protest zero bids. The WTV question was framed and set up analog to the WTP question with slight modifications. Respondents were asked how many hours annually they are willingly to support the salt marsh restoration in their free time. The multinomial choice question contained 3 pre-defined annual working hour amounts ranging from 4 to 16 hours and alternatively an open answer option to allow respondents setting their volunteer working hours individually.

(2) The importance of salt marshes for social values

The social values included in this question refer to the following values distinguished by Schmidt et al. (2016), namely, Therapeutic, Economic opportunities, Amenity, Heritage. Specifically, the following social values were included in our study: local education level, Local/traditional knowledge, local community's trust, fellowship and cooperation, Sense of care for and commitment to protect nature, community identity (e.g. as fishermen community), health and well-being of residents and visitors, jobs in local communities. Respondents were asked to rate, how important salt marshes are for these social values, applying a scale from 1 (not at all important) to 5 (very important). Distribution of resulting social value rates have been compared for both surveys.

4.3 Results

4.3.1 Respondent's perception and knowledge of lagoon and salt marsh change

Most respondents are generally aware of salt marsh erosion but less familiar with particular erosion causes (Table 4.2). The three most relevant erosion causes are unknown to 50% (2015) and 44% (2017) of respondents; further 40% mention only one of the most relevant causes. The most frequently mentioned erosion causes were (unspecified) waves (43% - 2015; 38% - 2017), boat induced waves (29% - 2015; 38% - 2017) and hydrodynamic changes in the lagoon (24% - 2015; 25% - 2017) (Figure 4.3 b).

Respondent's general knowledge on lagoon environmental changes is relatively low. On the average half of environmental changes have been identified correctly. However, the three changes that were addressed and communicated by VIMINE (i.e. erosion, salt marshes and vessel waves), seem to be rather well-known and were identified correctly by about three quarter of respondents (Figure 4.3 a).

The question whether and how respondents' knowledge on the lagoon environment and salt marsh erosion changed between 2015 and 2017 needs to distinguish between different aspects. While the general knowledge on lagoon changes dropped in 2017 the awareness of salt marsh erosion increased significantly. Looking at the most relevant erosion causes communicated by LIFE VIMINE (i.e. boat waves, sediment budget and hydrodynamics), there was in 2017 a strong increase of respondents mentioning boat induced waves (+9%), while fewer respondents mentioned the negative sediment budget (-3%) and there was hardly any change in respondents mentioning hydrodynamic changes.

Interestingly, while in 2015 only 3% of respondents mentioned the MOSE project as erosion cause, 14% have done so in 2017. This change occurs independently from LIFE-VIMINE activities since the project refrained from commenting on MOSE effects.

Table 4.2 Respondent's knowledge on salt marshes erosion and environmental changes of Venice Lagoon

	2015	2017	Difference
Knowledge rate[a] about the three major salt marsh erosion causes (mean (SD))	0.21 (0.26)	0.24 (0.25)	0.03W
"I do not know" responses to "Why are salt marshes eroding?" (%)	**16.3**	**17.7**	**1.4F**
Respondents aware of erosion (%)	**74.1**	**86.0**	**7.9F**
Knowledge rate[b] on lagoon environmental changes (mean (SD))	**0.53 (0.22)**	**0.47 (0.21)**	**-0.06W**

Significant changes in bold; W Welch's two sample t-test applied; F Fisher's exact test applied

[a] Knowledge rate has been determined for each respondent by thenumber of correctly mentioned erosion causes divided by 3 (i.e. there are three main erosion causes in Venice Lagoon)

b Knowledge rate has been determined for each respondent by the number of correctly identified environmental changes divided by 15 (i.e. the number of environmental changes included in questionnaire)

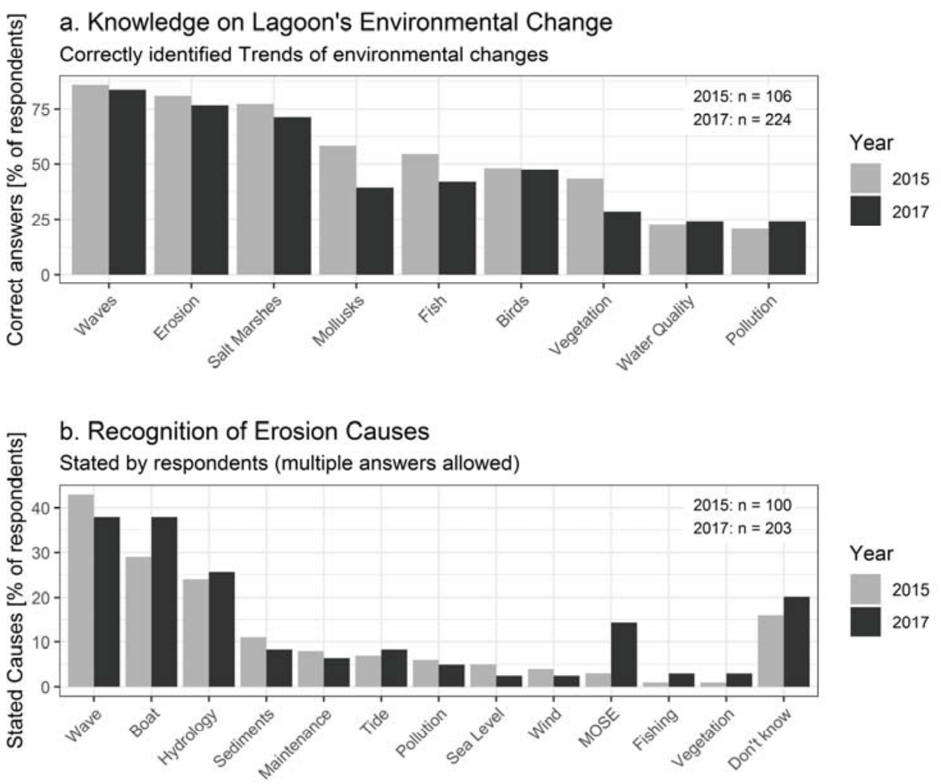

Figure 4.3 Respondents' lagoon and erosion knowledge. Bars in a. and b. indicate the percentage of respondents who answered respectively; b. is based on coded responses to an open-ended question.

4.3.2 Respondent's salt marsh management preferences

According to the selected salt marsh scenarios, about 90% of respondents prefer an increase in salt marsh extent. This increase is illustrated in the multiple use scenario, selected by 70% of respondents and in the nature reserve scenario, selected by 20%. The multiple use scenario combines sustainable fishing with salt marsh protection and restoration while the nature reserve additionally limits fishing activities and access to salt marshes, thus, establishing a relatively undisturbed area that is consequently more intensively frequented by water birds.

These different scenario features are also reflected in respondent's motivation for scenario selection (Figure 4.4). The selection was mainly motivated by the naturalness and suitability for nature observation in case of the two increasing salt-marsh-extent scenarios. For those selecting the multiple use scenario further important selection reasons were local traditions, support of the local economy and education opportunities. The societal importance of salt marshes is emphasized as between 30% and 37% of all respondents indicated that the importance for local traditions or the support for the local economy motivated their scenario choice. Aligning this societal importance with salt marsh conservation requirements is thus one challenge of future salt marsh management.

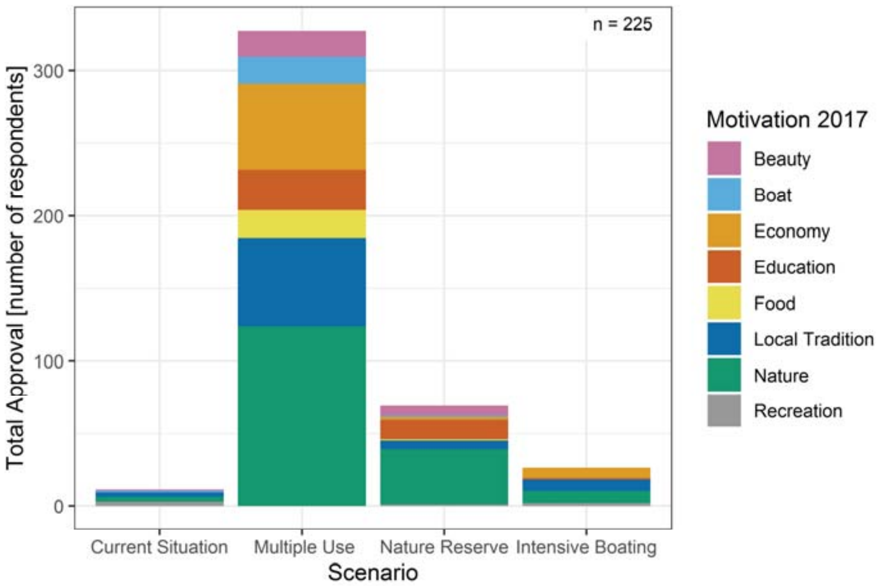

Figure 4.4 Scenario choice motivation underlying the chosen management options. Bars add up for each scenario the reasons why respondents have chosen a scenario. Respondents could select up to three choice reasons that where phrased as: **Beauty** – landscape is more beautiful; **Boat** – landscape more suitable/attractive for boating; **Economy** – landscape supports local economy and is better source of income; **Education** – landscape more suitable for nature education; **Food** – more seafood available to catch; landscape is part of **Local Traditions**; **Nature** – area is more natural and suitable for nature observation; Landscape more suitable for **Recreation**.

Salt marsh management preferences have been further elicited by a rating of salt marsh related ESs and intended future salt marsh uses (Figure 4.5) In both surveys the highest rating ES was nature conservation, i.e. the protection of a variety of habitats and species typical of salt marshes, followed by aesthetic information (i.e. the beauty of the area), erosion prevention and disturbance prevention or moderation (i.e. reducing wave energy, and protecting shores). These results are consistent with the above described scenario choice motivation. Regulating ESs like erosion and disturbance prevention were not included in the scenario choice motivation and thus only appear here.

Overall, the summed ES rates per respondent were in 2017 significantly higher compared to 2015 (p=0.01258; Welch's two sample t-test), suggesting a greater awareness and appreciation of the various salt marsh contributions to human well-being.

Respondent's scenario choice motivation and ES rating is also consistent with their intended future salt marsh uses. Both in 2015 and 2017 survey enjoying salt marshes' beauty and nature observation were the most frequently selected use types. Other future uses selected by one third up to half of respondents are to relax and to attend a guided salt marsh tour.

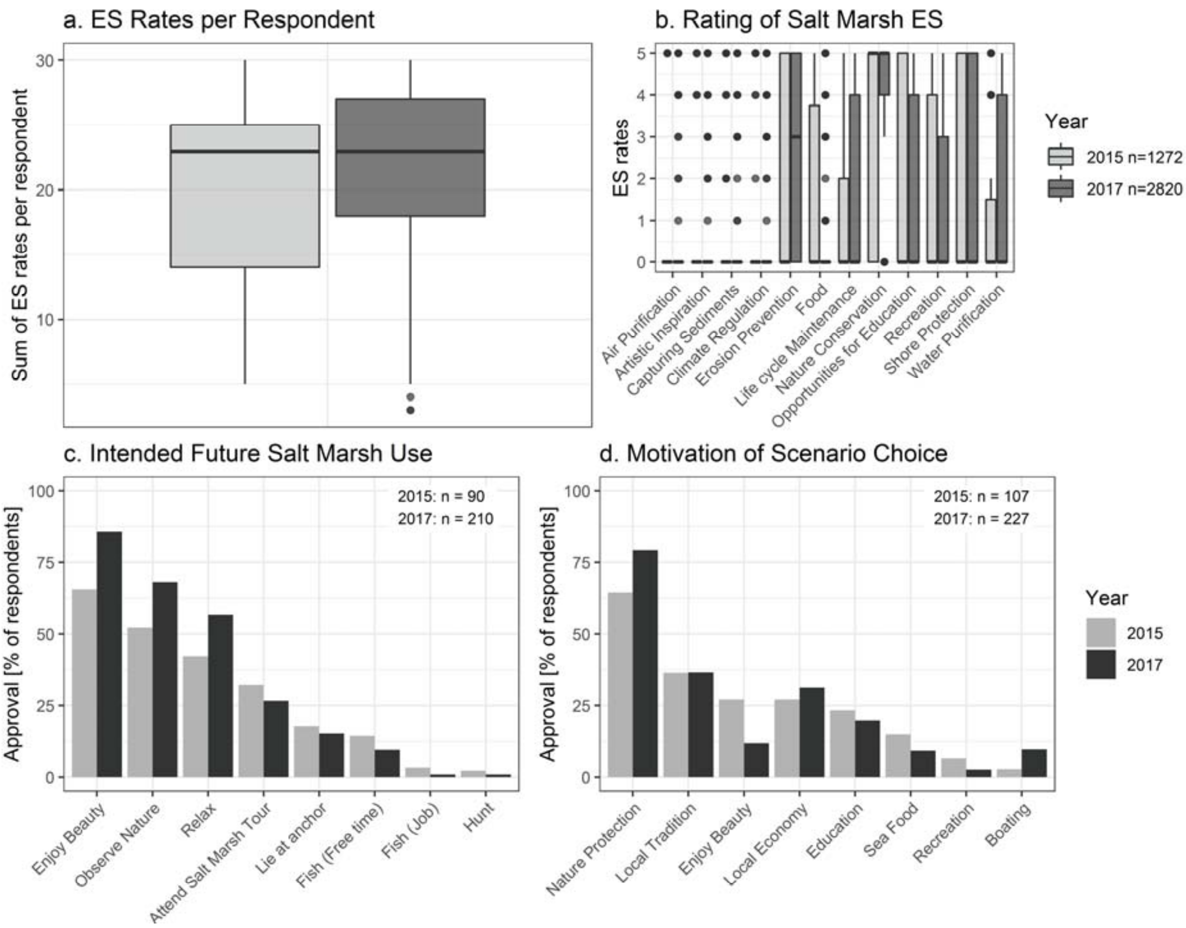

Figure 4.5 Respondents' salt marsh ES rating and management preferences, a. Box plots of summed ES rates per respondent in 2015 and 2017, b. Box plots of how important each salt marsh ES was rated in 2015 and 2017, c. Future salt marsh uses; bars indicate the percentage of respondents who selected each use, d. Reasons for choosing a salt marsh management scenario; bars indicate the percentage of respondents who selected each choice reason.

4.3.3 Eliciting respondent's salt marsh and ecosystem service values

Respondent's WTP is very similar in 2015 and 2017 with an average donation of about EUR 14 per year (Table 4.3). On the contrary, the WTV more than doubled in 2017 compared to the 2015 survey, indicating a significant change (p-value 0.01386; Welch's two sample t-test). This increase is consistent with an increasing share of respondents willingly to volunteer (+10%) while the share of respondents not willingly to contribute, either by monetary donation or volunteer work, dropped by 12% between 2015 and 2017. WTP and WTV estimates integrate both, the importance or appreciation of salt marshes as protected habitats on the one hand and a bundled ES value on the other hand due to survey question framing. This is important to note when interpreting results.

The salt marsh importance rated for seven social values was in the 2017 survey significantly higher compared to 2015 (Figure 4.6), suggesting an increase in the awareness of salt marsh importance and demonstrating that local residents perceive the social and ecological systems as intertwined. Most important social values were "sense of care for nature and commitment to protect nature", "local and traditional knowledge" and "community identity (e.g. as fishermen community)". These rating results are consistent with the scenario choice motivation, suggesting overall conscious responses.

Table 4.3 Change in WTP and WTV for salt marsh conservation and maintenance of salt marsh ESs

	2015	2017	Change
Monetary donation [EUR/year] (mean (SD))	14.38 (25.61)	14.17 (26.74)	-0.21W
Time donation [hours/year] (mean (SD))	8.02 (13.73)	17.37 (53.41)	9.35W

Significant changes in bold; W Welch's two sample t-test applied

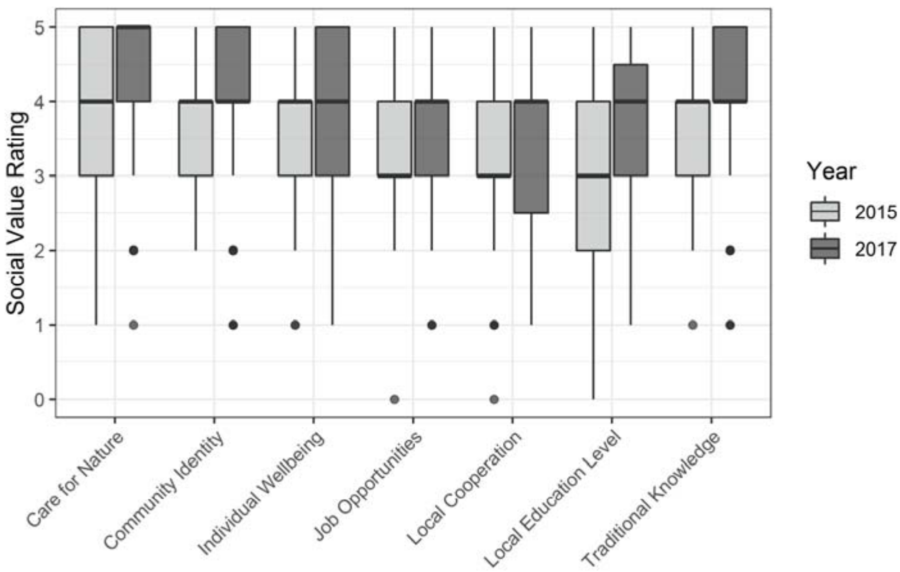

Figure 4.6 Social values of Venice lagoon salt marshes. Box plots show how important each social value was rated in 2015 and 2017.

4.4 Discussion

4.4.1 Comparability of samples in 2015 and 2017

To ensure comparability of the 2015 and 2017 samples, respondents' demographic characteristics were compared (see Appendix 3.D) and statistically tested. Both Welch's two sample t-test and Fisher's exact test did not reveal any significant differences on demographic aspects (i.e. age, gender, education level and annual household income). The samples are thus comparable.

Additionally, survey samples' demographic characteristics have been compared with the local population (Venice and Veneto region; see Appendix 3.D). Survey samples have a slightly lower female/male ratio than the population, but are similar regarding age and average household incomes. Respondents have a slightly lower income than the population. This indicates that the WTP estimate in our study is likely conservative.

The applied sampling strategy was partly self-selected (online surveys) and partly randomly selected through face-to-face surveys on the street and in water buses. The face-to-face surveys are considered a random sample here, because on the car-free lagoon islands distances are usually covered by foot or boat. We acknowledge, however, that the survey sample might be biased, because it misses people who rather stay at home or predominantly use their private boats. While in 2015 the majority of responses were collected by online surveys (60%), solely online surveys were used in 2017. Whether this affects results and consequently limits the potential to compare results of both surveys could be questioned. Self-selected respondents tend to be better informed and hold a strong opinion on the topic (Mitchell and Carson 1989, Walsh et al. 1992). This can cause a bias towards higher WTP estimates (Hudson et al. 2004). Self-selection is also reported to decrease by age and increase by education and environmental knowledge (Whitehead et al. 1993). Such differences are, however, undetectable in our samples, which do not differ significantly regarding age and education. Salt marsh and lagoon knowledge levels show no clear differences between the two surveys (Section 4.3.1). We thus consider both samples as sufficiently similar for our analysis.

4.4.2 Suitability of survey methodology

Although the reliability of contingent-valuation-study results has been extensively debated (Kahneman and Knetsch 1992, Carson et al. 2001, Veisten 2007, Carson 2012), the approach is frequently used (Perez-Verdin et al. 2016). Its results are considered reliable when several requirements (Carson 2012) are complied with: (i) explain the problem at hand and the intervention planned; (ii) exemplify that the intervention addresses the problem at hand properly; (iii) choose a clear payment mechanism that respondents can relate to and find plausible in case the intervention in question is implemented; and (iv) make plausible that the responsible authority will take results into account for decision making.

These requirements were considered. The survey started with an introduction on salt marshes, their erosion and the restoration approach, using images for illustration. Further, the survey clearly specified restoration actions and explained that LIFE VIMINE was actually implementing them, but that the donations were intended for the necessary long-term funding. Irrespective of all this information presented, respondents are considered to be rather familiar with salt marshes and their erosion since salt marshes are visible above water level and are noticeable when they turn lavender in August due to Limonium bloom. Moreover, most respondents live within the Venice Lagoon or directly at the lagoon's mainland coast and thus experience the lagoon daily.

Furthermore, responses across several questions are consistent, suggesting that respondents understood the survey properly and also captured underlying management trade-offs. For instance, highly rated social values are also reflected in respondents' scenario choice motivation. Another example, the salt-marsh scenario images not only show a potential future landscape, but also visualize different management implications. For example, the nature-reserve scenario implies limited access (for fishing and boating) and increased habitat quality for birds, while the intensive-boating scenario implies eroding salt marshes. Respondents very well captured these management implications that are reflected in their scenario choice motivation (Section 4.3.2). These observations thus suggest that responses reflect conscious decisions.

Identifying a suitable payment mechanism was a critical issue to our study. The initially intended payment mechanism was a tax, that could be payable as income tax. However, LIFE VIMINE started when the MOSE corruption affair became public, evoking a situation in which respondents were suggested to be particular skeptical about an additional tax (see Section 4.2.1). As payment vehicle thus annual donations have been chosen to adapt to this specific situation.

To limit the risk of inflating WTP estimates, respondents were reminded to carefully consider other expenditures that they incur, and were explicitly reminded to consider costs for house, food, health and recreation. The survey explained implications of WTP choices by telling that without sufficient funding salt-marsh restoration must be stopped.

A frequently mentioned potential bias is caused by the so-called embedding effect. It describes a situation when respondents are willingly to pay almost as much for environmental improvements in a small geographic area as for the same improvement in a much larger region (Kahneman and Knetsch 1992). Our study reduced this effect by asking for salt-marsh restoration donations not only for the project area but in general for Venice Lagoon.

A shortcoming of our study is the lacking control group, consisting of local residents who are excluded from any project interaction to be able to separate LIFE-VIMINE effects on management preferences and salt-marsh values from other (external) effects. While this was neither intended nor considered appropriate to exclude individuals from project interaction, establishing such a control group is very difficult, because LIFE-VIMINE information was present at several public spaces, restoration works were visible and also social interaction and exchange on the project could not be controlled. The lacking control group therefore had to be accepted, but this is important to consider when interpreting results.

4.4.3 Willingness To Volunteer reduces protest responses

Our results suggest that the included WTV-option helped to reduce protest responses. This was also suggested by Garcia-Llorente et al. (2011). WTV estimates can complement WTP estimates by offering another, non-monetary way of expressing importance, hence contributing a more integrated valuation approach (Jacobs et al. 2016) that reduces or avoids shortcomings associated with a single monetary approach (Gómez-Baggethun et al. 2010).

Overall, respondents' most preferred way of contributing to salt marsh restoration was to volunteer time (44% in 2015; and 54% in 2017) while one third of the respondents were willing to donate money. In contrast to monetary donation, WTV significantly more than doubled in 2017 compared to the 2015 survey because of both higher WTV values per respondent (+8 hours per year) and a 10% higher fraction of respondents willing to volunteer in 2017 which corresponds to a decrease in protest responses given by respondents, who are neither willingly to donate nor to volunteer. Protest rate was 27% in 2015 and 15% in 2017 respectively.

Protest responses and how they are treated in a valuation study can affect results (Carson and Hanemann 2005, Meyerhoff and Liebe 2010). Here, analyses of WTP and WTV estimates treat protest responses as donations of zero Euros or hours annually. The main reason for protesting was that public authorities are considered responsible (52% in 2015 and 66% in 2017) by protesters. A lack of trust in money that is spent appropriately, was for 14% (2015) and 17% (2017) of the protesters reason to refuse donations. Many protesters mention financial limitations (31% in 2015 and 40% in 2017). This indicates that our results may underestimate salt-marsh values held by respondents, since donations of financially limited respondents are expected to increase once their financial situation eases.

The protest rates observed here are comparable to those found in other studies. For valuation studies on wetlands or nature conservation, the meta-analysis by Meyerhoff and Liebe (2010) reports an average share of protesters of about 20%. Later marine focused valuation studies report between 11% and 19% of protesters (Batel et al. 2014, Jobstvogt et al. 2014b, Brouwer et al. 2016) or even considerably higher protest shares of 32% (Tseng et al. 2015) and 44% (Tonin 2018).

4.4.4 Multiple salt marsh values indicate public demand for conservation in Venice lagoon

Values expressed by WTP and WTV in our survey would be sufficient to sustain all remaining salt marshes in Venice lagoon. Salt marshes in Venice lagoon extend to about 30km^2 to 47km^2 today (Tambroni and Seminara 2006, Sarretta et al. 2010, Barausse et al. 2015) and their conservation would amount to annual costs of about 6.7 million EUR, based on annual restoration costs of 1,430 EUR ha-1, applicable to the small scale restoration approach adapted by LIFE VIMINE. These financial needs face an average annual WTP of 14 EUR per capita estimated by our study. Aggregating this WTP across all Venetians (about 260,000 inhabitants according to dati.istat.it), yields an annual WTP of 3.6 million EUR and thus would cover about half of the conservation costs. Additionally, our results show a substantial annual per capita WTV of 8 hours (survey 2015) and 17 hours (2017) on the average. This WTV is translated into a monetary value for better comparison with conservation costs, as follows: A general worker's working hour costs about 28 EUR, according to LIFE-VIMINE cost estimations. To adjust these working hour costs for volunteer's layperson working skills and to cover efforts required for volunteer training and instruction as well as insurance costs, a volunteer working hour here is estimated at 9 EUR. This is about one third of the general worker's costs. Multiplied by the above WTV estimates of 8 hours and 17 hours respectively, this yields annual estimates of EUR 72 to 153 per capita. Consequently, 43,000 or 11,000 volunteers respectively would be required to cover remaining 3.1 million Euros for salt marsh restoration. Though this volunteer number is large, it amounts to 17% (2015) and 4% (2017) of Venetians respectively. This is far less than the 44% (2015) to 54% (2017) of volunteers that are identified by our survey and also far less than the 41% of local volunteers found by Garcia-Llorente et al. (2011).

Due to the way WTP and WTV questions were framed, resulting estimates integrate both the importance or appreciation of salt marshes as protected habitats, and a bundled ES value. Hence, restoration actions should ensure that restored salt marshes function ecologically similarly to natural salt marshes to provide desired ESs.

WTP and WTV estimates obtained here can be interpreted as respondents' call for salt marsh protection and restoration (Pascual et al. 2010, Martín-López et al. 2014). Both value estimates, however, do not allow claiming local resident's financial contributions for salt marsh protection.

The public authorities have the responsibility to comply with the lagoon's European and national protection status and to implement appropriate management measures for which our study results can serve as additional justification. This is substantiated by respondent's preferences for salt-marsh use, ESs, preferred salt-marsh scenarios and their reasons for scenario selection. The dominant overarching aspect recurring in all these aspects is nature or salt marsh conservation. That could be explained by respondent's emotional affinity (Kals et al. 1999) toward their unique environment in Venice Lagoon, which is also reflected in its status as world heritage site.

Next to conservation, salt marsh use or their socio-cultural importance is relevant to local residents who possess a diversity of motives and preferences that go beyond the monetary value suggested by the WTP estimate (Jacobs et al. 2016). For instance, erosion prevention and shore protection where highly rated regulating ESs. Salt marsh management motives mentioned were salt marsh beauty, recreation and social aspects like education opportunities and the importance for local traditions and community identity, for instance, as fishing community. These multiple motives and preferences outline the challenges lagoon's salt marsh management is confronted with when aiming to align clearly preferred salt marsh conservation with other demands and preferences. These challenges need to be successfully solved since a combination of biodiversity with other motivations and preferences is considered crucial for conservation success (Reid et al. 2006). In protected areas like the lagoon of Venice such a combination must comply with obliged conservation objectives and must adopt the primacy of conservation over other demands.

4.4.5 Participatory salt marsh conservation affects local residents' management preferences, salt marsh knowledge and ecosystem service values of local residents

Comparing the 2015 and 2017 surveys, a change in salt marsh knowledge and perception was measurable for several aspects addressed by LIFE VIMINE. The project involved local stakeholders in various ways, covering the participation ladder's (Arnstein 1969) medium and upper levels and ranged from environmental information and education measures up to joint working groups and active cooperation. This way, local residents were offered various ways to interact with salt marsh conservation and thus to learn about, familiarize with and respond to salt marsh erosion while simultaneously interacting socially with other people interested in the project. Our results suggest this increased local resident's salt marsh knowledge, reflected by (1) a significantly larger awareness that erosion occur; (2) a slightly higher knowledge rate about the three main erosion causes; (3) considerably larger knowledge that boat induced waves cause salt marsh erosion (+10%) (this erosion cause has been particularly addressed by LIFE VIMINE by targeting specific information to boat owners); (4) significantly increased ESs rates. The surveys fail to detect however, whether this change can be attributed solely to LIFE-VIMINE activities or whether respondents also accessed other information sources. For instance, the EU-Project LIFE SERESTO that focuses on sea-grass restoration in the Venice Lagoon, provided information during the same period. Moreover, the study period was affected by the MOSE corruption scandal. Particularly the latter likely turned public attention to the lagoon environment, as our results suggest: While MOSE was mentioned by 3% of respondents as main erosion cause in 2015, in 2017 it was the fourth most frequently identified erosion cause and was mentioned by 14% of respondents.

Regardless of disentangling causes for respondent's knowledge and perception change, a knowledge transfer and knowledge gain as offered by LIFE VIMINE is crucial for generating restoration and conservation support (Ressurreição et al. 2012b, Abecasis et al. 2013, Sterling et al. 2017). This relationship is confirmed by our results since both salt marsh knowledge and ES ratings are positively correlated ($p<0.001$) with WTV and WTP values. Moreover, WTV increased significantly between the two surveys. This significant increase within the rather short project life time is remarkable and suggests that the participation opportunities offered by LIFE VIMINE resonated with respondents. So far, our findings agree with the widely adopted notion that stakeholder participation is central to conservation or natural resource management projects and to environmental decision making (Reed 2008, IPBES 2019). To increase conservation success, stakeholder involvement is a way to align multiple uses and management preferences with nature conservation (Klein et al. 2008). By revealing those management preferences, insights from our study can contribute to a more integrated sustainable lagoon management.

4.4.6 Preferred salt marsh management options and management implications

Out of four management scenarios to choose from in our survey the multiple-use scenario met the largest approval. It combines relatively equal levels of all considered management aspects (salt marsh extent, fishing, boating and nature conservation/bird watching) without emphasizing a single aspect. Apparently, the majority of respondents aligns nature conservation with their demand for using the salt marshes which has also been reported from other contexts (Soliva et al. 2008, Ruiz-Frau et al. 2011). Generally, multifunctional, multi-use landscape management is considered a promising sustainable approach to conservation (IPBES 2019). However, our study concerns a protected area which, by law, gives priority to defined conservation objectives and thus may require restrictions or bans of conflicting uses.

Similarly, conflicts may arise between different local stakeholders' management preferences. For instance, the nature reserve scenario has been approved by about one in five respondents and demands larger undisturbed and unused areas. This, however, contradicts the most preferred multiple use scenario. Solving these conflicts between different management preferences and between use preferences and legal obligations is one of the management challenges in Venice lagoon. Spatial zoning may be one approach to solve such conflicts (Douvere 2008) by spatially defining conservation only no-go zones as well as zones for conservation compatible uses.

According to this survey, many respondents want to enjoy the beauty of salt marshes and aesthetic information is a highly rated ES. Consequently, visual effects of conservation measures should be considered, for instance, when planning the shape of restored salt marsh shores (e.g. straight or structured) or on materials used. Further research is needed to better understand what is considered aesthetically appealing. To address respondents' demand for erosion prevention and nature conservation, salt-marsh management requires ensuring appropriate location, extent, quality and biodiversity of restored salt (e.g. by restoring varied salt marsh edge shapes), replanting natural halophytic vegetation diversity and targeting habitat demands of bird and fish species.

Salt-marsh management should include also traditional uses and offer an income source, as requested by four in five respondents. Our study provides first insights how this can be achieved.

For instance, one third of respondents prefers to observe nature in salt marshes. This can generate jobs and income via licenses, entrances fees or boat rental fees. Guided salt-marsh tours, as demanded by more than a quarter of the respondents, is an additional income source for fishermen who are very familiar with the lagoon.

While these are only first salt-marsh management ideas supported by our study results, future research could build on this and develop together with local stakeholders more detailed options for aligning nature conservation with local stakeholder's preferences in the Venice Lagoon.

4.5 Conclusions

Our results suggest, salt marshes are widely appreciated in Venice lagoon region and are associated with nature conservation but also with a range of different ESs and social benefits. Results further show a general understanding and acceptance that salt marsh conservation and restoration comes at a cost. Despite of this overall support for restoration, a coherent, lagoon-wide and long-term funded salt marsh management scheme is lacking so far, although these protected habitats are disappearing at high rates. Our study presents options to address this pressing challenge in Venice lagoon management.

Crucial to Venice lagoon salt marsh management is the involvement of local stakeholders. Our results show that involving local residents affects their salt marsh knowledge, management preferences and also their salt marsh appreciation in multiple ways. This was investigated by comparing data collected at an early and final stage during a restoration project. This dual survey approach addresses a gap in literature where management effects are usually analysed once, before or after an intervention has taken place.

Our study strongly benefits from measuring management preferences in an integrated way that combines different valuation approaches. This provides relevant context, reveals synergies and conflicts critical for tailoring and guiding future salt marsh conservation and restoration actions. Three important guiding management recommendations are highlighted here:

Information and education measures should accompany salt marsh conservation to ensure long term conservation support

Our study shows that future salt marsh management in Venice lagoon can build on a general awareness of erosion problems among people living within or in the vicinity of Venice lagoon. Underlying erosion causes are, however, less well known and suggest that further information and education is required for improving that. This might be of particular relevance where it is intended to address erosion causes with specific management measures, for instance by restricting boat speed or restoring lagoon's hydrodynamics. Results suggest that better salt marsh and erosion knowledge can increase overall support for restoring and conserving this habitat. This is relevant for ensuring the required long term, if not permanent, support for salt marsh restoration since salt marsh conservation can merely alleviate erosion symptoms. The main erosion causes like the altered lagoon's hydrodynamics, its negative sediment budget and vessel traffic waves cannot be solved at the scale of salt marsh restoration.

Spatial zoning solves conflicts between different salt marsh uses and their conservation

Increasing salt marsh extent is preferred by most respondents, but preferences are split between multiple salt marsh uses and conservation. Thus, despite the general consensus to restore salt marshes, agreement needs to be achieved on how salt marshes can and should be used. Spatial zoning, as frequently applied in conservation planning, probably aligns different demands, for instance, by designating areas with a strong conservation focus for most susceptible salt marshes and designating areas for certain salt marsh compatible uses.

Salt marsh management benefits from involving local residents

In general, the information and integration of local residents in restoration and conservation projects in Venice appears crucial, particularly in view of the existing top-down hierarchical structures. Munaretto and Huitema (2012) observed that for water and environmental management in the lagoon knowledge was not shared with the general public. This frustrated people with decision making processes.

Our study results reveal how a salt marsh conservation project affects management preferences and ecosystem-service values of local residents. Results suggest that informing and involving local residents in future salt marsh restoration can generate benefits in both directions: During LIFE VIMINE the appreciation of salt marshes and their conservation support increased significantly, thus benefitting restoration efforts. Local residents benefit when their preferences regarding salt marsh management are properly addressed and when they better understand management decisions.

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Chapter 5

Integrating methods for ecosystem service assessment and valuation: Mixed methods or mixed messages?

A mixed-method approach was used to assess and value the ecosystem services derived from the Dogger Bank, an extensive shallow sandbank in the southern North Sea. Three parallel studies were undertaken that 1) identified and quantified, where possible, how indicators for ecosystem service provision may change according to two future scenarios, 2) assessed members of the public's willingness-to-pay for improvements to a small number of ecosystem services as a consequence of a hypothetical management plan, and 3) facilitated a process of deliberation that allowed members of the public to explore the uses of the Dogger Bank and the conflicts and dilemmas involved in its management. Each of these studies was designed to answer different and specific research questions and therefore contributes different insights about the ecosystem services delivered by the Dogger Bank. This paper explores what can be gained by bringing these findings together post hoc and the extent to which the different methods are complementary. Findings suggest that mixed-method research brings more understanding than can be gained from the individual approaches alone. Nevertheless, the choice of methods used and how these methods are implemented strongly affects the results obtained.

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5.1 Introduction

The concept of ecosystem services, the contributions of ecosystems to human well-being (de Groot et al. 2010), is a useful approach for demonstrating the links between humans and the environment. It is readily acknowledged that many of these services go unrecognised (or under-recognised) in the environmental management process (Daily 1997, Dasgupta et al. 2000). Cumulative impacts and trade-offs between them are overlooked (Pahl-Wostl 2007, Lester et al. 2010). This often occurs because they may be used indirectly, or enjoyed directly (but maybe unconsciously), but are not traded through markets (Böhnke-Henrichs et al. 2013). It may also result, because the links between environment and human well-being are indirect, occurring at different spatial and temporal scales (Corvalan et al. 2005). To overcome this problem, quantification and valuation of ecosystem services has been advocated as a solution (e.g. Liu et al. 2010). Valuation can be approached from multiple perspectives, including ecological value (the degree to which an ecosystem component contributes to an objective or condition such as an ecosystem service; Farber et al. (2002)), economic value (often expressed in monetary terms; Brown (1984)) and socio-cultural value (or shared social values obtained through social interaction, open dialogue and social learning; Stagl (2004)).

Through assessment and valuation, the link between ecosystem services and human well-being is made more explicit (Fisher et al. 2009). Evidence of this link should therefore improve environmental decision-making, ensuring valued ecosystems continue to deliver the services essential to human well-being (Daily et al. 2009). Thus far, the many challenges involved in ecosystem service assessments and valuations have limited their use (Laurans et al. 2013), but within many environmental management circles, including marine planning, there is a growing call for wider ecosystem service assessment and valuation (e.g. Mooney et al. 2005, Börger et al. 2014a).

5.1.1 Quantification of ecosystem services through ecological assessment

Interest in ecosystem service quantification has led to numerous ecological assessments of ecosystem services. These typically identify indicators of ecosystem services, attempt their quantification and spatial mapping (e.g. Burkhard et al. 2012, Crossman et al. 2013) and demonstrate how they have changed over time and/or model how they may change into the future (e.g. Martín-López et al. 2010). For marine and especially offshore ecosystems, no examples known to the authors exist that involve all these steps and apply them to multiple ecosystem services. Such assessments, however, may be particularly useful for ecosystem management, because they facilitate the analysis of ecosystem service trade-offs made between alternative management options or possible future scenarios.

Being based on suitable indicators, outcomes of ecological assessments reflect ecosystem change (Hattam et al. 2015a). They demonstrate the ecological importance of the system and can also assist with identifying the processes involved in ecosystem service supply (e.g. Cook et al. 2014). This facilitates the identification of drivers of change, which can also inform ecosystem management. Ecological assessments allow the investigation of a broad range of ecosystem services based on existing data. Hence they help identify and quantify the most important ecosystem services and those most intensely affected by human activities in an area. It is important to note that while ecological assessments explore how the supply of ecosystem services change over time, they do not provide information about the value of these ecosystem services to society. By quantifying expected changes they can, however, inform the development and application of valuation studies that explicitly aim to assess the social and economic value of the benefits derived from ecosystem services. In an attempt to encourage ecological assessments of ecosystem services, guidelines for doing this have been produced by organisations and institutions (IPIECA 2011, Maes et al. 2014).

5.1.2 Economic valuation of ecosystem services

Economic valuation of the benefits from ecosystems is commonly the next step in the assessment (DEFRA 2007). Economic valuation provides a common currency for units of value. This, it is argued, provides a means for comparing the costs of environmental protection with the benefits generated, and for comparing different management or policy goals, including environmental protection (Balmford et al. 2002, Hanley et al. 2009). A further justification is that it should encourage more sustainable use of the environment and better motivate its conservation and protection (Daily and Matson 2008, Tallis et al. 2008). Public bodies are increasingly offering guidance to environmental managers on how to undertake such valuations (e.g. HM Treasury 2003, Pearce et al. 2006, DEFRA 2007, Hansjürgens et al. 2012, Baker and Ruting 2014) and incorporate the findings into policy and practice (e.g. DEFRA 2010).

The value of ecosystem service benefits that are not traded in markets can be assessed using non-market valuation techniques (Cooper et al. 2013). Borrowing the logic of voluntary exchange in the market, such assessments typically aim to gauge people's willingness to trade some fraction of their wealth or income for an increase in ecosystem service provision. This willingness-to-pay (WTP) is interpreted as an indicator of the change in utility the person expects from the consumption of these increased ecosystem services. When WTP cannot be assessed through market data, survey-based techniques, such as the contingent valuation method (CVM) (Carson and Hanemann 2005) and discrete choice experiments (DCE) (Hanley et al. 1998, Louviere et al. 2000) can be employed. These methods elicit WTP in a hypothetical market setting created in the survey interview. In the marine environment, the majority of valuation studies have been applied to coastal and near-shore ecosystems (e.g. Ressurreição et al. 2012a, Hynes et al. 2013, Loomis and Santiago 2013), but a growing number of applications to offshore and deep-sea sites and fauna can be found (e.g. McVittie and Moran 2010, Wattage et al. 2011, Jobstvogt et al. 2014a, Aanesen et al. 2015).

5.1.3 Alternatives to economic valuation

Economic valuation interprets private households as consumers of ecosystem services rather than as citizens holding attitudes and values regarding the provision of ecosystem services for society (Blamey et al. 1995, Orr 2007). Consequently, this framework has been criticised from both within the field of economics (e.g. Aldred 2006, Parks and Gowdy 2013) and elsewhere (e.g. Adams 2014). Economic valuation techniques such as survey-based elicitation of WTP and concepts such as ecosystem services and natural capital frame the nature-society relationship into one of utility and exchange prefiguring commodification as a reasonable response (Kallis et al. 2013). Gómez-Baggethun et al. (2010) argue that even though the focus on economic valuation and payment schemes has indeed attracted political support for conservation, it has also led to the commodification of a growing number of ecosystem services and the reproduction of the neoclassical economics paradigm and market logic to tackle environmental problems. There are competing values and interests relating to the environment between different groups and communities, something that also creates conflict among the groups and among communities across space and time (Martinez-Alier et al. 1998). Kosoy and Corbera (2010) highlight three invisibilities in the commodification of ecosystem services: (i) the technical difficulties and ethical implications that exist when narrowing down the complexity of ecosystems to a service, and how that changes the way we relate to and perceive nature; (ii) the fact that commodification of ecosystem services requires a single exchange-value, which in turn denies the multiplicity of values attributed to these services (i.e. there are values beyond monetary values that are important); and (iii) the fact that it reproduces rather than addresses existing inequalities in the access to natural resources and services.

Non-monetary approaches such as deliberative group discussions (Wilson and Howarth 2002), citizens' juries (Spash 2007) and q-methodology (Pike et al. 2015) utilise group based activities and participatory and deliberative approaches to attain detailed information about people's relationship with the natural environment and the socio-cultural values they place on it (Christie et al. 2012). Deliberation can refer to two kinds of discussions: one that involves the careful and serious weighing of reasons for and against some proposition, and another that involves an interior process by which an individual weighs reasons for and against courses of action (Fearon 1998). Unlike conventional non-market valuation techniques such as CVM or DCE, which attempt to elicit pre-existing preferences or those constructed at the time of the interview, deliberative group methods, including citizens' juries, are based on the assumption that the values people hold regarding matters of collective choice can be constructed through the process of reasoned discourse with other members of society (Wilson and Howarth 2002, Howarth and Wilson 2006, Spash 2007). In recognition of this, and the criticisms against economic valuation, public bodies are also providing guidance on a range of deliberative methods for the assessment of ecosystem services (e.g. Fish et al. 2011).

5.1.4 Integrating methods

Despite calls for the integration of methods that elicit ecological, socio-cultural and economic values (e.g. de Groot et al. 2010, Lopes and Videira 2013), most ecosystem service assessments focus on just one of these approaches, or combine ecological assessments with some form of economic or non-monetary valuation (Pascual et al. 2011, Pascual et al. 2012). In some cases mixed methods are applied drawing on both economic and non-monetary techniques (e.g. Szabó 2011, Kenter et al. 2013). What rarely happens is a synthesis of the findings arising from the different approaches. Only two published papers have been identified within this study that attempt to integrate the outputs from biophysical, socio-cultural and economic approaches using empirical data (Castro et al. 2014, Martín-López et al. 2014). Research into mixed-methods, however, indicates that multi-strategy approaches to research can bring more understanding than can be gained from the individual approaches alone (Bryman 2006). Effort is therefore needed to understand how the different approaches to ecosystem service assessment and valuation support each other, or not, as the case may be.

Using the Dogger Bank (a shallow sandbank in the southern North Sea) as a case study, this paper explores the complementarities between three approaches to ecosystem service assessment and valuation: 1) an ecological assessment, which identified and quantified, where possible, indicators for ecosystem services delivered by the Dogger Bank and explored how these services may change according to two future scenarios, 2) a DCE, which assessed members of the UK public's WTP for improvements to a small number of ecosystem services provided by the Dogger Bank as a consequence of hypothetical management plans, and 3) a citizens' jury workshop that allowed members of the UK public to explore the uses of the Dogger Bank and the conflicts and dilemmas involved in its management. Complementarity analysis is just one approach to combining mixed method data (e.g. Brannen 2005), but is particularly suitable for data that have been collected through different methods at the same time (Teddlie and Tashakkori 2009). The exploration of complementarities between these methods was undertaken retrospectively and was not planned as part of the original study. The approach taken is therefore only an example of how a synthesis stage could be undertaken. Ideally, integration should be planned from the outset with full understanding of what is required of the integrating approach. The growing call for evidence-based policy and practice combined with limited opportunities for primary data collection, suggests that such retrospective synthesis of data pertinent to ecosystem service assessments and valuation may become increasingly relevant.

By exploring the complementarities between the approaches used in this study, this paper “seeks elaboration, enhancement, illustration, clarification of the results from one method with the results from another” (Greene et al. 1989, p. 259). It therefore addresses the following research questions: To what extent do the different approaches used complement each other? How can the different methods be used more effectively together? And how can the findings be better incorporated into environmental management?

The paper is structured as follows. Section 5.2 introduces the Dogger Bank before providing a brief description of the methods used in each sub-study and the approach used to explore the complementarities between these methods. This is followed in Section 5.3 by a presentation of the results. The findings are then discussed in Section 5.4, with conclusions provided in Section 5.5.

5.2 Case Study and Methods

5.2.1 The Dogger Bank

Covering an area of 18,700 km^2, the submerged sandbank of the Dogger Bank is located in the southern part of the North Sea (Figure 5.1). It is an important location for commercial fishing as well as actual and potential energy generation. The UK Government is planning the world's largest offshore wind farm to be installed on its section of the Dogger Bank (Forewind 2010). It also provides a number of other less recognised benefits, for example, it acts as a nursery ground for fish (Diesing et al. 2009, Hufnagl et al. 2013) and it makes a contribution to carbon storage and sequestration, which in turn supports the regulation of the climate. In addition it is of cultural importance: fishermen and archaeologists have found a number of prehistoric remains on the Dogger Bank, and a small number of recreational anglers and scuba divers visit the Dogger Bank every year. As a consequence of its ecological importance and its vulnerability to human pressures, the UK, Germany and The Netherlands have designated their parts of the Dogger Bank as a Special Area of Conservation (SAC) under the EU Habitats and Species Directive (92/43/EEC) for the protection of Annex I Habitat H1110 ‘sandbanks which are slightly covered by seawater all the time’ (EC 1992). This designation requires that all human activities within the SAC are regulated to fulfil the conservation objectives for the site. Management measures are currently under negotiation between the UK, Germany and The Netherlands before submission to the EU. Proposals for these management measures formed the backdrop to the DCE and citizens' jury scenarios.

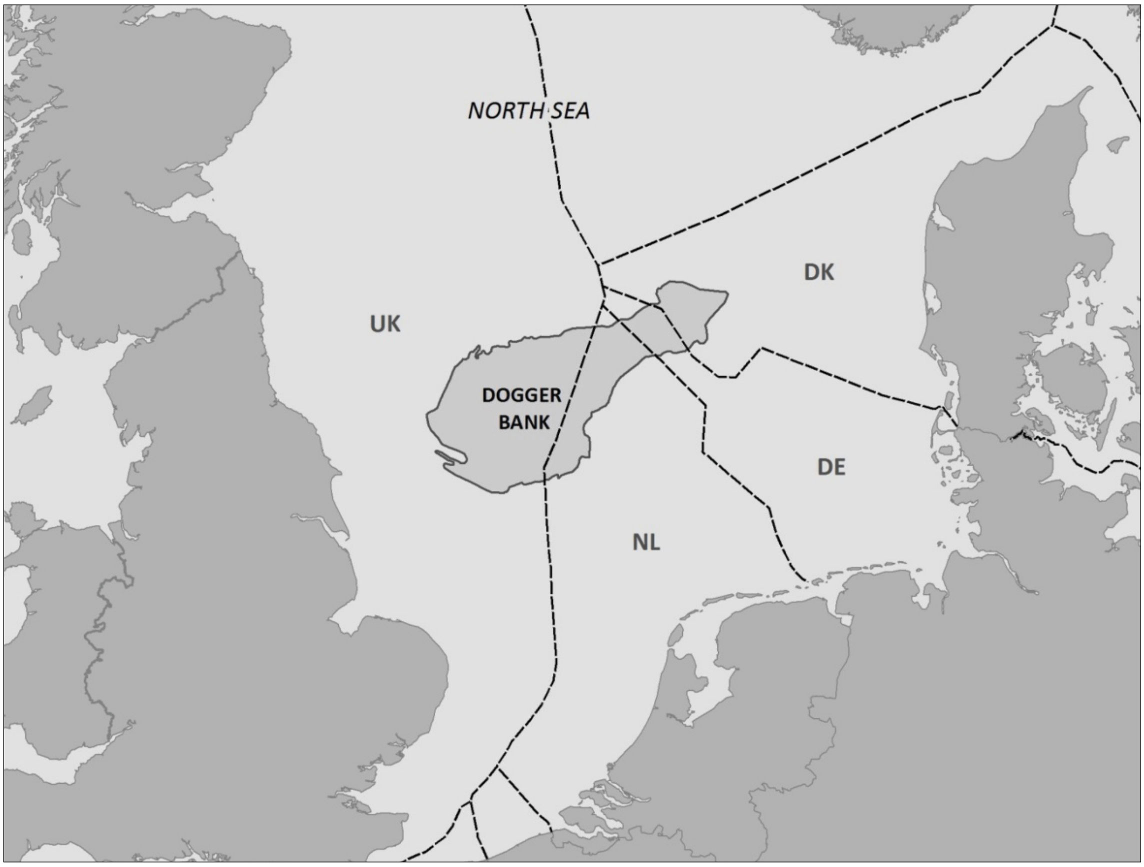

Figure 5.1 Location of the Dogger Bank (UK - United Kingdom; DK — Denmark; DE — Germany; NL — Netherlands).

5.2.2 Methods Applied

The ecosystem service framework and indicators defined by (Hattam et al. 2015a) formed the basis for this study. The three assessment and valuation studies then proceeded in parallel. The exploration of complementarities was undertaken *post hoc* and was not originally foreseen during the study development and planning phase.

Ecological Assessment

The main aim of the ecological assessment was to explore which ecosystem services are subject to change under different future scenarios. Indicators of ecosystem service quantity and quality were developed for all ecosystem services identified as relevant for the Dogger Bank (for details see Hattam et al. 2015a). For clarity and to facilitate the assessment, indicators of ecosystem services (i.e. of ecosystem service supply) are considered distinct to indicators of ecosystem benefits (i.e. the outputs of ecosystem services, created and derived by humans). Attempts were made to quantify each of the indicators identified. The absence of appropriate data meant that indicators for only six of the ecosystem services identified could be assessed (Table 5.1).

Table 5.1 Ecosystem services and their indicators as assessed for the Dogger Bank.

Ecosystem services	Dogger Bank specific indicators	Measurement (units) — measured over time
Food provision — wild capture sea food	Population of nephrops, cod, haddock and flatfish species such as plaice, turbot and lemon sole	Biomass (tonnes km^{-2}) of fish and shellfish
	Quality of the populations of nephrops, cod, haddock and flatfish species such as plaice, turbot and lemon sole	Species composition, age profile; length profile; % affected by disease; mortality rates
Biotic raw material	Population of sandeels	Same measurement units as for food provision
	Quality of the populations of sandeels	Same measurement units as for food provision
Climate regulation	Air-sea and sediment-water fluxes of carbon and CO_2, scaled to the area covered by the Dogger Bank	Modelled (mg C m^{-2} d^{-1})
	Levels of carbon in different components of the marine ecosystem, scaled to the area covered by the Dogger Bank	Modelled carbon levels: biomass of carbon (g m^{-2}); dissolved organic or inorganic carbon (mg C m^{-3}); suspended organic or inorganic carbon (mg C m^{-3}); buried particulate organic or inorganic carbon (mg C m^{-2})
	Permanence of carbon sequestration, scaled to the area covered by the Dogger Bank	% of annual carbon turnover from sediments
	Air-sea fluxes of other greenhouse gases (e.g. dimethyl sulphide, methane, nitrous oxide), scaled to the area covered by the Dogger Bank	Examined, but neither modelled nor empirically determined (µg greenhouse gases m^{-2} d^{-1}) data available
Migratory and nursery habitat	Spawning: abundance of cod, sandeels, plaice, nephrops Nursery: abundance of sprat, nephrops	Abundance m^{-2} and species diversity
Gene pool protection	Diversity of species and sub-species, phylogenetic distance, Biodiversity Intactness Index	Expert judgement on species change and changes to Biodiversity Intactness Index
Leisure, recreation and tourism	Species of recreational interest e.g. harbour porpoise, grey seal, seabirds, fish	Count data of key species of recreational interest
	Area of biotopes of key interest to recreational users, scaled to the area covered by the Dogger Bank	Expert judgement on changes in area of biotopes of key interest to recreational users

To evaluate how the services provided by the case study sites may change in the future, present day (2000–2009) provision was assessed and compared against intermediate future provision (2040–2049). Two contrasting scenarios were used based on the IPCC 2002 National Enterprise (A2) and Global Community (B1) scenarios (Nakicenovic et al. 2000), a description can be found in (Groeneveld et al. 2018). Briefly, both scenarios encompass intermediate levels of economic growth, but A2 envisages modest local environmental policy and limited global environmental policy, whilst B1 has ambitious local and global environmental policy. These global scenarios were augmented with location specific information (e.g. the B1 scenario included the construction of the existing planned wind farm on the UK sector and related fishing restrictions). Ecosystem service indicators were then assessed using various types of data, including measured data (e.g. fish catch data), modelled data (POLCOMS-ERSEM model output; Artioli et al. 2014) data reported in the literature. Additionally, expert judgment was used to qualitatively identify possible effects of the scenario on ecosystem service provision. See (Hattam et al. 2014) for more detail.

Discrete Choice Experiment (DCE)

In the absence of market data for the majority of ecosystem services provided by the Dogger Bank, primary valuation data were also collected through a survey with members of the public

(Börger et al. 2014b). The survey used a DCE (Hanley et al. 1998, Louviere et al. 2000) to elicit the WTP of members of the UK public for securing some future positive environmental change (or to prevent some negative change from happening) on the Dogger Bank. As far as possible, the attributes of the DCE were linked to the ecosystem service indicators developed for the ecological assessment and targeted towards indicators for which no quantitative data were available.

The survey was undertaken online during December 2013. It presented respondents with hypothetical management measures drawn from the negotiations held by the Dogger Bank Steering Group about proposed fisheries management plans for the Dogger Bank (NSRAC 2012). Respondents were informed that management would regulate fisheries and wind farm development (JNCC 2012) and that these regulations would affect different aspects, or attributes, of the ecosystem: overall species diversity; the protection of seals, porpoises and seabirds; and the spread of invasive species. Respondents were asked to choose between the current, no cost situation and different management scenarios, each with differing impacts on the ecosystem attributes and associated implementation costs Table 5.2. The inclusion of the cost component means that the value respondents attach to the different attributes can be inferred from respondents' stated choices and expressed as marginal WTP. For further details see (Börger et al. 2014b).

Table 5.2 Choice attributes (current, no costs situation in italics).

Attribute	Description in the questionnaire	Levels
Diversity of species	Reducing or removing trawling in some parts of the Dogger Bank will: • Increase the diversity of fish, invertebrates and other marine species • Enhance the natural functions provided by the Dogger Bank (contributing to the regulation of climate, maintenance of clean water and support of fish populations)	*No change*, 10% increase in species diversity, 25% increase in species diversity
Protection of porpoises, seals and seabirds	The Dogger Bank provides a natural home for porpoises and seals, and is a feeding ground for seabirds. • These animals and birds are sometimes accidentally caught in fishing nets. • The use of harmful nets will be regulated or forbidden on some parts of the Dogger Bank meaning these animals will be better protected. • Fishing vessels will not be banned from the whole area.	*Not protected*, protected on 25% of the Dogger Bank area, protected on 50% of the Dogger Bank area
Invasive species	The construction of wind turbines on the Dogger Bank provides space for invasive species, increasing their ability to spread elsewhere. • They may affect the survival of species normally found there. • The higher the numbers of turbines and the closer they are, the greater the likelihood of invasive species becoming established.	*Restricted spread*, wide spread
Additional tax	Monitoring and enforcing the Dogger Bank management plan will be costly. The government therefore needs to raise additional funds through taxes. • The tax is payable by all households in the UK for the next 5 years. • If the overall funds people are willing to contribute do not cover the cost of monitoring and enforcement, the plan cannot be put into action.	*£0*, £5, £10, £20, £30, £40, £60

Citizens' Jury

As an alternative to economic valuation, a citizens' jury workshop on the Dogger Bank was held in Newcastle, UK, in October 2013 with 19 members of the UK public. Participants were selected from the database of a marketing company, according to particular criteria (e.g. age, gender, socio-demographic status). It was anticipated that there would be a lack of knowledge among workshop participants about the Dogger Bank, and hence background information would need to be provided to facilitate discussions. Accordingly, the workshop was based on the principles of a citizens' jury in which expert witnesses are invited to state their case to a group of jurors selected from the general public (Huitema et al. 2007). Expert witnesses are people who are knowledgeable of the issue in question or strong advocates of particular positions in the debate. After hearing all the witnesses' accounts, the jurors (the participants) deliberate together on the issue in attempt to reach a common 'verdict' or conclusion. As consensus-seeking processes may silence minority perspectives (Travers 1990), the primary aim of the Dogger Bank workshop was not to get participants to arrive at a common conclusion. Instead, it aimed to understand all the diverging perspectives and positions, arguments, nuances and stakes which are represented among the participants, as well as how the group setting influenced the formation of opinions. It therefore explored shared social values, focusing on aspects of use and non-use of the Dogger Bank.

Participants were provided with information from expert witnesses about the Dogger Bank environment, the uses of the Dogger Bank and their impacts on the marine environment. Witnesses included representatives of the fishing and wind energy sectors, a marine biologist and a speaker putting forward the position of environmental non-governmental organisations involved with discussions on the Dogger Bank management plan. After hearing the witness presentations, participants were divided into four groups for two rounds of facilitated discussion. The first round focused on "what does the ocean mean to you?", "what should we use the ocean for?", and "uses of the Dogger Bank and the implications of this use". The second session focused on "conflicts and dilemmas in the management of the Dogger Bank" and "ranking competing uses of the Dogger Bank". Throughout the workshop, participants were reminded that the word 'use' was meant to cover all things provided by the ocean and the Dogger Bank that respondents and society might find of value or meaningful. This avoided the need to use the term ecosystem services and the discussion of the meaning of ecosystem services that might result. More information about the workshop can be found in (Hattam et al. 2014).

Exploration of Complementarities

The synthesis of the findings from the above methods was undertaken once the results were available from each stage. The three methods described were applied concurrently, which allowed for a parallel track analysis (Teddlie and Tashakkori 2009). Parallel track analyses are particularly suited to exploring complementarities as the data are analysed at the same time and the findings emerge together. This is the most common mixed analysis technique and "although the ... sets of analyses are independent, each provides an understanding of the phenomenon under investigation. These understandings are linked, combined, or integrated into meta-inferences" (Teddlie and Tashakkori 2009, p. 266).

The first stage in the assessment was to explore the complementarities between methods themselves and the way they were applied, rather than between the outcomes of those methods.

This involved examining the complementarities between the work steps taken in the application of the methods, followed by a matrix cross-tabulation, in which each method was compared against a set of criteria. Criteria ranged from what is being valued and how the value is expressed, to the types of data used, the approach to data analysis and interpretation, the transferability of related outcomes and the strengths and weaknesses of the methods. The second stage focused on the complementarities between the results. This drew loosely on (Greene 2007) and involved data transformation, whereby the quantitative findings from the DCE were expressed as a narrative to facilitate the comparison of mixed data types. Using matrix cross-tabulation, the relationships between findings were examined. This focused on the convergences and divergences between the findings and the trade-offs for management implied by them. The final stage in the assessment involved the drawing of inferences and conclusions. This approach provides just one example of how to explore the complementarities and combine the outputs of different methods.

5.3 Results

This section presents summary results for each method used. It emphasises the types of results obtained and key findings only. Full details on how these results were derived can be found in Hattam et al. (2014) and Börger et al. (2014b).

5.3.1 Ecological Assessment

Ecological indicators for this assessment were selected according to those that would best reflect the quantity and quality of the ecosystem service provision. To quantify these indicators, ecological assessments of ecosystem services as performed in this study require data relating to both the functioning of ecosystems, as well as quantifying what species or habitats are present or absent. While ecological data are available for the Dogger Bank, they are largely unsuitable for such assessments being either insufficiently resolved spatially, incomplete, or poorly resolved and understood in that area. If indicators could not be quantified, they were not replaced with inferior indicators, the services were simply left unassessed. Limitations in data availability and knowledge therefore restricted the possibilities for the ecological assessment of ecosystem services based on secondary data.

Quantitative data were available to assess the current state of 20 indicators corresponding to six ecosystem services. Modelled future projections, however, were only available for the indicators of climate regulation (Butenschön and Kay 2013). Assessments of change are therefore primarily based on the expert judgment of the multidisciplinary authors and mainly serve as an example of how changes in ecosystem services may be measured. The main output of this assessment is a qualitative statement of change (Table 5.3) for each of the ecosystem service indicators listed in Table 5.1. Information obtained from these indicators represents only a partial account of the situation found on the Dogger Bank. Where the assessment was based on expert judgment, or where indicators were insufficiently supported by data for any kind of assessment, the results highlight data gaps and areas for future study.

Table 5.3 Future trends in ecosystem service provision from the Dogger Bank area under two alternative scenarios. Indicators in italics have been assessed using modelled data, assessments of change in all other indicators are based on expert opinion.

Ecosystem services	High level indicator	Specific indicator	Dogger Bank	
			A2 scenario	B1 scenario
Food provision - wild capture seafood	Fish/shellfish populations	Biomass	↓	↑
		Abundance	↓	↑
	Quality of the fishery	Species composition	↓	↔
		Age profile	↓	↑
		Length profile	↓	↑
		Fishing mortality	↑	↓
		% affected by disease	↔	↔
Biotic raw materials	Quantity of raw materials	Biomass	↓	↑
	Quality of raw materials	Mortality	↑	↓
Climate regulation	Air–sea and sediment– water fluxes of carbon and CO_2	*Air–sea flux*	↑	↑
		Carbon burial	↔	↔
		Total organic carbon	↓	↑
	Air–sea and sediment– water fluxes of other greenhouse gases	*Air–sea flux*	?	?
Gene pool protection	Genetic diversity	Species diversity	↔	↑
		Biodiversity intactness index	↓	↑
Nursery and migratory habitat	Number and diversity of species using the area for nursery or reproduction	Abundance of fish/shellfish eggs	↓	↑
		Abundance of fish/shellfish larvae	↓	↑
	Dependence of off-site (commercial) populations	Dependence of off-site commercial species	↔	↔
	Area of habitat or density of biogenic habitat creating species “used” or identified as important for nursery or reproduction	Area of biogenic habitat	N/A	N/A
Leisure, recreation and tourism	Species of recreational interest	Seals, cetaceans and birds	↓	↑(but opposite for birds)
	Biotopes of recreational interest		↔	↓

As might be expected, the B1 (Global Community) scenario presents a much more positive future than A2 (National Enterprise) in terms of ecosystem service delivery (Table 5.3). Under the B1 scenario most indicators are anticipated to show upward trends or no change from the present. The downward trend for the fishery mortality indicator (see sea food and raw materials) requires care in its interpretation as it actually translates into positive overall change for fish stocks. Under A2 most indicators show downward trends or no change, suggesting that the related ecosystem services are decreasing. While useful in intimating future trends in ecosystem service supply, this assessment does not support the drawing of conclusions about changes in the relative values or importance of individual ecosystem services.

5.3.2. Discrete Choice Experiment (DCE)

Four types of results were produced from the DCE (Börger et al. 2014b):

1. Coefficients from choice models, which indicate the effect of attributes on choices;
2. WTP estimates as an expression of value and as an indicator of expected utility change resulting from the ecosystem changes described in the choice attributes (Table 5.4);
3. Respondent-specific determinants of different coefficient patterns (and thus WTP estimates) allowing differentiation between groups of respondents who hold different preferences; and
4. Measures of unobserved, i.e. random, heterogeneity of preferences across respondents.

Table 5.4 Implicit prices of consequences of a hypothetical Dogger Bank management plan as elicited in the DCE survey (Börger et al. 2014b).

Attributes		Mean WTP (£)	95% confidence interval
Species diversity	- no change[a]		
	- 10% increase	4.19	[0.70–7.69]
	- 25% increase	7.76	[5.15–10.35]
Protection of charismatic species	- no protection[a]		
	- on 25% of Dogger Bank area	24.02	[20.66–27.38]
	- on 50% of Dogger Bank area	30.32	[27.02–33.62]
Invasive species	- restricted spread[a]		
	- wide spread	– 25.39	[– 28.51 - -22.28]

WTP was calculated from a random parameters logit model with 5000 Halton draws based on a sample of 973 respondents completing six choice tasks each. Confidence intervals were computed based on the bootstrapping approach by Krinsky and Robb (1986).
[a] Indicates the current, no cost situation.

Results show that the respondents hold significant values for environmental benefits generated by the proposed management measures. Ecosystem attributes positively affect choice (i.e. the probability that a management option is chosen over the business-as-usual option), while cost negatively affects choice. These respective influences increase with the level of the attribute/cost. WTP for the protection of porpoises, seals and seabirds was higher than for restricting the spread of invasive species and general species diversity respectively. This implies that restrictions to fishing using nets that protect these charismatic species are preferred to restrictions to fishing using bottom trawling techniques that protect species diversity in general, as explained by the management scenario that framed the choice tasks.

Respondents who are members of an environmental organisation and have previously taken a ferry or flight over the North Sea prefer management measures for the Dogger Bank more often than respondents without these characteristics. Holding attitudes that favour the introduction of a management plan to protect species diversity and charismatic species also increases the WTP of respondents for different increases in the corresponding attributes. In addition, random preference heterogeneity is present that cannot be accounted for by respondent characteristics and attitudes. These findings show how DCEs can allow for some degree of diversity in values between respondents.

5.3.3. Citizens' Jury

Deliberations between respondents allowed multiple views on the ocean and the Dogger Bank to emerge. Participants were able to influence each other to generate new positions, with the shared experience affecting the outcomes. Responses to the questions “what does the ocean mean to you?” and “what should we use it for?” indicated the participants' views on the ocean as well as concerns over its use. Remarks such as “the integrity of the ocean”, “importance of the function of the ecosystem”, “the beauty of the natural environment”, as well as use of words such as preservation, sustainability, protection and responsibility highlight the importance of the ocean beyond economic values. At the same time however, the importance of the economic uses of the ocean was embedded in participants' understanding, as the ocean was also viewed as a “human resource” and used for “getting the resource(s) [for humans].”

The key output of the citizens' jury workshop is an identification of discourses. A qualitative discourse analysis of these deliberations identified two main themes:

- that fishing should be prioritised over wind farm development; and
- that conservation should be a priority, but with specific caveats.

The prioritisation of fishing arose from what was considered to be a lack of evidence supporting the potential impacts or benefits arising from the construction of a wind farm on the Dogger Bank. It also arose out of the perceived historical legitimacy of fishing (“*Fishing has been in place for years ... I don't feel that they are going to impact now because they have been there for so long*.”) and the ability of the expert fisheries witness to demonstrate the sustainability of the fishery on the Dogger Bank.

Conservation was a thread in many of the discussions with participants recognising the intrinsic value of the Dogger Bank. Conservation was not considered to exclude the use of the Dogger Bank for economic purposes, but ensuring this use is balanced and sustainable was highlighted by jury members. Many participants agreed that multiple activities should be allowed on the Dogger Bank through a system of zoning supporting both economic and non-economic uses. However, they felt that they lacked the information to discuss such zoning in more detail.

The deliberative exercises demonstrated the necessity for careful facilitation to ensure all views are heard and to understand the ways in which participants influence each other. For example, discussion uncovered that one of the participants worked in the energy management sector and was knowledgeable about renewable energy. This participant suggested convincingly during the question and answer session of the witnesses that offshore wind farms could lead to negative changes in biodiversity without reducing electricity bills. In the absence of data proving otherwise, this argument can be demonstrated to have influenced other participants' views on offshore wind farms.

5.3.4. Integration of Findings

In drawing together the three datasets, it is important to acknowledge the limitations of each. For example, the lack of quantitative data in the ecosystem service indicator assessment limits the understanding gained from their assessment. Consequently, the outputs largely reflect the direction of change indicated by the scenario narratives and the interpretation of the scenarios by the researchers. In the discrete choice experiment, the use of management measures to frame the choice experiment is novel, but makes interpretation of the results more challenging. It is not entirely clear whether respondents make choices on the basis of the management measure or the outcome of management (i.e. the attributes). The latter is more likely according to findings from a think aloud exercise conducted during the survey testing stage. For the citizens' jury workshop, more juries with different jurors and follow-up sessions with the same jurors would be needed to increase the level of confidence in the findings. It is possible that a jury with different jurors could have produced different results. Lastly, the size of the combined dataset is small, being based on only three studies. Had this integration been planned from the outset, the three methods may have been applied differently and additional or larger datasets sought. Despite these shortcomings, the potential to learn more from the combination of the data requires further attention. This will help to demonstrate the extent to which the data complement each other and whether a mixed methods approach can overcome any of the weaknesses in the individual methods.

Complementarities in Work-flow

Figure 5.2 demonstrates how the workflow for the different methods overlapped and where the development of methods supported each other. The ecological assessments were particularly important in terms of framing the DCE and focusing the citizens' jury, at both the preparatory and final stages. The preparatory stages of the DCE and the citizens' jury were also complementary. Both methods drew on the same exploratory semi-structured interviews with members of the public that were used to set the scene. As anticipated, there was little flow from the DCE and citizens' jury back to the ecological assessment, except during the development of scenarios.

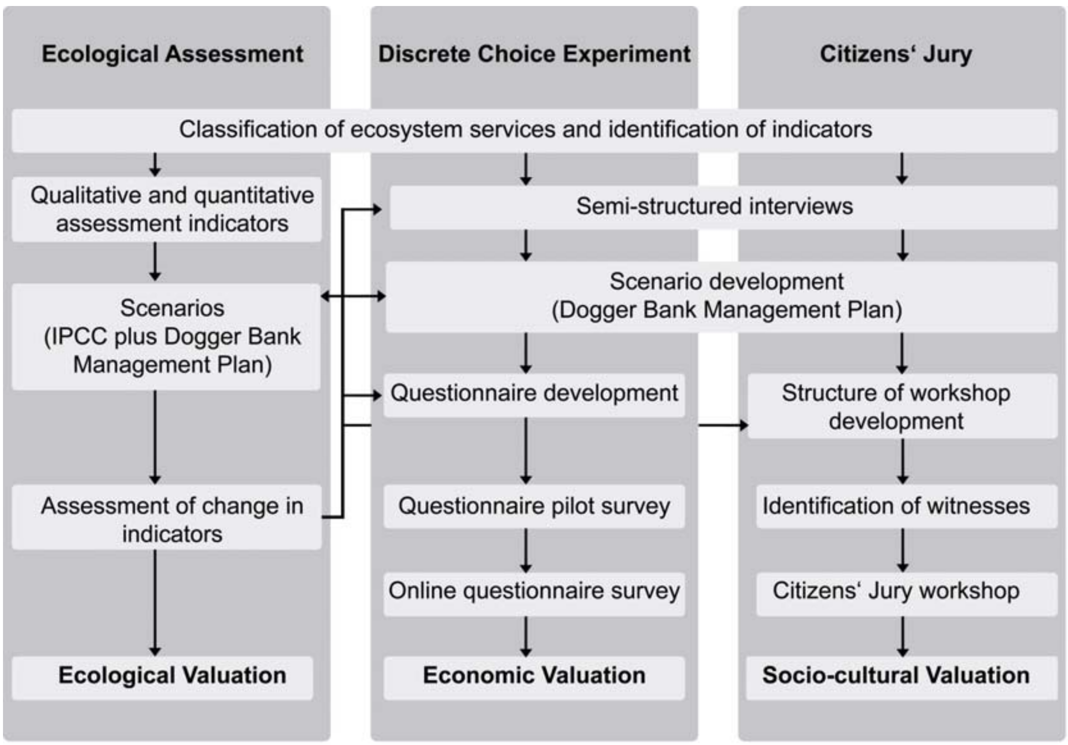

Figure 5.2 Complementarities in work-flow between methods.

Complementarities Between Methods

In terms of methodological detail, a matrix was developed (Table 5.5) to facilitate comparison across the three methods applied in this study.

Table 5.5 Method comparison and complementarity (as undertaken in this study).

Assessment method	Ecological assessment	Discrete choice experiment	Citizens' jury
Value type	Ecological value.	Economic (non-use) value.	Social/cultural value.
What is being valued?	Supply of individual ecosystem services.	Management and management outcomes. Demand for benefits arising from bundles of ecosystem services.	Activities/uses. Demand for environmental outcomes.
Output/unit	Units of quantity (e.g. tonnes of fish landed or available to be landed; tonnes of carbon sequestered) Units of quality (e.g. fish mortality rates, age profile).	Monetary values.	Discourses/themes. Preference ranking.
Directly address ecosystem services?	Direct.	Direct and indirect. Bundle of ecosystem services.	Indirect. Bundle of ecosystem services.
Information sources	Literature[a], expert opinion, ecosystem models, secondary data[b.]	Literature, expert opinion, preparatory interviews (with the public), survey data.	Literature, expert opinion (stakeholders), deliberation (with public).
Public engagement	No.	Yes.	Yes.
Transferability of results	Indicators may be transferred, but: • may need tailoring to specific site; • may respond differently in different sites.	Potential use of results in benefit transfer (when targeted to similar ecosystem type, management scenarios with defined ecosystem services).	Findings are specific to location/issue of interest.
Weaknesses/limitations	Some ecosystem services easier to quantify and assess than others, leading to bias in findings. Absence of appropriate data limits applicability, especially in the marine environment.	Limited understanding of why one attribute favoured over others. Focuses on limited number and bundled ecosystem services. Meaning of monetary values influenced by questionnaire design. Bundling of services limits understanding of trade-offs. Communicating ecosystem services is challenging.	Links to ecosystem services are weak. Influenced by: workshop design, witnesses and information provided, more knowledgeable participants. Communicating ecosystem services is challenging.
Strengths (overcoming weaknesses)	Focus on multiple ecosystem services, provided data/literature and experts are available.	Provide monetary estimates of ecosystem services value relevant to cost-benefit analysis.	Provides in depth understanding of theme/discourse emergence.
Method complementarity	Provides broad picture of ecosystem service change. Helps identify ecosystem services suitable for valuation. All ES considered equal. Combined with preference data, useful for exploration of mismatches between ecosystem services supply and demand.	Provides monetary value estimates for ecosystem services with no market value.	Captures detail of people's priorities not reflected in monetary valuation.

The three method approach has allowed different value types for ecosystem services to be estimated supporting, to some extent, an assessment of both the supply of ecosystem services (via the ecological assessment) and the demand for some of these services (through the DCE and the citizens' jury). None of the methods used capture all aspects of ecosystem service supply or demand, however. Despite drawing across a diverse range of information sources, as has been found elsewhere (Liquete et al. 2013) there is a bias towards services for which more data and understanding exist (e.g. food provision and carbon sequestration). The bundling of services within the DCE and citizen's jury also means the findings are hard to interpret in terms of individual ecosystem services. The outcome of the three approaches and their integration is therefore a partial understanding of the ecosystem services of the Dogger Bank and how they will change. Nevertheless, considering their transferability, the findings from the DCE and the indicators may be useful for similar assessments in other locations. The results of the DCE are drawn from a national survey and therefore could be used in benefit transfer, if applied to sites with comparable characteristics and facing similar management scenarios(Richardson et al. 2015). The indicators used in the ecological assessment could also be transferred, but tailoring to different locations would be necessary.

Consideration of the strengths of each of the methods helps identify where the methodological complementarities lie. The scope of the ecological assessment has the potential to be broad and can therefore offer a more rounded assessment of how ecosystems and the services they deliver may change as a result of human action or environmental variability. It thus provides insights on the capacity of an ecosystem to generate ecosystem services and it can also direct where it may be more useful to focus valuation studies. Both the DCE and the citizens' jury provide some understanding of society's demand for ecosystem services and how changes resulting from management actions may be valued. In the case of the DCE, these outputs generate information on the contribution of ecosystem services to human well-being and the hierarchy of preferences for ecosystem services. DCE outputs may also be used in cost-benefit analysis. The information obtained from the citizens' jury can augment these findings by providing greater understanding of why people hold the priorities that they do. Combining the three methods can be used to explore mismatches between ecosystem service supply and demand, and consequently identify any trade-off that may be necessary or preferable to make through environmental policy and ecosystem management.

Complementarities Between Results and the Trade-offs Implied

Identifying complementarities between the results of the three methods is challenging, given the limited size of the dataset and some of the limitations present in how the individual approaches were applied. Nevertheless, some complementarities between the findings are apparent, as are implied trade-offs (Table 5.6). Overlap between the three methods focuses on the impacts of management activities on fisheries, wind farm construction and conservation measures. The exploration of complementarities therefore concentrates on this overlap.

Table 5.6 Complementarities between results and indicated trade-offs.

	Topic of overlap **Conservation**	**Fisheries**	**Offshore Wind Farms**
Ecological assessment	Scenario B1 with least human pressure better for ecosystem services.	Suggests limitations to fisheries most favourable to supply of all ecosystem services.	B1 scenario would see extensive offshore wind development on the Dogger Bank.
Discrete choice experiment	WTP for charismatic species and species diversity conservation. WTP for conservation of charismatic species greater than for species diversity.	Preference for net fishing restrictions over restrictions to bottom trawling.	Preferences for or against wind farms not directly assessed. Respondents WTP for responsible wind farm design that limits invasive species.
Citizens' jury	Conservation a priority, although with caveats.	Fisheries considered historically legitimate.	Fisheries preferred over wind farms.
Trade-offs?	No. General agreement.	Yes. Partial agreement.	Yes. Limited agreement.

In the context of conservation issues, preferences for the supply and demand for ecosystem services appear to move in the same direction. The DCE and citizens' jury both indicate preferences for conservation, especially of charismatic species. This in turn indicates a preference for the outcomes of the B1 (Global Community) scenario of the ecological assessment. Conservation measures on the Dogger Bank will in part be delivered through fisheries management (NSRAC 2012) and here there is implied disagreement between the findings. The ecological assessment indicates that the closure of fisheries would be beneficial for ecosystem services supplied by the Dogger Bank (scenario B1). The DCE results, however, suggest that restrictions to net fishing would be preferred over restrictions to bottom trawling. This means that preferences for conservation of charismatic species would be met, but bottom trawling would continue to deliver fish but with no benefit to species diversity. In contrast, the outcomes of the citizens' jury suggest that, in terms of use of the Dogger Bank, fishing should be prioritised over other uses as a result of historical legitimacy.

In terms of wind farm construction the picture is less clear. The B1 scenario would see a substantial increase in the number of wind turbines constructed on the Dogger Bank (while the A2 scenario would only see some increase). While the acceptability of offshore wind farms was not assessed in the DCE, the relationship between offshore wind farms and fisheries has implications for the supply of fish. Fishing does not usually occur in wind farming areas, due to concerns over gear entanglement and infrastructure damage (Mackinson et al. 2006). Any increase in wind farm extent will therefore reduce fishing opportunities, in partial contradiction with the preferences expressed in the DCE results and complete contradiction with those from the citizens' jury.

Despite these apparent contradictions in findings, the methods do offer complementarities. Both DCE and the citizens' jury lend support to management aimed at achieving the B1 scenario of the ecological assessment and not the A2 scenario. Furthermore, they provide enhanced understanding of why this is the case. The DCE and the citizens' jury findings also largely agree, but the partial disagreement is illustrative of the complexity behind people's understanding of and demands for fisheries management. Where partial agreements or disagreements between findings occur, this indicates areas where trade-offs may arise when management decisions are taken. It highlights a mismatch between the supply and demand for ecosystem services in an area. The main trade-off implied by this work is in the context of fisheries restrictions and the interaction between fisheries and wind farms.

5.4 Discussion

Börger et al. (2014a) highlight a growing demand for wider assessment and valuation of marine ecosystem services in support of marine planning. For example, in the UK, ecosystem services have been identified as a priority research area by the Marine Management Organisation, the Government body responsible for marine planning (MMO 2014). In addition, there is a move towards national assessments of ecosystem services through the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES) in support of the Convention on Biodiversity and, for example, the European Unions' Biodiversity Strategy to 2020. Assessment of marine ecosystem services, however, often lags behind the assessment of terrestrial ecosystem services, hindered by inadequate knowledge and lack of data (Townsend et al. 2014). Applying a mixed-method approach may therefore provide useful insights by delivering a more comprehensive understanding.

5.4.1 Do the Methods Complement Each Other?

Three key areas of complementarities have been explored: between the work-stages of each method, between the methods themselves and between the findings. Complementarity between work stages is apparent, but this largely depends upon the communication within the multidisciplinary research team. In this case different aspects of the work did feed into each other, for example, sharing of preparatory semi-structured interviews between the DCE and citizens' jury, the use of multidisciplinary teams to develop scenarios and ensure ecological content validity in the DCE and citizens' jury.

In terms of methodological complementarity, the different stages of the assessment can be used to enhance each other. For example, the data gaps emerging from the ecological assessment were used to direct the DCE and citizens' jury, and each method covers a different aspect of value and more or fewer ecosystem services. Despite limitations in data availability, the ecological assessment was the broadest in scope. In contrast, the DCE and citizens' jury provided greater detail about more focused topics and particularly about demands for different ecosystem services or management outcomes. The ecological assessments help to identify how those demands might be met.

The findings from the Dogger Bank case study show complementarities between results. Conservation priorities were clearly demonstrated in the DCE and citizens' jury. This supports management actions that would lead to the more conservation focused scenario (B1 Global Community), which suggests a more positive future for ecosystem services. Even where divergence between findings is apparent (i.e. in the case of fisheries priorities), complementarities are evident as the outcomes from the citizens' jury improve understanding of why this divergence occurred. Potential mismatches between supply and demand for ecosystem services are highlighted, as are possible conflicts between management objectives desirable from an ecosystem perspective (e.g. fisheries closures) and those preferred by society (e.g. fish). The outcome is a more comprehensive understanding of the complex issues relating to the management of the Dogger Bank, which may better inform decision-making.

5.4.2. Does the Application of the Mixed-Methods Approach Overcome any of the Weaknesses of the Individual Methods?

The ecological assessment provides a general picture of how the Dogger Bank ecosystem may change. It reflects the capacity of the Dogger Bank to supply ecosystem services and identifies services worth exploring in valuation studies. The DCE elaborates upon this, through the provision of estimates of monetary value for little explored ecosystem services and those for which no secondary data exist. The citizens' jury furthers this understanding through an in-depth exploration of people's values, providing some explanation of individuals' priorities. The citizens' jury also allows greater understanding of members of the public's preferences for ecosystem management of the Dogger Bank and can be used to infer societal demand for ecosystem services beyond their economic value. Only by applying the different methods do the trade-offs between the supply of ecosystem services and the different demands for ecosystem services become apparent.

5.4.3 Applying the Methods More Effectively: Lessons Learnt

The findings from the three distinct methods applied here suggest a mixture of messages. These raise a number of issues that need to be considered if greater integration of findings is to be achieved from similar studies in future. Lessons include the need to plan for integration; the need for better understanding of what integrating involves; the limitations of data availability; and the need to carefully consider the use of scenarios across the approaches.

Planning for Mixed Method Integration

Method integration requires planning from the outset. Greater complementarity could have been found with different method combinations (i.e. using other methods than those applied here or applying the same methods in different ways). For example, the citizens' jury discussions could have been conducted differently with additional deliberative sessions or information from different witnesses provided to participants. Ecosystem services could have been focused on more explicitly to allow greater comparability to the DCE. In the DCE, ecosystem services could have been decoupled from the management scenarios and focused more clearly on the ecosystem service indicators used in the ecological assessment. The bundling of services in the DCE made the valuation outcomes harder to interpret and only indirectly addresses potential future changes in the provision of ecosystem services. To some extent context influenced design of both the DCE and the citizens' jury. Respondents' unfamiliarity with the Dogger Bank necessitated simplification, and consequently bundling, that may be unnecessary in more familiar settings. The design and focus of individual studies and any integrating stage therefore requires very careful co-planning to minimise unwanted divergence.

Understanding Data Integration

Understanding what is needed for data integration could also influence the way in which individual valuations are undertaken. For example, greater emphasis could be placed on quantitative rather than qualitative data collection, or different approaches to integration could be used. Complementarity mixed-methods studies are typically used to measure different as well as overlapping aspects of the same issue. Other approaches, such as triangulation, require that different methods are used to study the same issue (Greene et al. 1989). In situations where additional numerical data are available, quantitative integration may be possible. Martín-López et al. (2014) draw on multiple quantitative data sources to which, once standardised, they apply principal component analysis to identify the relationships between biophysical, socio-cultural and monetary values. Ecosystem service assessment and valuation researchers may be able to learn lessons from disciplines where application and integration of mixed-methods is more commonplace (e.g. Greene 2007, Teddlie and Tashakkori 2009).

Impacts of Data Limitations

The availability of suitable data hindered all methods used in this study, but in particular the ecological assessment. This absence of data, especially prevalent in the marine environment, presents a difficulty for future assessments. It is recognised as one of the main challenges for the incorporation of ecosystem service assessments and valuation into marine planning. The gaps identified here indicate where future monitoring effort is needed if ecosystem services are to be incorporated into marine management for the Dogger Bank.

The absence of appropriate information for the citizens' jury also affected the ability of members of the public to discuss the uses and benefits of the Dogger Bank, and how the Dogger Bank should be managed. Despite providing participants with background information and experts to question, they still felt they had insufficient information to make informed decisions. Follow-up sessions are needed with the same participants to allow them to reflect on the information they have received and allow further discussion, as well as additional workshops with different participants (e.g. Abelson et al. 2003). This would enrich the data from the citizens' jury and provide increased confidence in the results.

Improving the effectiveness of complementary studies requires not only improvement in the input data used in the different methods, but also increased generation of data from the application of different methods. Additional economic valuation, through DCE surveys or other methods, is needed to cover a wider range of ecosystem services. For example, (Martín-López et al. 2014) draw on seven monetary valuation studies covering nine ecosystem services. This suggests an opportunity for benefit transfer, however, benefit transfer may present challenges for integration, if the data are being used for a purpose that is different to that for which the data were originally collected.

Alternatively, the outcomes of complementarity studies such as this could be used to focus future ecosystem service assessments and valuations of the same study site. This would enable complementarities or divergences emerging from the first cycle to inform the next. For example, the preferences highlighted by DCE and the citizens' jury could be used to focus future ecological assessments and modelling efforts. Any divergences apparent between methods could form the focus of deliberations in a future study or inform economic valuations such as DCEs.

Mismatches Between Scenarios Used

Future scenarios were incorporated into each of the three methods used in this study. A mismatch is apparent, however, in the time-frames used. The ecological assessments considered changes to 2050, a relatively short time-frame for ecological change, while the DCE and the citizens' jury explored change in the near future (undefined in the citizens' jury and over the next five years for the DCE). This mismatch results from the very different time-frames suitable for the different approaches. While for ecological assessments a five year time frame is in most cases too short for any change to become apparent, a 50 year period is far too long for workshop or survey participants to be able to assess. Furthermore, preferences are unlikely to be stable over such a long period meaning resulting preference data may be too uncertain for use in long-term environmental management.

This mismatch is not necessarily a problem and is potentially a strength of mixed-method approaches. The implications of current actions needed to achieve future ecological outcomes and the trade-offs they imply can be more easily evaluated through mixed-method approaches. In addition, if accompanied by biological/ecological monitoring and updated assessments of societal and individual preferences, management could be adapted to better achieve desired goals. This would ensure ecosystem management is responsive not only to environmental change but also to changing preferences or societal demand.

5.5 Conclusion: Better Supporting Marine Management

Growing use of the marine environment demands careful spatial planning (Douvere 2008, Douvere and Ehler 2009). The integration of findings from different ecosystem service assessment and valuation approaches can highlight complexities relating to management outcomes (e.g. for the Dogger Bank in relation to fishing) that would not become apparent using a single method approach. The combination of an ecological assessment (describing the supply of ecosystem services) with a DCE and a citizens' jury (that assess ecosystem service demand) identified areas where mismatches may occur between ecosystem service supply and demand in the future. This study has also highlighted potentially contentious issues (e.g. fisheries management) that will require careful consideration if societal demands are to be balanced with conservation needs.

There will always be trade-offs between improving approaches to ecosystem service assessments and having the resources to cover all relevant aspects of such assessments. Including an integration stage at the end of ecosystem service assessments may allow researchers and funders to obtain greater understanding from their data. It may therefore prove a powerful tool for supporting environmental management decisions. As shown in this case study, mixed methods approaches can (and probably most likely will) generate mixed messages. Where those mixed messages are understood as challenges or used to focus ecosystem management, the full potential of mixed methods approaches can be utilised, offering more than single method approaches can deliver.

Acknowledgements

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Chapter 6

Synthesis, discussion and conclusions

Marine ecosystems sustain the livelihoods of millions of people (FAO 2018) and even far away from coasts people benefit from marine ecosystems and their ecosystem services (ESs). For example, salt marshes, seagrass meadows and calcifying species uptake and store carbon (Nellemann et al. 2009, Sousa et al. 2017). This climate regulation process is an ES that benefits everybody, but this is rarely recognized and the actual benefits, just as many other marine ESs' benefits, are jeopardized by climate change and other human pressures (e.g. over-exploitation of fisheries, plastic pollution and coastal infrastructure (Halpern et al. 2008, Pendleton et al. 2012).

Preserving marine ESs requires the preservation and sustainable management of healthy and resilient marine ecosystems. This is acknowledged and addressed by international policies. For example, the Convention on Biological Diversity aims to conserve biodiversity, and promote the sustainable use of its components and the fair and equitable sharing of the benefits. Similarly, the European Marine Strategy Framework Directive (MSFD) aims for a 'Good Environmental Status' in all European Seas by 2020 to ensure sustainable use of ESs today and in the future. These policy aims, however, have not yet been achieved. This highlights a current management challenge, which is to be addressed by applying an ecosystem approach to marine management that aims, inter alia, to balance marine conservation and the sustainable use of ESs (see MSFD). To integrate marine ESs in assessing the effects of marine management is thus a crucial step to implement an ecosystem approach. Consequently, the major objective of my thesis was to develop, adapt and apply ES assessments towards the policy goal of healthy seas. This objective was addressed by interdisciplinary research that was guided by the following research questions (RQs):

RQ 1 Which marine ESs can be identified and which indicators can be used to quantify them?

RQ 2 How can changes in marine ES supply, as a consequence of various management activities, be determined?

RQ3 How can stakeholder involvement and analysing ES demand inform marine ecosystem managers?

RQ 4 How can different methods to analyse marine ESs be integrated and what is the added value of such integration?

RQ 5 How do marine ecosystem-service assessments contribute to preserving healthy marine ecosystems?

Three different case studies contributed to addressing these RQs. The Black Sea case study assessed ES supply under different fisheries and nutrient management scenarios. The assessment extent was the entire Black Sea. The Mediterranean case study focused on local salt-marsh conservation and stakeholder participation in the northern Venice Lagoon. This study explored local residents' demand for salt-marsh ESs and management. The sub-regional North Sea case study analysed how assessments on ES supply and demand can be integrated and complement each other to improve management decisions.

This chapter synthetizes the findings and insights obtained from addressing these RQs and explores, discusses and defines remaining challenges. Section 6.1 reflects on the appropriateness of the marine ES typology that I developed for and applied in my thesis (RQ 1). This section also puts the marine typology in the context of other typologies. Section 6.2 relates to RQ 2 and discusses how marine ES supply can be measured while Section 6.3 is concerned with analysing ES demand (RQ 3). How ES supply and demand can be integrated and what can be gained from that integration is addressed in Section 6.4 (RQ 4). Section 6.5 discusses the role of ES assessments in implementing (marine) environmental policies that aim at achieving healthy marine ecosystems and their sustainable use (RQ 5). Section 6.6 draws overall conclusions.

6.1 Classifying and defining marine ESs

My thesis aligned with the TEEB definition and classification of ESs (Table 6.1) as a widely used, commonly agreed ES definition and typology. ESs are defined here as the direct and indirect contributions of ecosystems to human well-being (de Groot et al. 2010). The TEEB classification distinguishes 22 general ES types without defining each of them too narrow to keep the typology open and flexible for adaptation to diverse assessment contexts. This, however, required to develop own specific definitions for all (sub)services. I addressed this challenge and developed an ES typology specific to marine ecosystems (Chapter 2) which formed the basis for all subsequent case studies of my thesis.

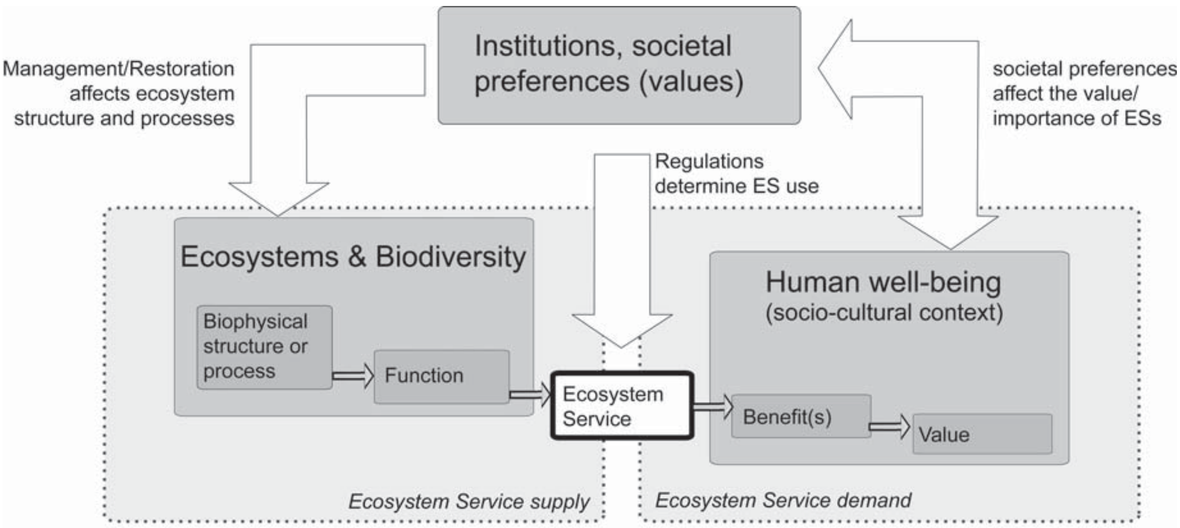

Figure 6.1 The ES cascade as a framework for structuring the complexity of socio-ecological systems. (adapted from de Groot et al. 2010)

I developed my marine typology with a focus on my thesis' policy context that is mainly framed by the MSFD. The directive requires European marine management to adopt an ecosystem approach that aims at the conservation of marine ecosystems and ensures the sustainable use of marine ESs. Consequently, my typology and its individual ESs' definitions were particularly designed to reflect such marine management effects. These effects occur, for instance, when marine management restores habitats or reduces human pressures. Both interventions improve ecosystem processes and functions as prerequisites for ES supply. To reflect such ES-supply changes, only those marine aspects were included in my typology that depend on biotic-driven ecosystem processes and functions (Hattam et al. 2015a), as conceptualized by the ES cascade (Figure 6.1). This implies that marine aspects that are purely abiotic or utilize the so-called carrier function of marine ecosystems are excluded from the typology. Abiotic marine aspects are, for instance, seawater (in case its use or extraction is dependent solely on quantity) or sediments that depend on physical weathering processes. They support shipping, sediment extraction or coastal and offshore infrastructure, all of which are related to human pressures

(Halpern et al. 2007, Halpern et al. 2008). The carrier function uses marine space or abiotic components as media, as the seafloor to place infrastructure or seawater as literally providing a carrier function for transportation (shipping) (de Groot 2006). But also recreational uses can rely predominantly or exclusively on abiotic components or carrier functions. Examples are beaches used for sunbathing or sports (volleyball) or seawater and wind used for sailing.

The MSFD suggests another argument to exclude abiotic components and carrier functions from an ES typology. The Directive explicitly states (Article 1): "Marine strategies shall apply an ecosystem-based approach to the management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised while enabling the sustainable use of marine goods and services by present and future generations." Abiotic components and carrier functions refer to human activities whose pressures are to be reduced, according to the MSFD. If they were considered ESs, they would, however, suddenly become desired management objectives of the MSFD (see Article 1 above). Thus, the extraction of sediments, the use of seawater for shipping or marine space for infrastructure would turn into something that is aimed at by the MSFD. I see this in conflict with the overall management aim of the MSFD and thus argue that for marine management, clearly distinguishing pressures to be managed (abiotic components, carrier function) from the desired management objectives (ESs) is important.

For the typology this meant to redefine the ES 'Seawater' as "Marine water in oceans, seas and inland seas that is through biological processes maintained at appropriate quality and extracted for use in industry and economic activity" and to define the related indicator as "number of days seawater is of insufficient quality for desired application". For example, The Guardian headlined "Jellyfish clog pipes of Swedish nuclear reactor forcing plant shutdown" (The Guardian 2013). This illustrates human benefit implications of insufficient seawater quality.

My thesis applied its marine ES typology (Table 6.1) to assess marine management effects in the Black Sea, Mediterranean Sea and the North Sea in the context of the MSFD and the EU Habitats Directive. All three case studies assessed ESs at different spatial scales that range from the entire regional sea to a sub-regional part of the North Sea, to a local case study on a part of a Mediterranean lagoon (Figure 1.2). The typology proved for all these different policy contexts and spatial scales sufficiently comprehensive and flexible. Nevertheless, the typology required adaptation to specific assessment conditions. Both indicator-based assessments (Chapters 3 and 5) refined the typology by distinguishing particular sub-ESs. I considered this necessary and appropriate to allow for sufficient assessment specificity. For example, the ES 'Climate regulation' can refer to the regulation of various climate-relevant atmospheric components and respective sub-ESs revealed which components were assessed. Another example, recreation and leisure can involve various different interactions with marine ecosystems and here again the specified sub-ESs allowed to trace which ones were assessed. For the survey-based assessment (Chapter 4) the terminology of the typology turned out to be not sufficiently comprehensible to respondents. Thus, while the marine ES typology was maintained as the underlying concept, the particular ES definitions and descriptions were re-phrased to avoid technical terms.

Table 6.1 The TEEB ES typology as the basis of the ES typology developed in my thesis (based on de Groot et al. 2002, Beaumont et al. 2007, de Groot et al. 2010) and sub-services as assessed in the Black Sea case study

Ecosystem Services, TEEB (de Groot et al. 2010)	Ecosystem services (Chapter 2)	Definition (Chapter 2)	Sub-services as distinguished by Black Sea case study[1] (Chapter 3)
Provisioning Services			
Food	Seafood	All available marine fauna and flora extracted from coastal/marine environments for the specific purpose of human consumption as food (i.e. excluding for consumption as supplements)[2]	Fish, seaweed
Water	Sea Water	Marine water in oceans, seas and inland seas that is through biological processes maintained at appropriate quality and extracted for use in industry and economic activity	water for desalinization, ballast water, water for industrial cooling
Raw Materials	Raw Materials	Biotic material extracted from coastal/marine environments, excluding those included in Ornamental Resources	fish meal; fish oil, macroalgae
Genetic Resources	Genetic Resources	Genetic material from marine flora and fauna extracted for use in non-medicinal contexts, excluding the research value on Genetic Resources that is covered by ES Information for Cognitive Development	Tursiops truncatus ponticus, Delphinus delphis, Acipenser gueldenstaedti, Acipenser nudiventris, Acipenser ruthenus, Acipenser stellatus, Acipenser sturio, Huso huso, Alosa caspia, Alosa maeotica, Alosa immaculata, Clupeonella cultriventis
Medicinal Resources	Medicinal Resources	Any biotic material that is extracted from the coastal/marine environment for its ability to provide medicinal benefits, excluding the research value on Medicinal Resources which is covered by ES Information for Cognitive Development	Rapana venosa, Squalus acanthias, Coccotylus truncatus (Phyllophora brodiaei), Cystoseira barbat, Mytilus galloprovincialis, Molgula euprocta, Botryllus schlosseri
Ornamental Resources	Ornamental Resources	Any biotic material extracted for use in decoration, fashion, handicrafts, souvenirs, etc.	Rapana venosa, Mytilus galloprovincialis
Regulating Services			
Air quality regulation	Air Purification	Removal of air pollutants by coastal/marine ecosystems	Capturing fine dust (PM10), NO_x and SO_2
Climate Regulation	Climate Regulation	The contribution of the biotic elements of a coastal/marine ecosystem to the maintenance of a favourable climate	Carbon sequestration, Capturing N_2O, DMS release, Methane emissions
Moderation of Extreme Events	Disturbance Prevention or Moderation	The contribution of biotic marine ecosystem structures to the dampening of the intensity of environmental disturbances such as storm floods, tsunamis, and hurricanes	dampening the intensity of storm floods, tsunamis, hurricanes
Regulation of Water Flows	Regulation of Water Flows	The contribution of biotic marine ecosystem structures to the maintenance of localized coastal current structures	
Waste Treatment	Waste Treatment	Storage, burial, and biochemical recycling of pollutants by coastal/marine ecosystems	removal of nutrients
Erosion prevention	Coastal Erosion Prevention	The contribution of coastal/marine ecosystems to Coastal Erosion Prevention, excluding what is covered by Regulation of Water Flows	
	Biological Control	The contribution of marine/coastal ecosystems to the maintenance of natural healthy population dynamics to support ecosystem resilience through maintaining food web structure and flows.	Control population size of harmful jellyfish, control population size of phytoplankton
Pollination	Not relevant in marine context		

Table 6.1 (continued)

ES TEEB	ES Chapter 2	Definition - Chapter 2	Sub-services - Chapter 3
Habitat Services			
Maintenance of Life cycles of migratory species	Lifecycle Maintenance	provision of essential habitat for reproduction, juvenile maturation, resting or wintering of migratory species	Contribution of a study area to commercial catches elsewhere
Maintenance of genetic diversity	Gene Pool Protection	The contribution of marine habitats to the maintenance of viable gene pools through natural selection/evolutionary processes	maintenance of viable gene pools through natural selection/evolutionary processes
Cultural and Amenity Services			
Opportunities for recreation & tourism	Recreation and Leisure	The provision of opportunities for Recreation and Leisure that depend on a particular state of marine/coastal ecosystems	Recreational fishing, SCUBA Diving (both related to the abundance of target/iconic fish species), SCUBA Diving and beach recreation (related to phytoplankton concentration and thus visual range and attractiveness), SCUBA Diving and beach recreation (related to jellyfish abundance and thus attractiveness), Bird/whale/seal watching
Aesthetic information	Aesthetic Information	The contribution of coastal/marine ecosystems to surface or subsurface coastal and marine sea-/landscapes that generate a noticeable emotional response within the individual observer. This includes informal Spiritual Experiences but excludes that which is covered by other cultural ESs	
Inspiration for culture, art and design	Inspiration for Culture, Art and Design	The contribution of coastal/marine ecosystems that inspire elements of culture, art, and/or design. This excludes that which is covered by Ornamental Resources, and other cultural ESs.	
Spiritual experience	Spiritual Experience	The contribution that coastal/marine ecosystems make to formal religious experiences.	
Information for cognitive development	Information for Cognitive Development	The contribution that a coastal/marine ecosystem makes to education, research, etc. This includes the contributions of coastal/marine ecosystems makes to bionic design and biomimetic and to research on applications of marine Genetic Resources and pharmaceuticals.	
	Cultural Heritage and Identity	The contribution that a coastal/marine ecosystem makes to Cultural Heritage and Identity (excluding aesthetic and formal religious experiences). This includes the contribution of marine/coastal ecosystems in cultural traditions and folklore. This covers the appreciation of a coastal community for local coastal/marine environments and ecosystems (e.g. for a particular coastline or cliff formation) or identity related to sea dependent practices (e.g. identity as a fishing community)	

1 Below listed sub-services are limited to those considered in the Black Sea case study. This list of sub-services is thus not to be considered exhaustive.
2 This ES is restricted to seafood from capture fisheries and excludes seafood from aquaculture.

Comparison of (marine) ES typologies

To put my typology in context, I compare it here with four other typologies (Table 6.2). This comparison aims to understand the differences and similarities between these typologies. This section closes with more general considerations on if, when and how to use ES typologies.

Table 6.2 Comparison of ecosystem service typologies. Green fill indicates agreement of marine ES typology (Chapter 2) with another typology. Green shading indicates partial agreement, no fill indicates differences in ES description or in the ES type itself. Orange fill indicates that a service is purely abiotic or relies on the carrier function. This is in general disagreement with my marine typology.

Böhnke-Henrichs et al. (2013), Chapter 2	**Beaumont et al. (2007)**	**Liquete et al. (2013)**	**CICES v 5.1, Haines-Young and Potschin (2018) (included here only ESs with marine relevance)**	**IPBES, Díaz et al. (2018) (included here only ESs with marine relevance)**	**Comments; Comparison with typology in Chapter 2**
ES definition	**ES definition**	**ES definition**	**ES definition**	**Nature's contributions to people definition**	
the direct and indirect contributions of ecosystems to human well-being	the direct and indirect benefits people obtain from ecosystems	the benefits people derive from nature	the contributions that ecosystems make to human well-being	all the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life	Some definitions mix ESs and benefits; NCP is restricted to living nature which aligns with ES interpretation in this thesis
Provisioning	**Production**	**Provisioning**	**Provisioning**	**Material NCP**	
Seafood	Food provision	Food provision from fishing	Wild animals and plants for nutritional purposes	Food and feed from wild, managed or domesticated organisms	Haines-Young and Potschin (2018) refer to carrier function; IPBES' domesticated organisms refer to carrier function
		Food provision from aquaculture	Food from aquaculture		
			Mineral substances used for nutrition		
Seawater		Water Storage and Provision	Coastal and marine water as energy source	Regulating NCP Regulation of freshwater and coastal water quality	IPBES' focus on water quality in line with Chapter 2; Definition by Liquete et al. (2013) refers also to technical infrastructure (desalination) and onshore aquaculture; Haines-Young and Potschin (2018) refer to carrier function (water as medium to transfer energy)
Raw materials	Raw materials	Biotic Materials and Biofuels	Wild animals or plants as energy/material source	Energy	Haines-Young and Potschin (2018) refer to carrier function; IPBES' Energy rather refers to carrier function; use of peat (though non-marine example) is not sustainable
			Animals or plants from aquaculture as energy/material source		

Table 6.2 (continued)

Böhnke-Henrichs	Beaumont	Liquete	CICES	IPBES	Comparison
Genetic resources			Genetic material to breed new varieties or design new biological entities	Medicinal, biochemical and genetic resources	Rather agreement if included
Medicinal resources					
Ornamental resources				Materials, companionship and labor	Rather agreement if included
			Wind and solar energy, gas		Abiotic 'service', uses carrier function
				Materials, companionship and labor	Use of marine mammals for therapeutic or military purposes ethically questionable
Regulating	**Regulation**	**Regulating and maintenance**	**Regulation and maintenance**	**Regulating NCP**	
Air purification		Air quality regulation	Filtration/sequestration/ storage/accumulation by micro-organisms, algae, plants, and animals	Regulation of air quality	Rather agreement if included; CICES v5.1 has a broader definition not restricted to air quality
Climate regulation	Gas and climate regulation	Climate regulation	Regulation of chemical composition of atmosphere	Regulation of climate	Rather agreement
			Regulation of the chemical condition of salt waters by living processes	Regulation of ocean acidification	Regulation of chemical water condition or ocean-acidification refers to overall 'climate regulation'; distinction with Climate regulation unclear
		Weather regulation	Regulation of temperature and humidity, including ventilation and transpiration		Unclear whether in marine environment weather regulation from biota can be distinguished from weather regulation by physical processes (evaporation from sea surface)
Disturbance prevention or moderation	Disturbance prevention		wind protection	Regulation of hazards and extreme events	Rather agreement if included
			Hydrological cycle and water flow regulation (Including flood control)		
Regulation of water flows					
Waste treatment	Bioremediation of waste	Water purification	Bioremediation	Regulation of freshwater and coastal water quality	Rather agreement; CICES v5.1 has a broader definition not restricted to water quality
			Filtration, sequestration, storage, accumulation		

Table 6.2 (continued)

Böhnke-Henrichs	**Beaumont**	**Liquete**	**CICES**	**IPBES**	**Comparison**
Coastal erosion prevention			Control of erosion rates		
Biological control	Resilience and resistence	Biological regulation	Pest, Disease control (including invasive species)	Regulation of detrimental organisms and biological processes	resilience aspect not covered by most typologies
		Ocean nourishment			Seems to overlap/counteract with water purification; given the eutrophication observed in many seas or coasts, benefits related to this ES are unclear
			Dilution by water or atmosphere of waste, toxics, other nuisances by non-living processes; Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)		Abiotic; ecosystems as waste disposal sites
Habitat	**Over-arching support services**				
Lifecycle maintenance		Lifecycle Maintenance	Maintaining nursery populations and habitats (Including gene pool protection)		
Gene pool protection					CICES v5.1 description rather focused on lifecycle maintenance
	Biologically mediated habitat			Habitat creation and maintenance	
	Nutrient cycling				
Cultural and Amenity	**Cultural**	**Cultural**	**Cultural**	**Non-material NCP**	
Recreation and leisure	Leisure and recreation	Recreation and tourism	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through interactions	Physical and psychological experiences	Largest agreement with Liquete et al. (2013) in focus on interaction with/activities in marine ecosystems; other definitions rather focus on the mental or psychological effect; CICES v5.1 focuses stronger on the ecosystem components that provide opportunities for recreation
			Elements of living systems used for entertainment or representation		

Table 6.2 (continued)

Böhnke-Henrichs	Beaumont	Liquete	CICES	IPBES	Comparison
Aesthetic information		Symbolic and aesthetic values	Characteristics of living systems that enable aesthetic experiences	Physical and psychological experiences	IPBES and (Liquete et al. 2013) have a broader definition in which aesthetic information is only one aspect among others
Inspiration for culture, art and design		Cognitive effects		Learning and inspiration	IPBES and (Liquete et al. 2013) have a broader definition of this ESs
Spiritual experience		Symbolic and aesthetic values	Elements of living systems that have sacred or religious meaning	Supporting identities	IPBES and (Liquete et al. 2013) have a broader definition of this ES; CICES v5.1 focuses stronger on the ecosystem components that provide this ES while typology in Chapter 2 focuses more on the experience; i.e. the result from interacting with ecosystems
Information for cognitive development	Cognitive benefits	Cognitive effects	Scientific investigations, traditional knowledge, education and training enabled by living systems	Learning and inspiration	IPBES, CICES v 5.1 and (Liquete et al. 2013) have a broader definition of this ES
Cultural heritage and identity	Cultural heritage and identity	Symbolic and aesthetic values	Characteristics of living systems that are resonant in terms of culture or heritage Elements of living systems that have symbolic meaning	Supporting identities	IPBES and (Liquete et al. 2013) have a broader definition of this ES CICES v5.1 focuses stronger on the ecosystem components that provide this ES
			Abiotic characteristics of nature that enable above cultural interactions		Abiotic; unclear how human interaction with biotic and abiotic characteristics can be distinguished
	Feel good or warm glow (non-use benefits)		Characteristics or features of living systems that have an existence value		According to the Total Economic Value Approach (see for instance, Pascual et al. 2010) non-use and existence values are part of the total value that can be attributed to every single ES. To include these values as additional ESs confuses ESs and values
	Option use value				
	Future unknown and speculative benefits		Characteristics or features of living systems that have a bequest value	Maintenance of options	According to the Total Economic Value Approach (see for instance, Pascual et al. 2010) option and bequest values are part of the total value that can be attributed to every single ES. To include these values as additional ESs confuses ESs and values

The comparison includes three marine typologies (Beaumont et al. 2007, Böhnke-Henrichs et al. 2013, Liquete et al. 2013) and two general typologies that are widely recognized. One of them was developed by the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) (Díaz et al. 2018), the other one is known as the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin 2018). All five typologies are compared regarding their ES definition, their structure that groups ESs in categories like provisioning or regulating services, their individual ESs included and their underlying definitions or interpretations of these ESs. The observations of this comparison are documented in the last column of Table 6.2 and summarized and discussed below.

ES definitions

The typologies partly differ regarding the ES definition used and regarding their comprehensiveness and individual ES types. The compared typologies basically use two different ES definitions: ESs are benefits people derive from ecosystems as proposed by the Millennium Ecosystem Assessment (Beaumont et al. 2007, Liquete et al. 2013) and ESs are contributions to human well-being or people's quality of life, as suggested by the TEEB study (de Groot et al. 2010) (Böhnke-Henrichs et al. 2013, Díaz et al. 2018, Haines-Young and Potschin 2018). Although the definition used by Díaz et al. (2018) appears similar to the TEEB definition, Díaz et al. (2018) use the more paraphrasing term 'nature's contributions to people' (NCP) instead of the term 'ecosystem services'. Their overall framework includes 'ecosystem services' as one way amongst others to describe the relationship and dependencies between nature and people (Díaz et al. 2015). These adaptations proposed by Díaz et al. (2015) may appear subtle (Braat 2018) but triggered an intense scientific debate between the ESs community and the nature's-contributions-to-people community (see Kadykalo et al. 2019 for an overview). The adaptations by Díaz et al. (2018) offer a different framing on the dependencies of human well-being on nature. A suitable framing, in general, can be crucial for successful communication on environmental issues (Lakoff 2010) which has not yet been achieved by ES terminology (Thompson et al. 2016). From my perspective, the major advancement by Díaz et al. (2018) is to go beyond the technical concept and vocabulary of ESs rooted in academia. They complement ESs with a framework that aims to be inclusive to other world views and other ways of describing how people depend on nature. Whether this framework achieves its aims has to be proven by related assessments that apply the typology and framework by Díaz et al. (2018). However, the adapted wording allows for better contemplating and recognizing the notion of how nature or ecosystems contribute to human well-being.

Typologies' structure and ES included

To continue with the comparison, the typologies are rather similar regarding their structure in distinguishing different ES categories. All of them distinguish a 'provisioning' (or 'production' or 'material NCP'[11]), 'regulating' (or 'regulation and maintenance') and a 'cultural' (or non-material NCP) ESs category. The typology presented in Chapter 2 additionally includes a 'habitat' category, in line with de Groot et al. (2010). Beaumont et al. (2007) additionally include an 'over-arching support services' and an 'option use value' category. These additional ES categories and

[11] IPBES (Diaz et al. 2018) use 'NCP' instead of 'ES'. This involves that also ES categories are labelled 'NCP' categories. Although Diaz et al. (2018) establish this alternative terminology, their work is considered here as an ES typology and therefore included in my comparison.

the ES definition used by Beaumont et al. (2007) raise concerns that problems may occur when applying this typology: Its definition confuses ESs and their benefits and its ES types confuse ESs and related values. According to the Total-Economic-Value Approach (see for instance, Pascual et al. 2010), option and bequest values are part of the total value that can be attributed to every single ES. To include these values as additional ESs can cause double counting in case the option use value is included in the Total Economic Value of individual ESs as well. These concerns apply also to the typologies by Haines-Young and Potschin (2018) and Díaz et al. (2018) which include existence and bequest values or maintenance of options as individual ES or NCP category.

The Comparison of the individual ESs in each typology reveals, that most ESs included in my marine typology are also considered at least in one other typology. The marine typologies by Beaumont et al. (2007) and Liquete et al. (2013) are less comprehensive but particularly with the latter, my typology shows rather agreement with the exception of 'food provision from aquaculture' which I consider to rely on the carrier function since the contribution of the ecosystem can be questioned. The same applies to the 'domesticated organism' aspect of the Food NCP by Díaz et al. (2018) and their inclusion of the 'Energy' NCP. They have further included the NCP 'Materials, companionship and labor'. Such an ES remained neglected in my typology and I question whether this NCP is applicable to marine ecosystems. Relevant marine examples would include the use of marine mammals for military or therapeutic purposes. This, however, would require to remove marine mammals from marine ecosystems, which is not sustainably possible as the international whaling moratorium suggests and hence should not be considered an ES (Schröter et al. 2017). The comparison reveals the largest disagreement between my typology and the CICES v5.1 typology (Haines-Young and Potschin 2018). The reason is mainly that Haines-Young and Potschin (2018) include several ESs that are purely abiotic or rely on the carrier function. The problems that arise when such ESs are included, are explained above and should be carefully considered before choosing an assessment typology.

The comparison further shows, that even if ESs are labeled similarly, the underlying interpretation varies. For instance, the ES 'biological control' is included in all typologies, but some consider only pest/disease control, while others (Chapter 2) also include resilience. This indicates that assessment results for a single ES are not per se easily transferable across different assessments if different typologies have been used. This also demonstrates that each study should either adopt an available typology with its specific ES descriptions or provide own descriptions for each ES. Otherwise how an individual ES has been defined and assessed is not reproducible.

General considerations on applying ES typologies

Given the above observed partially fundamental differences between different ES typologies, a generally agreed ES typology seems to be beyond reach and some consider a general typology not feasible for diverse assessment contexts and ecosystems (Costanza 2008, Fisher et al. 2009). But what does that imply for ES assessments? The benefits of a typology include that it structures and guides assessments regarding which ESs to include. Moreover, a generally agreed typology facilitates the transfer of assessment results to other places or allows comparisons between different assessments. However, these benefits are hardly accomplishable, as insights from my three case studies suggest. Even an agreed general typology leaves room for interpretation that can question the comparability of different assessments. Particularly the Black Sea case study (Chapter 3) illustrates that each ES is linked to a number of sub-ESs. This makes it even more unlikely that different assessments are comparable regarding their considered sub-ESs. Moreover, there are also risks to applying an agreed general ES typology. Even a comprehensive typology may fail to capture very specific local ways of how ecosystems contribute to human well-being. Such local characteristics can easily be missed when a pre-defined typology is applied as a rigid template. To summarize, ES typologies can be a very useful tool that should be carefully applied. Even comprehensive typologies most likely need adaptation to case study conditions. Perhaps even more relevant than a general typology is to agree on the question, what is to be considered an ES (and what not)? Particularly regarding purely abiotic ecosystem components and the carrier function my typology comparison revealed larger disagreement.

6.2 Measuring marine ES supply

My thesis assessed changes in ES supply in the Black Sea and in the North Sea (i.e. Dogger Bank) using ES indicators. These indicators are applied in the two case studies to compare how different marine management options affect ES supply. The ES indicators developed and applied in this thesis also reflect the different sub-ESs assessed and are compiled in Table 6.3. Each indicator developed here and in other marine and terrestrial studies (see e.g. van Oudenhoven et al. 2012, Hattam et al. 2015a) measures only a single aspect of an ESs like a sub-ES or ES quality or quantity. This means, for a more comprehensive understanding of ES changes each ES requires usually a set of different indicators to capture different aspects. My thesis addressed this and assessed, where applicable, multiple sub-ESs with their individual indicators and for some ESs also assessed indicators for both ES quality and quantity. For instance, seafood was assessed as biomass of target fish species (quantity) next to their size (quality). Leisure and recreation was measured by abundance of iconic species, visual range in seawater and duration and frequency of algal blooms or jellyfish outbreaks. However, even with its multiple indicators for several ESs my assessment is still not exhaustive. Further possible indicators on seafood or recreation could capture seafood contaminants or the number and area of desired recreational spots like beach area, number of coves or reefs etc. Simultaneously, any additional indicator increases data demand and assessment effort. This trade-off between assessment effort and comprehensiveness has to be solved by each assessment individually based on its objectives and acknowledging the restrictions that are associated with a limited number of assessed indicators.

Marine ecosystems face frequently pressures from multiple uses that interact and thus have cumulative effects. Similarly, marine management as demanded by the European MSFD has multiple management objectives that address various aspects of marine ecosystems, including marine biodiversity conservation, seafloor integrity or underwater noise reduction. These different objectives require different management measures that can interact and cumulatively respond differently compared to a single measure. Understanding this cumulative response is crucial to marine management for better anticipating desired and undesired interplay (Bennett et al. 2009). The Black Sea ES assessment (Chapter 3) mapped cumulative effects of eutrophication and fisheries management and revealed the complexity of interactions occurring with only two measures.

To understand ES supply changes is relevant for management decision making since these changes potentially affect human well-being, as demonstrated by the ES cascade (Figure 6.1). Whether human well-being is actually affected, depends on, for instance, whether an ES is used and how much of it is used. In case ES use rates are far below ES supply, a decrease in ESs, though, measurable, has probably no human well-being effects. These considerations point at a shortcoming of ES supply assessments in general. According to the ES definition, a prerequisite for an ES is its contribution to human well-being. ES supply assessments are, however, restricted to analyse what an ecosystem potentially contributes. This potential supply is thus assessed in my thesis. For an assessment of actual ES changes a next assessment step would require to address societal demand of the ESs and how much of an ESs actually ‘flows’ to people (i.e. how much is actually used, enjoyed or appropriated (Bagstad et al. 2013, Burkhard et al. 2014). This is addressed in the following section.

Management measures affect ESs’ availability not only in terms of ES supply as conceptualized by the ES cascade (Figure 6.1) but also regulate ES use or appropriation. Such management regulation effects are important to consider, as Chapter 3 highlighted. For example, fishing quotas immediately affect the amount of seafood that can be legally obtained from seas. In contrast, ES supply effects usually occur with a larger time lag after management measure implementation, because they first require an ecosystem to respond to the management. Analysing both regulation and supply effects in ES assessments allows revealing those different time scale-dependent management effects that are crucial for understanding, communicating and negotiating management implications with affected stakeholder groups.

Table 6.3 Ecosystem Services and their indicators assessed in each of the three studies considered (Chapters 3 to 5)

ESs (Chapter 2)	ESs/sub-service and [indicators] assessed in Black Sea (Chapter 3)	ESs assessed in Venice Lagoon (Chapter 4)	ESs and [indicators] assessed on Dogger Bank (Chapter 5)
Seafood	fish, shellfish, seaweed [biomass: t/km^2; abundance: number per km^2; size (length and weight of target fish species]	Fish, mollusks, birds	nephrops, cod, haddock and flatfish species such as plaice, turbot and lemon sole [t/km^2, Species composition, age profile; length profile; % affected by disease; mortality rates]
Seawater	seawater for industrial cooling Number of jellyfish per m^3	--	--
Raw Materials	fish for fish meal/oil, macroalgae [biomass: t/km^2; abundance: number per km^2]	--	Sandeels; indicators see Seafood
Genetic Resources	Species providing genetic resources [number of species]	--	--
Medicinal Resources	Species providing medicinal resources [number of species]	--	--
Ornamental Resources	Sea shell [abundance and quality (size)]	--	--
Air Purification	--	Filtering the air and health risk prevention	--
Climate Regulation	Carbon storage [tonnes stored in the Black Sea over long geological time scales] N_2O, Dimethylsulfide Regulation [amount of N_2O and DMS released by the Black Sea]	Capturing greenhouse gases as local contribution against global warming	Air-sea and sediment-water fluxes of carbon and CO_2, scaled to the area covered by the Dogger Bank [(mg C)/(m^{2}d)]; Carbon levels: biomass of carbon [g/m^2]; dissolved organic or inorganic carbon [mg C/m^3]; suspended organic or inorganic carbon [mg C/m^3]; buried particulate organic or inorganic carbon [mg C/m^2]; permanence of carbon sequestration [% of annual carbon turnover from sediments]

Table 6.3 (continued)

ESs	Black Sea	Venice Lagoon	Dogger Bank
Disturbance Prevention or Moderation	--	Reducing the open water areas in the lagoon, thus, reducing wave energy, and protecting shores	--
Regulation of Water Flows	--	Capturing sediments and reduction of navigation effects	--
Waste Treatment	Nutrient removal [tons removed from water by mussels in Black Sea]	Filtering the water and health risk prevention	--
Coastal Erosion Prevention	--	Preventing erosion of protected habitats (thus, saving money/efforts required for habitat protection and restoration)	--
Biological Control	(harmful) Jellyfish, phytoplankton [number and frequency of outbreaks/blooms of marine biota at coast]		--
Lifecycle Maintenance	[Number of offspring of commercial species in a certain area that affect catches elsewhere]	Supporting future availability of food due to the presence of areas where fish and birds reproduce	Spawning and nursery habitat [abundance per m^2 and species diversity]
Gene Pool Protection	Maintenance of viable gene pool [Evolution of commercial species triggered by fisheries]	Nature conservation, in relation to the variety of habitats and species typical of the salt marshes	Species diversity, Biodiversity Intactness Index [Expert judgment on species change and changes to Biodiversity Intactness Index]
Recreation and Leisure	Fishing, Diving, snorkeling, beach recreation, bird-, whale-, seal-watching [fish biomass: tonnes per km^2; fish abundance: number per km^2; fish size (length and weight of target fish species; abundance and size of attractive/iconic species; number and frequency of outbreaks/blooms of marine biota at coast; visual range in meters]	Opportunities for recreation (mooring close to salt marshes, observing flora and fauna, fishing, hunting, excursions)	Key species and biotopes of recreational interest [count data of species; expert judgment on changes in area of biotopes]
Aesthetic Information	Dependent on seawater quality [number and frequency of outbreaks/blooms of marine biota at coast; visual range in meters]	Contribution to the beauty and attractiveness of the lagoon	--
Inspiration for Culture, Art and Design	--	Inspiration for artists (paintings, music, design, other)	--
Spiritual Experience	Dependent on seawater quality and iconic species [Number of cultural practices/events that involve/are related to water quality; abundance and size of attractive/iconic species relevant for spiritual experience]	Importance for local religious congregations and their spiritual traditions	--
Information for Cognitive Development	--	Opportunities for education (environmental education)	--
Cultural Heritage and Identity	Dependent on seawater quality and iconic species [Number of cultural practices/events that involve/are related to water quality; abundance and size of attractive/iconic species relevant for spiritual experience]	Contribution to local communities' traditions (thus, contribution to the social well-being)	--

6.3 Analysing stakeholder management preferences and ES demand

Just as ES supply, also societal demand for ESs varies over time and responds to management measures (Chapter 4). ES demand can be assessed by stated or revealed preference methods (Scholte et al. 2015, Schmidt et al. 2016). My thesis adopted a stated preferences approach and analysed local resident's ES demand and management preferences in a Venice Lagoon case study that was concerned with a participatory salt marsh conservation project. In this case study, we surveyed local residents twice at an early and at the final stage of the project and compared the results of both surveys. This dual survey approach addressed a gap in the literature where management effects are usually analysed once before or after an intervention has taken place. The dual approach allowed tracing how local residents' preferences changed during the conservation project. Local residents' preferences were measured in multiple complementary dimensions: through a rating of ecosystem services and social benefits, willingness-to-pay and willingness-to-volunteer estimates. Salt marsh management preferences were revealed through photo-realistic management scenarios from which interviewees could select their most preferred scenario. These scenario images captured also cumulative management effects or trade-offs by combining only compatible uses with salt marsh restoration. A limitation of the scenario images was that they accommodate only a limited number of trade-offs to ensure that these are comprehendible to interviewees. Further caveats were potentially associated with the dual survey approach. To avoid a biased survey sample, the sampling method of both surveys should be comparable. Another caveat relates to the lacking control group. When analysing effects of an ongoing conservation project, excluding individuals from interacting with the conservation project was neither feasible, nor intended. This means, however, that a control group was missing against which project effects could be compared. Hence, survey results most likely yielded a mix of project effects and other external effects. These limitations must be acknowledged when interpreting dual survey results.

The survey applied different valuation approaches, which together provided detailed insights into local residents' various salt-marsh management preferences. Results also allowed to analyse conflicts between different management preferences and were consequently used to infer management recommendations. Two general management recommendations are: (1) Conservation measures should be accompanied by environmental information and education measures. Results suggested that better salt marsh and erosion knowledge can increase overall support for restoration and conservation. I consider this particularly relevant to ensure the required long term, if not permanent, support by local residents. (2) Spatial zoning can solve conflicts between different management preferences. Some residents preferred uses like boating or fishing that are not always compatible with salt marsh restoration. To designate areas suitable for fishing and boating can address this conflict without compromising nature conservation objectives.

These recommendations illustrate how insights obtained from analysing local residents' ES demand and management preferences can improve management and align their preferences with nature conservation.

6.4 Integrating ES supply and demand

A combined analysis of ES supply and demand is a relevant basis for ecosystem management, because a societal ES demand, that exceeds sustainable ES supply, indicates a conflict within the managed system. A case study on the Dogger Bank, a large sandbank in the southern North Sea, addressed the challenge to integrate insights gained on ES supply and demand (Hattam et al. 2015b, Chapter 5). The case study focused on the three management foci conservation, fisheries and wind farms. The integrated insights were provided by three different methods, an indicator-bases assessment of ES supply, a Discrete Choice Experiment to reveal ES demand and a Citizens' jury that reveals public's management preferences for the Dogger Bank. Integrating such different methods' findings proved challenging, because they differ regarding the ESs covered and regarding their output units. The ES supply assessment analysed how indicators of six ESs change under two different management scenarios and consequently yielded both quantitative changes in biophysical units (e.g. tonnes of seafood) or qualitative results that show the direction of change for ES indicators. The Discrete Choice Experiment yielded monetary values for different choice options. These choice options covered the following attributes: species diversity (included options: no change, 10% increase and 25% increase), protection of charismatic species (included options: no protection, protected on 25% of Dogger Bank and protected on 50% of Dogger Bank) and invasive species (included options: restricted spread and widespread). Consequently, the monetary value, that reflected societal demand, was rather indirectly linked with bundles of ESs that are relevant for achieving the chosen or most preferred options. The Citizens' jury yielded insights on management issues that were important to the public and a ranking of management preferences.

These considerable differences in outputs hampered a smooth comparison of individual ESs' supply and demand. Instead, findings were integrated based on their major management implications for the three management foci conservation, fisheries and wind farms. All three methods largely agreed in their favour for conserving the Dogger Bank. Regarding ES supply, the management scenario that reduced most human pressures was the one that had the most increasing ESs. Also public management preferences and ES demand favoured conservation. For instance, in the Discrete Choice Experiment the highest Willingness to Pay has been estimated for protecting 50% of the Dogger Bank for iconic species (porpoises, seals and birds). Results for the other management foci were, however, rather mixed. While the indicator assessment suggested that ESs benefit most from fishing restrictions, the Citizens' jury acknowledged the Dogger Bank as traditional fishing ground and derived a legitimation for fisheries from that. Similar conflicts applied to offshore wind farms as management focus. The management scenario that involved the most positive changes in ES supply expected birds to decrease as species of recreational interest. This decrease is in conflict with the high willingness to pay for iconic species conservation revealed by the Dogger Bank and the Citizens' jury preferred fisheries over wind farms. These contradicting results can still provide valuable information to management decisions, because they highlight management issues that require attention and can also reveal underlying reasons for management conflicts. For example, the publics' perception of fisheries as the historically legitimate user of the Dogger Bank is potentially one reason why fisheries restrictions are difficult to achieve. In contrast, insights gained from the ES-supply assessment suggest that many ESs suffer from fisheries. Sharing and debating such insights likely contribute to better informed management decisions.

This exemplifies what can be gained from integrating different methods that assess ES supply and demand. Both, matches and mismatches between the different methods provide insights to inform management decisions. Although integration of different methods is best planned at a very early conceptual stage of an assessment, later integration, with caveats, is possible as well, but still requires commonalities between the different methods such as similar management scenarios, management foci or overlap in ESs assessed.

6.5 How do marine ecosystem service assessments contribute to preserving healthy seas?

The policy target of healthy marine ecosystems is recognized both by the United Nations' global 2030 Sustainable Development Agenda and the EU's MSFD. However, a clear and agreed definition of ecosystem health is missing but instead is frequently framed on an individual case basis, depending on respective management objectives (O'Brien et al. 2016). My thesis adopted the ecosystem health interpretation proposed by Burkhard et al. (2008) who characterize a healthy ecosystem as resilient and thus able to maintain its organization under stress (i.e. external human pressures) and acknowledge that a healthy ecosystem is able to sustainably supply ESs. This understanding of ecosystem health coincides with the ecosystem-based approach interpretation of the MSFD that is also based on the dual criteria of ecosystem resilience and the capacity to sustainably provide ESs.

Table 6.4 Global and European policies that aim at healthy seas and how these policies are addressed in my thesis

Policy goals towards healthy seas	This thesis...
United Nations, Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources	analyses ocean use in relation to ES provision (Chapters 3 to 5), derives management recommendations for two protected areas (Chapters 4 and 5)
Convention on Biological Diversity: Malawi Principles of an ecosystem approach	contributes to a better understanding of the balance between ecosystem conservation and use, facilitates consideration of management benefits (ES gains) (Chapters 3 to 5)
CBD Aichi targets: #2 (integrate biodiversity benefits in planning), #11 (protected areas to be effectively managed), #14 (ecosystems that provide essential ESs are safeguarded and restored taking into account, amongst others, local communities)	defines marine ES and provides guidance on how to integrate ES in marine management (Chapter 2), analyses management options for marine ecosystems regarding ES effects and thus contributes to knowledge base relevant for enhancing benefits from these ecosystems (Chapters 3 to 5), derives management recommendations for two protected areas (Chapters 4 and 5), explores stakeholder preferences regarding ecosystem restoration (Chapter 4)
EU's Habitats Directive: species and habitats to be maintained at or restored to favourable conservation status	derives insights on ES supply and stakeholder management preferences and ES demand for the Dogger Bank and salt marshes in Venice Lagoon, both protected under habitats directive (Chapters 4 and 5)
EU's Marine Strategy Framework Directive: Achieve Good environmental Status of European Seas (e.g. maintenance of biodiversity/habitats); healthy stocks of commercial fish species; eutrophication minimized,	investigates ESs and management preferences related to habitat conservation (Chapter 4), analyses effects of nutrient and fisheries management on ES supply (Chapter 3)

Despite the policy goal of healthy seas, marine ecosystems are still degraded due to several human pressures (IPBES 2019, IPCC 2019). How marine ES assessments can contribute to turn the tide and to address this management challenge is addressed in this section based on the work presented in my thesis. Therefore, this section exemplifies how ESs, and particularly my thesis, address the implementation of two global and two European policies with relevance to marine systems (see Table 6.4).

The two global policies addressed here are the United Nations' Sustainable Development Goals and the Convention on Biological Diversity. The Sustainable Development Goal number 14 aims to conserve and sustainably use the oceans, seas and marine resources. The Convention on Biological Diversity specifies in the Malawi Principle the requirements for implementing an Ecosystem Approach to achieve conservation targets and simultaneously ensure sustainable use of ecosystems. The Conventions' Aichi targets aim to integrate biodiversity benefits in planning, manage protected areas effectively, safeguard and restore ecosystems that provide essential ESs. My thesis showed that ES assessments can contribute to these objectives by analysing ES demand in relation to ES supply. This is relevant for understanding and managing overuses. Further, my thesis showed how ES assessments can be used to understand management conflicts and to derive management recommendations.

The two European policies addressed in my thesis are the Habitats Directive and the Marine Strategy Framework Directive. Both provide the policy context of my case studies. The Habitats Directive more generally aims at a favourable conservation status of particular habitats and species, amongst which are salt marshes (Chapter 4) and sandbanks (Chapter 5). The conservation of such habitats or protected species generally benefits from stakeholder participation (Reed 2008, IPBES 2019). This participation can be facilitated by the ES concept, for instance, when ES typologies are used as a starting point to discuss and explore how people benefit from marine ecosystems. The MSFD aims to achieve a good environmental status which is specified by eleven descriptors that reveal the MSFD's understanding of ecosystem health. Four of these descriptors were addressed in my thesis (Box 1.1).

Despite this potential to contribute to environmental policies, this potential of the ES concept is not yet capitalized. The data requirements of ES assessments or the frequently mentioned lack of marine data (Bertram et al. 2014, Beaumont et al. 2017, Drakou et al. 2017) are probably only one reason for this. Rather, it is a huge step from broad policy goals to their actual implementation (Daily and Matson 2008). While policies adopt sustainable ES use as management objective, this is not consistently integrated in policy implementation and decision making. When implementing the MSFD, for example, ESs are in theory recognized in obligatory cost-benefit analyses to evaluate proposed measures. However, due to data scarcity, ESs remain unvalued or undervalued (Bertram et al. 2014, Dupont et al. 2017). To close this gap by further marine ES assessments with a particular focus on MSFD descriptors is thus urgently required. My thesis contributed to close this gap and analysed management effects on marine ESs and management preferences in relation to four MSFD descriptors. Descriptor 1 (habitats and biodiversity) was addressed in the case studies of Chapter 4 and 5), descriptor 2 (control of non-indigenous species) was considered in Chapter 5, descriptor 3 (healthy stocks of commercial species) and descriptor 5 (reduction of anthropogenic eutrophication) were addressed in Chapter 3.

A further reason for the continued decline of marine ecosystems and their ESs is that marine environmental policies lack the direct instruments to regulate relevant pressures. To address this issue, ESs should be integrated into decision making on marine uses. Relevant policies for such integration are the EU's Common Fisheries Policy, Marine Spatial Planning Initiatives or permit procedures for marine infrastructure. Marine infrastructure alters and degrades marine systems, but the required environmental impact assessment (as required by the European

Environmental Impact Assessment Directive) does not address ES impacts of infrastructure construction. Consequently, decision making cannot take ES changes into account. So far, according to the European Environmental Impact Assessment Directive, quantification and valuation of ES changes due to infrastructure construction are not legally required. To change this and integrate ES assessments in the requirements for an Environmental Impact Assessment can be an important step towards the policy goal of sustaining marine ESs.

6.6 Conclusions

This thesis contributes to an understanding of marine ESs by defining and delineating marine ES in a consistent typology and by developing indicators for their assessment. Both are useful tools in ES assessments and correspond with my RQ 1. This thesis applied its ES typology in different contexts and for different spatial scales, namely fisheries and nutrient management effects on ES supply at the entire Black Sea scale; local residents' ES demand and management preferences in a Mediterranean coastal lagoon; and integration of ES supply and societal ES demand and management preferences at a large sandbank in the North Sea. The typology proved comprehensive and sufficiently flexible for these different contexts and scales.

In response to my RQ 2, my thesis applied an indicator-based approach to analyse changes in ES supply. To increase specificity and adapt to the complexity of marine ecosystems, ESs were split into several sub-ESs that reflect different aspects or components of an ES. The sub-ESs were measured by individual indicators and can be added up for a more comprehensive consideration of an ES. The thesis concludes that distinguishing different sub-ESs makes an ES assessment more precise regarding the specific ecological processes and functions analysed. The thesis further demonstrates that measuring ecosystem management implications requires a cumulative assessment of all considered management aspects, because different management aspects can have synergistic or antagonistic effects that can either support each other or attenuate overall effects. Consequently, a cumulative assessment delivers more reliable results but can also provide insights on how different management aspects can be combined for alleviating undesired management outcomes. This way, this thesis addresses a current challenge in marine management where multiple uses cause cumulative pressures on ecosystems while management to address these pressures frequently remains restricted to single separated sectors.

This thesis analysed in a case study on salt marsh management in Venice Lagoon local residents' ecosystem management demand in a protected area, their environmental knowledge and their ES values (RQ 3). Therefore, the case study applied multiple different methods to reveal these preferences and values. The resulting integrated valuation approach revealed synergies and conflicts (e.g. between salt-marsh uses and conservation). To understand these synergies and conflicts is critical for tailoring and guiding conservation actions. The thesis concludes that for more conservation success understanding these various demands and preference aspects is crucial, because they improve aligning residents' preferences with nature conservation. This makes management decisions more inclusive and sustainable. The case study further revealed that stakeholders' demand and preferences are changeable even on a rather short time scale as a result of information, education and participatory conservation measures. The thesis thus concludes that conservation projects can benefit from involving local residents as that revealed to be a way to positively affect their attitude towards conservation.

This thesis used different methods to assess marine ESs. If well aligned, different assessment methods can complement each other and thus provide a more complete understanding of ecosystem management outcomes. In response to my RQ 4, such integration was the particular focus of the case study in the North Sea which disclosed potential management conflicts and explores whether the ES supply meets ES demand. The obtained insights allow ecosystem management to respond and adapt and are thus relevant for better informed management decisions.

This thesis analysed human-environment relations in European seas which to understand is crucial for solving several current marine management challenges. A challenge particularly relevant to Europe is to implement the European Marine Strategy Framework Directive, aiming at a Good Environmental Status of European Seas by 2020. Europe has not yet achieved this aim. Marine Biodiversity is still in an unfavourable condition, overfishing, eutrophication or underwater noise, amongst others, still harm marine ecosystems. This suggests, either other management approaches are required or existing approaches need to be implemented more effectively.

I recognize several options of how ES assessments can inform marine policies and thus contribute to preserving healthy marine ecosystems (RQ 5). Though, the ES concept alone is not sufficient and in its focus too narrow to solve all current management challenges (Norgaard 2010), ESs are considered a tool to implement at least some of the Malawi principles (CBD 2006, Waylen). This is particularly relevant as the complex, comprehensive and ambitious Malawi Principles are a chance for improved marine management. ESs are not yet fully implemented in marine management decision processes. A way to overcome this challenge would be to include ES formally and obligatory in marine governance (e.g. marine spatial planning) and in further European Policies or Directives that govern marine uses (e.g. the Common Fisheries Policy or the Environmental Impact Assessment Directive) or national law. A guiding principle therefor would be that adopted projects or plans must ensure to sustain marine ESs, as requested by both the MSFD and the CBD. This means, for example, that marine spatial planning processes, planning permit procedures or the European Common Fisheries Policy would obligatorily be complemented by an ES assessment as basis for decision making. This is ambitious and probably not easily implemented. However, given that current approaches failed to conserve biodiversity and to preserve our life-sustaining seas, the application of the ES concept certainly offers a way forward and likely contributes to turning the tide in marine ecosystem management.

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Appendix 1

Examples of interdependencies between the ecosystem services included in the proposed typology.

Interdependencies of Provisioning Services

Harvesting ***Sea Food*** can influence *Climate Regulation*: one process for carbon sequestration in the ocean is via buried organic matter. To harvest Sea Food means to remove organic matter (and therefore carbon) from the system and preventing it from being buried. Another impact is on the service itself: harvesting one species can influence availability of other species.

The use of ***Sea Water*** as ballast water, for instance, can influence the services *Sea Food, Recreation and Leisure, Aesthetic Information*: if as a consequence of water extraction (e.g. for ballast water) invasive species were brought to a new location, this could change 1) availability of Sea Food 2) suitability for recreational activities (impact of occurrence of jelly fish on beach tourism) 3) Aesthetic Information of a location.

Extracting ***Raw Materials*** can have several different implications: Removing kelp forests or mangroves as Raw Materials impacts on the species harvested as *Sea Food* that depend on these ecosystems and harvesting material that may also be part of dampening structures (e.g. coral reefs, sand banks) may impact on *Disturbance Prevention or Moderation*.

The extraction of ***Genetic and Medicinal Resources*** drives education and research (service *Information for Cognitive Development*).

The extraction of corals as an ***Ornamental Resource*** has an impact on species that use corals as nursery habitat and are harvested elsewhere (service *Life Cycle Maintenance*) and can also change the aesthetic feature of a sea scape (*Aesthetic Information*).

Interdependencies of Regulating Services

Air Purification can impact on *Waste Treatment*: Pollutants that are removed from the atmosphere by marine and coastal environments may end up in coastal/marine waters, and there may impact on the biota which are involved processing of wastes in these environments.

Carbon Sequestration in oceans is driving research and education (*Information for Cognitive Development*) and can also influence on Sea Food provision: Ocean acidification due to uptake of atmospheric CO_2 may influence the availability of *Sea Food* like shell fish, especially in the future.

The ***Disturbance Prevention or Moderation*** by marine ecosystems can influence a range of different services in a similar way: The capacity of an ecosystem to dissipate wave/wind energy has an impact on populations of local marine flora and fauna, which may (locally) influence *Sea Food* provision, *Habitat services* and *Recreation and Leisure*.

The capacity of an ecosystem to maintain coastal current structures (service ***Regulation of Water flows***) can impact on *Coastal Erosion Prevention* either by intensifying or mitigating erosion.

Moreover, local current intensity can determine the suitability of a nursery area for a particular species (service *Life Cycle Maintenance*).

The capacity of an ecosystem to filter waste water/remove pollutants (***Waste Treatment***) might influence quality (contamination) and quantity of available *Sea Food* and may also impact on *Aesthetic Information* and suitability of an area for *Recreation and Leisure*.

Coastal Erosion Prevention can influence on *Lifecycle Maintenance* since coastal erosion patterns may affect the extent of smothering in nursery areas.

Biological Control can impact on *Sea Food* because changes to food web dynamics can influence the availability of target fish species.

Interdependencies of Habitat Services

Lifecycle Maintenance can influence on *Sea Food* provision, *Biological Control*, and *Recreation & Leisure*: Changes to nurseries can impact on the availability of Sea Food harvestable in an area, on the food web, and on recreational activities related to observation of nurseries.

Gene Pool Protection is linked to *Genetic and Medicinal Resources*: Changes to genetic diversity (due to changes in gene pool protection) might affect the ability of humans to extract new genes or compounds for pharmaceutical research.

Interdependencies of Cultural and Amenity Services

Recreation and Leisure can influence on *Sea Water* and *Raw Materials* provision: The availability of recreation opportunities in an area might cause restrictions for the use of these other services.

The ***Aesthetic Information*** of an area might influence services related to human perception of an area, such as *Recreation and Leisure*, *Inspiration for Culture, Art and Design*, and *Spiritual Experience*. The interdependency with *Cultural Heritage & Identity* may be connected to the aesthetics of a place because changes in ***Aesthetic Information*** can influence the sense of place feeling.

The ability of an area to inspire artists (***Inspiration for Culture, Art and Design***) can influence *Recreation and Leisure* where this service is used for recreational activities like painting holidays.

The ***Spiritual Experience*** is linked to *Cultural Heritage and Identity*: Changes in the formal religious experiences related to an area may change ones sense of place.

The ***Information for Cognitive Development*** can influence on *Genetic and Medicinal Resource* provision: Research would be capable of driving extraction of genetic and medicinal materials.

Information for Cognitive Development is also linked to *Climate Regulation*: Research on techniques to sequester carbon in the ocean might influence this service.

Cultural Heritage and Identity that involves *Sea Food* or the extraction of marine *Raw Materials* or *Medicinal Resources* can influence these services.

Appendix 2

This appendix presents data and references that support the results presented Chapter 3.

1 Seafood

1.1 Seafood - fish

Methodology

The ES Seafood, defined as *All available marine species extracted for the specific purpose of human consumption as food* (Böhnke-Henrichs et al. 2013), is probably one of the most important ESs provided by the Black Sea ecosystem. Especially during the 1980s total fishery catches peaked at about 1 million tonnes annually and ever since the anchovy stock collapse in 1989 (Kideys 2002), catches maintained levels of about 500 kilo-tonnes. Catches are largely comprised of small pelagic fish, mainly Black Sea anchovy (Engraulis encrasicolus ponticus; Alexandrov, 1927) and Black Sea sprat (Sprattus sprattus phalaericus; Risso, 1827), in addition to demersal fish, Black Sea whiting (Merlangius merlangus euxinus, Nordmann, 1840) and turbot (Psetta maeotica, Pallas, 1814) as among the most valuable commercial species.

To assess changes in fish biomass, a time-dynamic trophic Ecopath with Ecosim (Christensen et al. 2005) model of the Black Sea was set up and was based on a modified version of the model in Akoglu et al. (2014). The model foci were the above four fish species as separate model state variables. The model included further the following functional groups:

- ‘piscivorous fish’ to represent Atlantic bonito (Sarda sarda; Bloch, 1973), bluefish (Pomatomus saltator; Linnaeus, 1776) and Atlantic mackerel (Scomber scombrus; Linnaeus, 1758) as the top predators;
- three separate jellyfish species: moon jelly Aurelia aurita (Linnaeus, 1758) and two non-indigenous comb jelly species, Mnemiopsis leidyi (Agassiz, 1865) and Beroe ovata (Mayer, 1912);
- the heterotrophic dinoflagellate Noctiluca scintillans (Ehrenberg, 1834);
- zooplankton;
- primary producers, i.e. phytoplankton;
- detritus to represent the Black Sea sediment.

First, a static mass-balanced Ecopath model of the Black Seafood web was set up and parametrized following Akoglu et al. (2014) (see Table A.1 and Table A.2). Then time series of fishing mortality estimates from the report “Assessment of Black Sea Stocks” of the Scientific, Technical and Economic Committee for Fisheries (Daskalov et al. 2011) were used to drive the time-dynamic Ecosim model. The hindcast model scenario was run between 2000 and 2010 and the simulation results were validated against the fisheries landing statistics and stock assessments from Daskalov et al. (2011) as well as from field data available to authors concerning the time period between 2000-2010. As a second step, future progressions (between 2010-2020) of the food web conditions under three different scenarios were investigated assuming that the conditions of 2010 (in terms of production and fisheries exploitation) will prevail throughout the future scenarios.

Table A.1. Input parameters and initial conditions for the time-dynamic Ecopath with Ecosim model used in the Black Sea case study. The biomasses are in grams of carbon per square meter. “Est.” denotes parameters estimated by the model.

Group name	**Biomass in habitat area (gC/m^2)**	**Production/ biomass (/year)**	**Consumption/ biomass (/year)**	**Ecotrophic Efficiency**	**Landings (gC/m^2/year)**
Piscivorous fish	Est.	0.5	5	0.9	0.01
Whiting	0.037	0.65	1.5	Est.	0.011
Turbot	0.00637	0.7	1.5	Est.	0.002
Anchovy	0.32	2.5	10.9	Est.	0.207
Sprat	0.42	2.5	10.9	Est.	0.037
A. aurita	0.39	10.95	29.2	Est.	-
B. ovata	0.02	10.95	29.2	Est.	-
M. lediyi	0.482	10.95	29.2	Est.	-
N. scintillans	1.2	7.3	36.2	Est.	-
Zooplankton	0.405	110	325	Est.	-
Phytoplankton	2.6	177	-	Est.	-
Detritus	80	-	-	Est.	-

Table A.2. Relative diet composition matrix for the time-dynamic Ecopath with Ecosim model of the Black Sea case study.

Predator / **Prey**	Piscivorous fish	Whiting	Turbot	Anchovy	Sprat	A. aurita	B. ovata	M. leidyi	N. scintillans	Zoo-plankton
Piscivorous fish										
Whiting										
Turbot										
Anchovy	0.3	0.4	0.2							
Sprat	0.3	0.4	0.2							
A. aurita										
B. ovata										
M. leidyi							1			
N. scintillans										
Zooplankton				1	1	0.5		0.5	0.2	
Phytoplankton									0.8	1
Detritus	0	0.2	0.6			0.5		0.5		
Import	0.4									

Results

For an overview see Table A.3

The simulation results reveal three important aspects of management scenario effects:

Under the Sustainable Fishing scenario the biomass ratio fodder zooplankton to opportunistic zooplankton increases because the predators of planktivorous fish species increase by more than 25%. This exerts a top-down control on planktivorous fish (i.e. anchovy and sprat) and thus releases the predation pressure on zooplankton. Anchovy and sprat increase only slightly under this scenario by 1.3% and 4.8% respectively.

Under the Clear Water scenario, the bottom-up control of primary production causes the biomasses of zooplankters and fish groups to decrease concurrently.

Under the Agricultural Intensification scenario, similarly but contrary to Clear water scenario, the biomasses of all zooplankton and fish groups increase, however, at the cost of degrading ecosystem quality, because the ratio of non-edible zooplankton (jellies) and opportunistic organisms like heterotrophic dinoflagellate Noctiluca to trophic/fodder zooplankton (i.e. edible zooplankton for planktivorous fish such as copepods) increases significantly. The increase in non-edible zooplankton and opportunistic dinoflagellates (that both graze on fodder zooplankton), in turn, reinforces the decrease of fodder zooplankton. However, this phenomenon was not found to decrease the forage fish biomass due to the sustainable regulation of fisheries applied in this scenario. This means, the fish stocks that otherwise would collapse due to the decrease of fodder zooplankton (reflected by the significant reduction in the ratio fodder zooplankton to non-edible zooplankton under the status quo fishing exploitation), are able to maintain their stock biomasses. This ensures Seafood and Raw Materials supply under these degraded ecosystem conditions.

Table A3. Relative change in Biomass four fish species and plankton according to model outputs

	Sustainable fishing	**Clear Water**	**Agricultural intensification**
Anchovy	1.3%	-85%	66%
Sprat	4.8%	-86%	73%
Turbot	32%	-85%	135%
Whiting	26%	-83%	110%
Zooplankton	~0%	-85%	64%
Phytoplankton	~0%	-90%	90%

1.2 Seafood – seaweed

The management scenarios associated with changes in nutrient loads can affect macroalgal availability. Seaweed can decrease under higher nutrient loads when its habitat is reduced due to increasing anoxic and hypoxic areas or decreasing light availability due to turbidity. Berov et al. (2012) found that under increasing nutrient loads the depth in which macroalgae communities occur has decreased. Thus, the Agricultural Intensification scenario has the potential to decrease seaweed availability while it could increase under Clear Water.

2 Seawater

Seawater is used as ballast water and for cooling purposes in the Black Sea (see Table A.4).

Table A.4. Industries that extract seawater from the Black Sea to be used in their operations

Industry	Operations/Applications
Shipping	Major ports in the Ukraine, Romania, Turkey and Bulgaria support shipping, where seawater is extracted for ballast water.
Nuclear Power	Nuclear reactors based in Bulgaria (2) and Romania (2) extract seawater for its operations. In Ukraine, nuclear power plants are located far from the coast, and seawater ist not used for their operation.

For ballast water use no effects related to insufficient water quality have been reported to our best available knowledge. This suggests that this aspect is not affected by a change in water quality and it is thus not further considered in this assessment.

In the Baltic Sea, a Swedish nuclear power plant has recently been shut down (Bilefsky 2013) due to insufficient water quality (jellyfish outbreak). Such events of insufficient seawater quality can affect power plants in the Black Sea region as well.

To estimate effects on this ES, the management scenarios have been compared regarding their effect on jellyfish by using the modeling results as presented under Seafood (Table A.5)

Table A.5: Trend for seawater availability in suitable quality under management scenarios

Scenario	Effects on jellyfish	Trend for seawater availability/quality
Sustainable Fishing	No Change	No change
Clear Water	Decrease in proportion of opportunistic jellyfish species due to reduced PP	Increase
Agricultural Intensification	Increase in proportion of opportunistic jellyfish species due to increased PP	decrease

3 Raw Materials

The sub-services fish meal and fish oil, aggregates and algae (for non-consumptive use) are considered here.

3.1 Aggregates

No information could be obtained on the extraction of biogenic aggregates. Geogenic aggregates are not considered an ecosystem service. Due to a lack of more detailed information, this subservice is not included in this assessment.

3.2 Fish meal and fish oil

Modelling results obtained under ES Seafood are used to estimate effects on fish meal and fish oil. It is assumed, that a 1:1 relationship between availability of fish meal/fish oil and the above modelled fish biomass applies. This means, the changes in biomass of fish species as presented under Seafood above also reflect the changes of fish meal and fish oil under the respective management scenarios (Table A.6).

Table A.6: Change in fish biomass under management scenarios (Paijmans et al. 2013)

Scenario	Change in fish biomass	Trend for ES fish meal/oil
Sustainable Fishing	Slight increase for Anchovy, Sprat (1.3%-4.8%), strong increase for Whiting and Turbot (26%-32%)	Increase
Clear Water	Strong decrease by 83-86%	Decrease
Agricultural Intensification	Strong increase for all species (66%-135%)	Increase

3.3 Algae

Different species of Black Sea macroalgae (Enteromorpha intestinalis, Ulva rigida and Ceramium rubrum) have been identified as suitable for fertilizer in agriculture (Negreanu-Pîrjol et al. 2011). Management scenarios associated with changes in nutrient loads can affect macroalgae availability. Algae can decrease under higher nutrient loads when its habitat is reduced due to increasing anoxic and hypoxic areas and decreasing light availability. Berov et al. (2012) found that under increasing nutrient loads the depth in which macroalgae communities occur is decreasing. Following this rationale, Agricultural Intensification has the potential to decrease algae availability while it could increase under Clear Water.

A change in this ES is driven by changes in primary production, i.e. nutrient availability. For Sustainable Fishing nutrient levels are considered stable compared to current levels. For this scenario no change is expected.

4 Genetic Resources

We have developed the following approach for identifying changes or effects on ES Genetic Resources: The assessment of management scenarios on the provision of this ES considers only future use (option or bequest use) of endemic species for the following reasons:

1) Only for genetic resources from endemic species, humans depend on the Black Sea. For other species, any genetic resources can be replaced by specimen extracted from other seas and thus, ES provision is not necessarily linked with Black Sea management.

2) It is assumed that once a gene sequence is identified, isolated and used it will be synthesized rather than repeatedly extracted from oceans. Thus, the importance of oceans and coasts relates to the future use/availability of gene sequences because currently used/extracted sequences will no longer be affected by management.

For assessing changes of this ES under the proposed management scenarios, a screening of Black Sea species has been performed (see Table A.7) that aimed to identify those species which are 1) endemic in the Black Sea, AND 2) are threatened according to IUCN red list, AND 3) are affected by the management measures considered. Criterion (2) was included because threatened species are potentially vulnerable to management changes while abundant species are rather not.

Table A.7: Trends for endangered endemic Black Sea species under management scenarios

Endangered endemic Black Sea species	Effects of management scenarios on endangered endemic species	Trend under management scenarios
Tursiops truncatus ponticus Delphinus delphis ponticus	T. truncatus ponticus strandings and deaths are due to entanglement with fishing nets while searching for food. These dolphins are discarded from fishing nets by fishermen and result in strandings along coastal shores. Stomach gut analysis of those individuals washed up on shores indicate low food content causing hunger and malnutrition (Tonay pers. comm), the population is suffering from the poor Black Sea environmental state and is in IUCN Red List category ‘endangered’(Culik 2011); Fish populations under Sustainable Fishing and Agricultural Intensification are expected to increase and therefore provide more food resources for T. truncatus ponticus populations in the Black Sea. However, under Clear Water populations will continue to decline due to the lack of nutrition due to decreasing fish biomass.	Increase under Sustainable Fishing and Agricultural Intensification Decrease under Clear Water
Acipenser gueldenstaedti Acipenser nudiventris Acipenser ruthenus Acipenser stellatus Acipenser sturio	Increase of fish stocks under the Sustainable Fishing and Agricultural Intensification could provide some additional food for sturgeons. However, since food is not a limiting factor for these species, an increase in food availability would not restore their stocks. For recovery of sturgeon populations it is necessary to protect their key spawning and nursery habitats in the Danube, Dnieper, Rioni Rivers (CITES 1998).	No change
Huso huso	See Acipenser	No Change
Alosa caspia Alosa maeotica Alosa immaculata	Alosa species feed mainly on fish (anchovy, sprat) (BSC 2008). Anchovy and sprat populations under Sustainable Fishing and Agricultural Intensification are expected to increase (see modelling for Seafood) and therefore provide more food resources for Alosa species in the Black Sea. The most significant increase in anchovy and sprat populations (66 and 73%) is predicted under Agricultural Intensification. The biomass of anchovis and sprat is expected to decrease under Clear Water. This decrease is expected to translate into a decrease in Alosa species who feed on anchovis and sprat.	overall trend for Alosa positive under Sustainable Fishing and Agricultural Intensification; negative trend for Clear Water
Clupeonella cultriventris	Clupeonella cultriventis is a niche competitor of Anchovy and has similar habitat requirements. It is thus plausible that direction of change in Clupeonella biomass is the same as direction of change modelled for Anchovy under the ES Seafood.	Increase under Sustainable Fishing and Agricultural Intensification Decrease under Clear Water

5 Medicinal Resources

A literature review has been performed to identify Black Sea species that are subject to medical research or that have been identified to have positive health effects. To be considered as a potential medicinal resource here, it was sufficient that there are developments underway but it was not required that a treatment or pharmaceuticals are already available. The literature shows that several Black Sea marine organisms have the potential to serve as medicinal resources (Table A.8). When analysing whether these are affected by the assessed management scenarios, species that are usually grown in aquaculture, were considered unaffected.

Table A.8. Potential Black Sea Medicinal Resources, expected change in supply

Biological Group	**Species used in medical application**	**Explanation**	**Effects of management scenarios on ES provision**
Macroalgae	Coccotylus truncatus (Phyllophora brodiei) and Cystoseira barbata	These species of macroalgae are a mixture of green, brown and red seaweeds. Each of these species can be applied for their ability to supply amino acids, vitamins, and minerals (Vitalie 1986). Macroalgae are endangered species in the Black Sea and the extraction of Phyllaphora ssp. is prohibited (IUCN 2013, Milchakova et al. 2013)	Management scenarios associated with changes in nutrient loads (i.e Clear Water, Agricultural Intensification) can affect the macroalgae availability. Increasing nutrient levels can reduce macroalgae habitat (through increased turbidity and increased hypoxic areas and/or longer hypoxic events) while it remains constant under current nutrient levels and can increase when nutrient levels decrease.
Bivalvia	Mytilus galloprovincialis	This bivalve is used as an agent for cancer treatment and prevention ("Bipolan", see http://.bipolan.com.ua). Mytilus used for Bipolan production are grown in aquaculture.	Not affected because Mytilus used for Bipolan production are grown in aquaculture.
Ascidiacae	Molgula euprocta (Drasche)	M. euprocta produces anti-cancer agents (Rinehart 2000, Dalekaya 2010). This species is being mass cultivated to reduce wild extraction of individuals.	Not affected because M. euprocta are grown in aquaculture.
	Botryllus schlosseri (Pallas)	B. schlosseri produces anti-cancer agents (Rinehart 2000, Dalekaya 2010). This species is being mass cultivated to reduce wild extraction of individuals.	Not affected because B. schlosseri are grown in aquaculture.
Gastropoda	Rapana venosa	Medical compounds based on Rapana venosa are reported to have positive effects on burned skin and as supplement to diets (Badiu et al. 2008b, Badiu et al. 2010, Rodica et al. 2017).	The mollusks can be affected by changes in nutrient loads under scenarios Clear Water and Agricultural Intensification. A higher nutrient load (Agricultural Intensification) can increase abundance, growth rate, size and habitat extent of sea shell (Beukema and Cadée 1991, Wolowicz et al. 2006, Schmidt et al. 2017), however, if eutrophication causes hypoxic events, the sea shells are negatively affected (Diaz and Rosenberg 1995, Cebrian et al. 2014) Thus nutrient level changes can cause opposing effects on Rapana venosa. This makes it impossible to estimate a clear trend for the management scenarios considered.
Fish	Squalus acanthias	S. acanthias, referred to as the spiny dogfish, produces squalamine which is an anti-viral drug (Zasloff et al. 2011) and anti-angiogenic drug (Newman and Cragg 2004, Badiu et al. 2008a). Treatments against cancer, macular degeneration and control of weight have been reported (Newman and Cragg 2004, Brunel et al. 2005). This species is found in the Black Sea inshore and offshore and along the shelves and upper slopes.	This species could benefit from reduced fishing pressure. Different eutrophication levels (+/- 50%) as considered in the case study scenarios Clear Water and Agricultural Intensification could affect food availability for this species, as reported for the other fish species under ES Seafood. For Clear Water, there are two opposing trends, an increase related to reduced fishing pressure and a decrease due to reduced food availability. Hence, the direction of change is unclear for this scenario.

6 Ornamental Resources

Molluscs relevant as ornamental resources like Rapana venosa and Mytilus galloprovincialis can be affected by changes in nutrient loads under scenarios Clear Water and Agricultural Intensification. A higher nutrient load (Agricultural Intensification) can increase abundance, growth rate, size and habitat extent of sea shell (Beukema and Cadée 1991, Wolowicz et al. 2006, Schmidt et al. 2017), however, if eutrophication causes hypoxic events, the effect on epifaunal abundance is negative (Cebrian et al. 2014). Diaz and Rosenberg (1995) report about mass mortalities of benthic fauna in shallow parts of the Black Sea. As a result, the availability of ornamental resources can be reduced. Thus, there are opposing trends involved when nutrient levels change, making it impossible to estimate a clear trend for the management scenarios considered.

7 Air Purification

In the Black Sea area leafy coastal vegetation provides this ES. Changes in the nutrient loads or fisheries management as considered under management scenarios are expected to not affect the extent or quality of these habitats. Thus, the provision of this ES is expected not to change under these scenarios.

8 Climate Regulation

Three different processes have been considered as sub-services: (a) Carbon Sequestration; (b) N_2O release; (c) Dimethylsulphide release; (d) methane release.

8.1 Carbon Sequestration

Methodology

Marine ecosystems regulate anthropogenic CO_2 emissions by up-taking and burying the greenhouse gas. This assessment only considers processes that are contingent on the state of the marine ecosystem and involve biological processes (Böhnke-Henrichs et al. 2013). The solution of CO_2 in seawater, causing ocean acidification, is an abiotic process and is consequently not considered an ES.

The estimated air-sea CO_2 fluxes for 2007-2008 (FCO_2, mmol m^{-2} d^{-1}) in the Black Sea based on data from SESAME Project (2008) are: Southwestern Black Sea: -3.1±1.9 mmol m^{-2} d^{-1} (p CO_2 ppm =272±62); Central Black Sea: -0.3±0.4 mmol m^{-2} d^{-1} (pCO_2 ppm = 380±39); Northeastern Black Sea: -2.4±2.3 mmol m^{-2} d^{-1} (p CO_2 ppm =344±95). This means, the basin is a sink of CO_2. The surface chlorophyll-a records generally mirrored those of p CO_2 and a negative correlation exists between p CO_2 and chlorophyll-a, suggesting that the riverine nutrients loads enhance the biological activity and cause the drawdown of CO_2.

Biosequestration of CO_2 from the environment is related with growth of plankton microalgae species such as coccolithophores. The coccolithophores differ from other phytoplankton taxons by small calcium carbonate plates (coccoliths) that cover their cells (Balch et al. 1992). Coccolithophores are considered to be one of the main drivers of the biological carbon pump because their calcium carbonate coccoliths ($CaCO_3$) sink down to the sea floor and get deposited in sediments (Thierstein and Young 2004). This reduces the atmospheric carbon dioxide concentration and contributes to carbon sequesteration over geologic time scales. In contrast, organic carbon bound in biomass is subject to microbial decomposition and is released as CO_2 in rather short time scales (Gulin 2000).

An estimation of carbon sequestration changes under the three management scenarios could be done based on primary production (PP) of coccolithophores with the following assumptions:

a) carbon-specific photosynthesis rate does not differ between taxon groups;
b) contribution of coccolithophores to total phytoplankton biomass is not depth-dependent within upper mixed layer (i.e. equal to the ratio at surface);
c) calcification/photosynthesis ratio is close to 1 (Paasche 2001).

Carbon (C) sequestration in the Black Sea was assessed based on phytoplankton monitoring data in two stations (deep-waters and shelf) (Berseneva et al. 2004) and PP values were simulated by a regional model based on satellite data (Finenko et al. 2010). The average PP for the entire Black Sea basin (for the period 2000-2010) amounts to PP = 150gC$m^{-2}y^{-1}$ (Black Sea area = 423,000 km^2). The eutrophic northwestern shelf is the most productive area of the Black Sea. The average primary productivity for the shelf region near Danube delta is estimated at PP = 240 gC$m^{-2}y^{-1}$ (area of this particular region = 20,000 km^2). In the deep waters annual averaged C sequestration is ~ 4-5 % of total PP and in coastal waters ~ 8-10% of total PP. The basin average of C sequestration is ~ 7 % of total PP.

Our estimates here are in good agreement with a other model estimating PP in the northwestern shelf. According to Grégoire and Lacroix (2003) average PP in the northwestern shelf amounts to 220 gC$m^{-2}y^{-1}$ while average basin-wide PP amounts to 130 gC m^{-2} y^{-1})(Grégoire and Friedrich 2004). 12% thereof reaches the sediments according to modelling results (Grégoire and Lacroix 2003).

Results

According to the assumptions made for this ES, expected changes depend on changes in primary production (PP). Consequently, for Sustainable Fishing no change is expected.

For the other scenarios it is likely that 50% increasing PP in NW shelf (under Agricultural Intensification Scenario) or 50 % decreasing PP in NW shelf (under Clear Water Scenario) is related to about 10 - 15 % PP increase/decrease for the entire Black Sea basin. Whether the relative coccolithophore contribution to total annual PP is affected under these increases or decreases remains unknown due to lack of data. Here we assumed that the relative contribution of coccolithophores would not change. Consequently, a change in carbon sequestration could be interpreted and assessed as a change in PP. As mentioned above, this results in a 10 - 15 % increase under Agricultural Intensification and a 10-15% decrease under Clear Water. The confidence with this result is rather low, however, since in the past the intensity of coccolithophore blooms differed considerably between years. The underlying mechanisms are not yet understood.

Table A.9. Change in C sequestration under different management scenarios

Scenario	**Change in PP**	**Change in C Sequestration**	**Change in C Sequestration**
		Entire Black Sea	NW shelf
Sustainable Fishing	No change	No change	No change
Clear Water	50% decrease	-2163 kt C y^{-1}	-192 to -240 kt C y^{-1}
Agricultural Intensification	50% increase	2163 kt C y^{-1}	240 kt C y^{-1}

8.2 N_2O release

As a greenhouse gas nitrous oxide has a considerably higher impact than CO_2. It is emitted as a by-product of microbial metabolic processes in terrestrial and marine ecosystems. In the marine environment, its production and consumption is regulated in complex processes within different horizontal layers of the sea (Babbin et al. 2015). Availability of oxygen plays a crucial role in these processes (Walter et al. 2006). Babbin et al. (2015) argue that an increase in nutrient availability will stimulate primary production and as a consequence increase N_2O outgassing.

Because of the complexity of processes involved implications of the assessed management scenarios cannot be quantified but direction of change as suggested by Babbin et al. (2015) are as follows:

- Sustainable Fishing: no change (because of no change in primary production);
- Clear Water: reduced outgassing (due to reduced primary production);
- Agricultural Intensification: increased outgassing (due to increased primary production).

8.3 Dimethylsulphide release

Dimethylsulphide (DMS) is a semivolatile organic sulphur compound that accounts for 50–60% of the total naturally produced sulphur flux to the atmosphere, including emissions from volcanoes and from vegetation (Stefels et al. 2007). By providing 95% of the flux to the atmosphere, the oceans are the main source for DMS, with estimates of its emission ranging between 15 and 33 Tg S y^{-1} (Kettle et al. 1999). After emission to the atmosphere, this volatile sulphur compound is oxidised to sulphur dioxide (SO_2) and other products. From SO_2, non-sea-salt (nss) sulphate is produced, which can form sulphate (SO_4^{2-}) particles that act as condensation nuclei for water vapour. These nuclei affect the radiative properties of the atmosphere and clouds and thus affects climate. Higher numbers of condensation nuclei will reflect more incoming solar radiation back into space, thereby reducing the temperature on earth. The hypothesis that this process may modulate the greenhouse effect of increased anthropogenic CO_2 input to the atmosphere was indirectly supported by the modelling results of the effect of anthropogenic SO_2 input to the atmosphere (Andreae et al. 2005), but a quantitative understanding of all sources and sinks of atmospheric aerosols is still lacking.

Gondwe et al. (2003) calculated that the contribution of DMS to the total (global) atmospheric nss-sulphate burden is 18% and that it shows significant regional and temporal differences. For example, in the Southern Hemisphere its annual contribution is 43% and over the Southern Ocean it is 80% during summer.

DMS mainly results from the enzymatic cleavage of DMSP, a compound that is produced in several groups of marine phytoplankton, among which the most important are haptophyte taxa Phaeocystis sp. and Emiliania huxleyi. During the last decade the blooms of the coccolithophore Emiliania huxleyi emerge as a robust feature of phytoplankton alterations in the Black sea. Emiliana huxleyi dominates the assemblage especially in spring-summer months and accounts for 40-60% of the total abundance and biomass (Moncheva et al. 2006, Nesterova et al. 2008, Mikaelyan et al. 2011). However, reports on conditions that favour Emiliana huxleyi proliferation are rather contradicting. According to model simulations, the species flourishs after a diatomdominated bloom in March and a dinoflagellate-dominated bloom in April under nitrogen depleted conditions while the top-down grazing pressure is reported to control timing and intensity of E. huxleyi blooms (Cokacar et al. 2001, Cokacar et al. 2004, Oguz and Merico 2006). Based on a 40 years long-term data set Mikaelyan et al. (2011) found a close correlation between the phosphate content and the size of the coccolythophorids fraction in the total phytoplankton biomass. Kubilay et al. (2002) reported Methanesulfonate (MSA) and non-sea-salt (nss) sulfate concentrations, on average 42 ± 52 ng m^{-3} MSA, and 6.8 ± 5.2 µg m^{-3} nss sulfate and suggest that the majority of the biogenic contribution over the Eastern Mediterranean originated from summer coccolithophorid Emiliania huxleyi blooms developed in the Black Sea.

This above brief review of Black Sea DMS release shows that DMS emissions to the atmosphere are a result of ecosystem processes of very complex nature: different processes in production (such as species composition and abiotic factors and conversion of DMSP to DMS by algal and bacterial enzymes) and removal (removal of DMSP sulphur due to grazing, microbial consumption, sedimentation and photo-oxidation) make it difficult to predict temporal and geographical distribution patterns of DMS concentrations (Stefels et al. 2007). Amouroux et al. (2002) estimate an upper limit for Black Sea DMS emissions at 0.30 to 0.80 Gmol y^{-1}. However, it remains unclear how far and in which direction these emissions will change under any of the assessed scenarios. Because of the complex interactions and processes it is beyond the scope of this study to estimate changes in DMS release associated with assessed management scenarios.

8.4 Methane release

According to the review of Egorov et al. (2011), methane seeps in the Black Sea are widely distributed over the entire basin from the coastal to the open deep sea with 3297 identified locations. The highest density of these formations is reported to be 20 per m^2 and the maximum estimated yield amounts to 26,800 m^3y^{-1} methane at a single location. The composition of the methane seeps consist of methane (between 61-99.9%), Nitrogen (up to 20%) CO_2 (up to 10%) and H_2 (up to 2.5%). Methane released from deep sea locations totally dissolves in the water column and only methane-seep structures located at depth shallower than 250m represent a methane source to the atmosphere. For the Black Sea ecosystem the methane seeps are an important habitat that supports specific communities of symbiotic methane oxidizing archaea and sulfate reducing bacteria. In addition to its specific biodiversity the seeps form unique carbonate structures that play an important biochemical role as a barriers that reduce the methane flux to the atmosphere. However, still there are a lot of uncertainties both related to the research methodologies and to lack of scientific consensus about the origin of the gas seeps, gas hydrates resources in the Black sea and their potential vulnerability to seismic and volcanic activities. According to best available knowledge the management scenarios considered do not affect methane seeps, thus, no management induced changes in methane release are expected.

9 Waste Treatment

The Black Sea is considered an efficient sink for nutrients (Grégoire and Friedrich 2004) and nutrient loads are expected to change along with the changes in primary production (PP) as specified in the scenario descriptions. This suggests a change in the Waste Treatment ES.

It is estimated that with a 50% decrease or increase of PP (Clear Water and Agricultural Intensification respectively), the corresponding nutrient loads (DIN and DIP) double (Agricultural Intensification) or are reduced by 50% (Clear Water). We assume a linear relationship between nutrient loads and the amount of nutrients removed through burial or through denitrification. This means, Agricultural Intensification would correspond to an increase in nutrients removed and Clear Water would correspond with a decrease respectively. However, this change simply driven by a change in nutrient loads entering the Black Sea. Obviously, the more nutrients are present, the more can potentially be buried. This, however, does not describe the ES Waste Treatment because it does not consider the capacity of the ecological processes involved in the nutrient removal and how they are affected by the management considered. We thus focus here on ecological processes that are affected by the assessed management scenarios. Several processes are involved in the storage, burial and recycling of pollutants and nutrients in marine ecosystems. To analyse all of them is beyond the scope of this study. Here we focuses on the role of mussels.

Mussels are recognized worldwide as pollution bioindicators and used in Mussel Watch programs, because they accumulate pollutants in their tissues in relation to pollutant biological availability in the marine environment. The mussel’s bioaccumulation of metal depends on various factors, like type of food, hydrochemistry conditions, metal bioavailability, genetic differences, physiological state (Wang and Fisher 1997). Metals accumulate in higher concentrations in tissues directly exposed (gills, skin) or involved in detoxification (liver, kidney) and less in muscles. Numerous studies show that the chemical composition of bivalve shells may reflect human impact on the ecosystems (Protasowicki et al. 2008).

In the Black Sea, the bivalve Mytilus galloprovincialis contributes to the ES Waste Treatment. The filtering capacity of M. galloprovincialis can be affected by increased nutrient loads (Agricultural Intensification) that result in higher algal concentrations. The filtering activity of bivalves depends on the food concentration in the water. As a general rule, clearance and ingestion rates increase rapidly when particle concentration increases until the ingestion rate reaches a maximum. After this point, the clearance rate declines whilst the ingestion rate remains constant until the whole digestive apparatus collapses at a very high concentration of particles and the ingestion rate drops considerably (Pérez Camacho et al. 2000).

The reported filtration rate of M.edulis is high (about 30 ml min-1) at algal concentrations below about 6x103 cells ml^{-1}. At high algal concentrations of 1.3 to 2.4x104 cells ml^{-1} the filtration rate is considerably reduced (Clausen and Riisgård 1996). Whether this threshold for algae concentration in the Black Sea is usually exceeded, is unknown. For the Baltic Sea it has been reported that the available phytoplankton biomasses in nature, even in the eutrophic Limfjord (Riisgard and Poulsen 1981), usually does not exceed the concentration level at which the maximum filtration rate of the mussels is affected (Clausen and Riisgård 1996).

Hence, available knowledge suggests that the capacity of bivalves to improve water quality is probably not affected by current or reduced nutrient loads (Sustainable Fishing and Clear Water scenario). It is unknown whether a 50% increase of PP (Agricultural Intensification) affects bivalves and their capacity to contribute to the waste treatment ES.

A potential long-term effect under reduced PP (Clear Water) relates to an increase in waste treatment capacity due to a reduction in hypoxic areas. Those areas could be again occupied by filtrating benthic organisms. However, the time scale for such habiotat recoveries is unknown and no data are available on the extent of potential additional bivalve habitat.

10 Disturbance Prevention or Moderation

Habitat types like seagrass meadows, salt marshes or biogenic reefs have the capacity to reduce wave energy that reaches coasts. This reduces damages at the coast and protects human lifes. For salt marshes and biogenic reefs no direct effects of nutrient loads or introduction of fishing mortality at maximum sustainable yield have been identified. It may, however, still be possible that specific more local measures taken under the proposed scenarios result in changes of this ES. For instance, coastal wetlands may be restored to help reduce nutrient loads. Those wetlands would at the same time help to prevent or moderate extreme events. The regional sea scale of this assessment, however, does not specify measures at that level of detail.

For seagrass meadows effects due to changing nutrient loads are likely. Increased nutrient loads have been reported to reduce seagreass extent in various seas while decreased nutrient loads have the potential to restore seagrass meadows (Boesch 2002, Burkholder et al. 2007). Thus, the management scenarios are expected to affect this ES as follows:

- Sustainable Fishing: no change (due to constant nutrient loads/primary production);
- Clear Water: increase (due to decresed nutrient loads);
- Agricultural Intensification: decrease (due to increased nutrient loads).

11 Coastal Erosion Prevention

Habitat types like sea grass meadows and salt marshes can bind sediments, affect local current patterns and can reduce or prevent coastal erosion. Increased nutrient loads have been reported to reduce seagreass extent in various seas while decreased nutrient loads have the potential to restore seagrass meadows (Boesch 2002, Burkholder et al. 2007).

Thus, the management scenarios are expected to affect this ES as follows:

- Sustainable Fishing: no change (due to constant nutrient loads/primary production);
- Clear Water: increase (due to decresed nutrient loads);
- Agricultural Intensification: decrease (due to increased nutrient loads).

12 Biological Control

In the Black Sea, a range of different outbreaks, invasions or blooms is observed. For assessing the ES Biological control this study focuses on two types of undesired events: jelly fish outbreaks and phytoplankton blooms. The following explanation and Table A.10 specify for each undesirable event the effects on humans, their biological control and direction of change under assessed management scenarios.

12.1 Management effects on Biological Control of Mnemiopsis leidyi

M.leidyi, especially in the first years of its introduction, affected tourism and clogged water intakes of vessels (Konsulov 1989). Large catches of this jellyfish split fishing nets and ruin the quality of the catch (Purcell et al. 2007). Ecosystem services related with food provision, biodiversity, aesthetic and recreational values, and nutrient cycling were affected.

Recently, population increases of Beroe ovata excert biological control on M. leidyi due to predation but there is still a negative impact by M.leidyi on mesozooplankton biomass in summer, particularly in the Western Black Sea (Kamburska et al. 2006). Mesozooplankton community inshore is more vulnerable to M. leidyi impact in summer due to a time-lag in B.ovata occurrence and its reproduction in the coastal area (Finenko et al. 2003, Kamburska et al. 2003). After the years of mass development in the 1990's and introduction of B.ovata, M.leidyi population has shown high year to year variability with no clear trend. Recently, M.leidyi blooms are rare and with lower intensity but still exist especially in the western Black Sea (Kamburska et al. 2006, Mihneva 2011).

A possible approach to further improve biological control of ctenophores (M. leidyi) is to reduce the existing high fishing effort on small pelagic fish. Small pelagic fish species are food competitors of M. leidyi. Increases of small pelagic fish biomass would reduce food available to M.leidyi and thus control their population.

How the assessed management scenarios affect M. leidyi biomass has been assessed by the Ecopath with Ecosim model (see section on Seafood methods). In this model, an increased input of nutrients (inorganic nitrogen and phosphorous) resulted in an increase of the total primary production and increased phytoplankton biomass. A reduction in fishing mortality of small pelagic fish has been helps small pelagic fish to compete against jelly fish (Sustainable Fishing Scenario). Under reduced primary production (Clear Water scenario) the biomass of opportunistic jelly fish is expected to decrease but also the biomass of small pelagic fish decreases which limits the top-down control of M. leidyi. Under the Agricultural Intensification scenario the increased primary production increases jelly fish biomass. The simultaneously increasing biomass of small pelagic fish could appear contradictory, however, the increase of small pelagic fish biomass is due to the sustainably-managed fisheries which ensures the increased resilience of the stocks in resource competition against jelly fish.

12.2 Management effects on control of eutrophication events and phytoplankton blooms

Phytoplankton booms directly respond to nutrient availability in seawater. Thus, under Clear Water reduced phytoplankton blooms are expected while under Agricultural Intensification increased phytoplankton blooms are expected. However, these changes are driven by antropogenic nutrient input to the Black Sea and are not related to ES changes. Not relationship has been identified between assessed management scenarios and the biological control of phytoplankton blooms.

Table A.10. Undesirable events in the Black Sea, the potential for their biological control and related management effects.

Undesirable event	Effects for humans	Control of this event (reduction in frequency, duration and extent)	References	Is the control affected by management scenarios?
Outbreaks of Mnemiopsis leidyi	Recreation experience, shipping (clogging water intakes), destruction of fishing gear	Controlled by Beroe ovata and small pelagic fish	Finenko et al. (2003); Shiganova et al. (2001); Gucu (2002); Daskalov (2002)	Sustainable Fishing: change in fishing improves top-down control of undesirable events due to increased predation pressure on zooplankton. Clear Water: nutrient management improves bottom-up control of zooplankton; improved top-down control due to Fmsy implementation. Agricultural Intensification: nutrient management impairs bottom-up control of zooplankton; improved top-down control due to Fmsy implementation
eutrophication/phyto plankton blooms	Recreation experience	Restoration of the level of top predators, mussel beds and macrophytes and sea grass beds to help restore the food-web function and ecosystem resilience; event also controlled not biologically but by nutrient loads	Daskalov (2002); Llope et al. (2011); Mee et al. (2005); Oguz and Gilbert (2007); Oguz and Velikova (2010); Oguz et al. (2012)	The improved control of phytoplankton is not caused by a improved ecosystem processes but rather bottom-up controlled by a reduction in nutrient inputs.

13 Lifecycle Maintenance

The approach applied for the assessment of Life Cycle Maintenance identifies whether commercial migratory species depend for their juvenile life stages, spawning or breeding on habitats in one Blck Sea country's territorial sea or Exclusive Economic Zone (EEZ) but are caught in another country's territorial sea or EEZ. For those migratory commercial species it is assessed whether the management scenarios affect the (spawning/nursery) habitat quality in one country, thus, affecting the catches of another country. Important to note that this ES is scale dependent and can vary depending on the spatial units relevant to an assessment. The spatial units used here are the territorial seas and EEZs of Black Sea countries. It is acknowledged that marine ecosystems also support the lifecycle of species that spend their entire lifecycle within one single spatial unit and are caught in that unit. However, considering this as a separate ES would double count benefits as catches in general are already captured under the Seafood ES.

In the Black Sea, Anchovy is the main migratory and commercially important species. Black sea anchovy is distributed across the entire Black Sea. In October-November it migrates to the wintering grounds along the Anatolian and Caucasian coasts in the southern Black Sea. In these areas it forms in November-March dense wintering concentrations which are intensively fished (Main catches of anchovy are related to Turkey). In the rest of the year anchovy occupies its usual spawning and feeding habitats across the sea with some preference to the shelf areas and the north-western part of the sea in Ukrainian, Bulgarian and Romanian EEZs. The north-western shelf is the largest shelf area and characterized by high productivity (Faschuk et al. 1995, Daskalov 1999).

However, according to another study carried out in the southern Black Sea (Turkey's EEZ) anchovy spawns also in that area (Niermann et al. 1994).

These different observations suggest that available knowledge on Anchovy spawning habitat and its location and distribution in the Black Sea is contradictory (Table A.11). While Ivanov and Beverton (1985) highlight the importance of north-western shelf habitats to support also catches in the Turkish EEZ, Niermann et al. (1994) emphasize the importance of spawning habitats in Turkish waters (Table A.11). Thus, available data are not sufficient for an assessment of this ES.

Table A.11. Relative importance of Black Sea Anchovy Spawning grounds

Country	Relative importance of anchovy spawning ground per country listed	Reference
Ukraine	According to: Ivanov and Beverton 1985 (40%) Niermann et al. 1994 (5%)	Ivanov and Beverton (1985) and Niermann et al. (1994) in Daskalov et al. (2012)
Romania	According to: Ivanov and Beverton 1985 (30%), Niermann et al. 1994 (5%)	Ivanov and Beverton (1985) and Niermann et al. (1994) in Daskalov et al. (2012)
Bulgaria	According to: Ivanov and Beverton 1985 (15%), Niermann et al. 1994 (10%)	Ivanov and Beverton (1985) and Niermann et al. (1994) in Daskalov et al. (2012)
Turkey	According to: Ivanov and Beverton 1985 (5%), Niermann et al. 1994 (70%)	Ivanov and Beverton (1985) and Niermann et al. (1994) in Daskalov et al. (2012)

14 Gene Pool Protection

The effects of changes in nutrient loads on this ES are unknown.

Effects of fisheries on commercial species evolution (i.e. their gene pool) have been reported (Garcia et al. 2003, Hard et al. 2008) but there is not sufficient evidence to determine any direction of change due to management scenarios. Thus, effects of management scenarios remain unknown.

15 Recreation and Leisure

Moncheva et al. (2012) emphasize the central importance of water quality for the tourism industry at the Bulgarian coast since water quality determines attractiveness for swimming and bathing. A study of Brown (1996) revealed that tourists associate the followingparameters with environmental quality: debris in the water, poor water clarity and oil in the water and on beaches. In their study on the Bulgarian coast, Taylor and Longo (2010) identified water quality as well as cleanliness of beaches as crucial for beach tourism and recreation. Thus, the management scenarios associated with changes in primary production can affect this ES (Table A.12). Besides beach recreation, the sub-ESs recreational fishing, SCUBA diving, and bird/whale/seal watching are considered and impacts of management scenarios are estimated (Table A.12). This assessment was also informed by the food web modelling as performed under the Seafood ES.

Table A.12. Management scenario effects on Recreation and Leisure.

Sub-ES	Effect	Effects of management scenarios
Recreational fishing	Changes in fisheries and nutrient management change the abundance of fish species	Sustainable Fishing: slight increase (more target species due to fisheries management) Clear Water: decrease (less target species due to strong reduction in nutrient availability) Agricultural Intensification: increase (more target species due to fisheries management and increased productivity and fisheries management)
SCUBA diving, beach recreation	Change in phytoplankton concentration changes the visual range and attractiveness	Sustainable Fishing: no change Clear Water: increase in visual range and thus recreation experience Agricultural Intensification: decrease in visual range
SCUBA diving, beach recreation	Change in jelly fish abundance affects the recreation experience	Sustainable Fishing: no change in zooplankton biomass Clear Water: decrease (i.e. improved recreational experience) Agricultural Intensification: increase in zooplankton biomass (i.e. declined recreational experience)
Bird/whale/seal... watching	Changes in nutrient loads and fish biomass change the abundance of target species	Sustainable Fishing and Agricultural Intensification: increase due to increase of food availability of target species Clear Water: decrease due to decrease of food availability of target species

16 Aesthetic Information

This ES considers water quality and jellyfish outbreaks. It is thus closely related to recreation and leisure and therefore not assessed separately.

17 Inspiration for Culture, Art and Design

It is not yet understood whether and how changes in ecosystem state drive this ES. Changes in this ES cannot be assessed based on knowledge available.

18 Spiritual Experience

A workshop with marine management experts from the Black Sea region indicated that a couple spiritual ceremonies and festivities are celebrated that relate to the Black Sea. Our assessment focuses on those that depend on sea water (and sea water quality) and the abundance of iconic species. Under Sustainable Fishing and Agricultural Intensification fish populations and iconic species are expected to increase while they are likely to decrease under Clear Water. In terms of sea water quality, improvements are expected under Sustainable Fishing and Clear Water while a decrease in sea water quality is likely under Agricultural Intensification. Thus, different aspects of this ES are contradictory. It is not yet understood whether and how management induced changes of fisheries and nutrients affect this ES and there is probably no direct and no linear link between spiritual experiences made at the Black Sea and changes in fish, iconic species or plankton (including jelly fish) abundance.

It is, however, worth noting that workshop participants identified the following ecological characteristics as relevant for the provision of spiritual experience: Littoral rock (including benthic flora and fauna), littoral sediment (including benthic flora and fauna), sublittoral rock (including benthic flora and fauna), sublittoral sediment (including benthic flora and fauna), the water column, and pelagic fish. Littoral Rock, the water column, demersal fish, and pelagic fish were identified to make the largest relative contribution to the delivery of this service, two of which (water column, demersal fish) are potentially affected by the management scenarios considered. Although this would need a much more in depth verification, it does highlight that this service may be more important than has been previously realised.

19 Information for Cognitive Development

It is not expected that changes in fishery and nutrient management affect research or environmental education in the Black Sea region.

20 Cultural Heritage and Identity

It is not yet well understood which components of the Black Sea ecosystem contribute to this ES. Fletcher et al. (2014) identified fish to be related with this ES in Turkey. Focusing on fish species only, the modelling performed under Seafood can provide an indication of potential changes of this ES under the assessed management scenarios (Table A.2). However, just as for the ES Spiritual Experience, it is not yet understood whether and how those changes in fish species affect this ES and there is probably no direct and no linear link. Thus, expected changes in fish species rather indicate a trend which informs Table A.13.

Table A.13. Potential scenario effects on the ES Cultural Heritage and Identity

Scenario	**Effects on fish species**	**Potential trend of ES**
Sustainable Fishing	increasing fish biomass	increasing
Clear Water	decreasing fish biomass	decreasing
Agricultural Intensification	Strongly increasing fish biomass	Strongly increasing

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Appendix 3.A

LIFE VIMINE

VENICE INTEGRATED MANAGEMENT OF INTERTIDAL ENVIRONMENTS

LIFE12 NAT/IT/001122

SURVEY

The importance of salt marshes in the lagoon of Venice

Within the framework of the **European project LIFE VIMINE**, the **University of Padua** (Italy) in collaboration with the **Foundation for Sustainable Development** (Netherlands) are carrying out a survey to understand the importance of salt marshes in the lagoon of Venice for the people.
By answering the questions of this survey, you will significantly help our research and contribute to the success of the project.

What is LIFE VIMINE?

LIFE VIMINE is an **European project** that aims to **reduce erosion of salt marshes in the northern part of the lagoon of Venice.** Salt marshes are areas mostly covered by vegetation, similar to little islands [Figure 1]. They are submerged during high tide. About 70% of the salt marshes of the Venice lagoon have been lost during the last century because of erosion [Figure 2]. LIFE VIMINE aims to stop this process by protecting these areas. These salt marshes are, due to their ecological importance, part of the Natura 2000 network, an European network of protected areas.

In particular, the LIFE VIMINE project aims to defend the salt marshes near the islands of Burano, Mazzorbo, Torcello and the Laghi wetland (Northern lagoon), through simple and lightweight protections that create the **smallest possible impact on the environment** [Figure 3, 4, 5] and **involving local people**, who know the territory.

Why this survey?

This survey is essential for the LIFE VIMINE project because it will allow us to **understand the importance of the salt marshes for the people who visit or live in or near the Venice lagoon**, and the preferences of these people about the management of the landscape.

Figure 1 - Flowering salt marshes of the Venice lagoon

Figure 2 – Erosion of a salt marsh in the lagoon of Venice

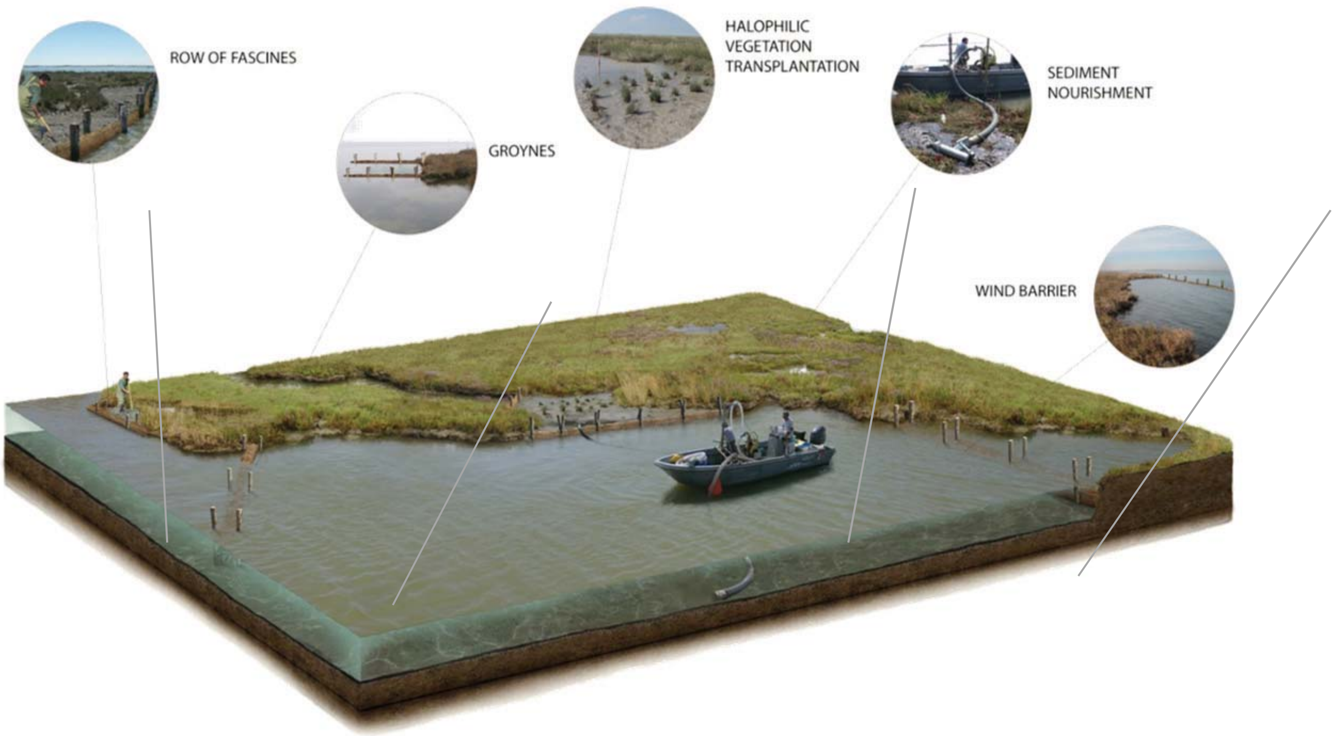

Figure 3 - The protection works of the salt marshes in LIFE VIMINE

Figure 4 - The fascines (wooden branches tied together with vegetable nets and cords) of LIFE VIMINE to protect salt marshes from erosion

Figure 5 - Fascines being placed to protect a salt marsh edge in LIFE VIMINE

Do you have questions or want to learn more about LIFE VIMINE?

Please do not hesitate to contact:

Alberto Barausse via email: alberto.barausse@unipd.it or phone +39 049 827 5528

Anne Böhnke-Henrichs via email: anne.boehnke-henrichs@wur.nl

Or visit the LIFE VIMINE website: **www.lifevimine.eu**

Thank you for taking the time for this survey!

The survey is anonymous, the collected data will be treated in accordance with privacy legislation (Italian Legislative Decree 196/2003).

Have you taken the first LIFE VIMINE salt marsh survey in summer 2015?

- ☐ Yes
- ☐ No

(A) **Personal values and perception of salt marshes**

1. I consider the environmental issue to be…

   Please tick one answer you agree with most.

   - ☐ An important issue to engage with
   - ☐ An issue that we have to worry about like other issues
   - ☐ Not important

2. Do you believe that the nature of the Venice lagoon can offer benefits useful for humans?

   - ☐ Yes
   - ☐ No

   2 a. If yes, in your opinion, how important are these benefits that the nature in the lagoon of Venice offers to human?

   - ☐ Very important
   - ☐ Moderately important
   - ☐ I am undecided
   - ☐ Rather not important
   - ☐ Not at all important

3. Have you already visited a salt marsh in the Venice lagoon? Please note, "visiting" here includes also trips with a boat in short distance to the salt marshes where you did not actually leave the boat.

   - ☐ Yes
   - ☐ No

   If yes, please answer the next questions in the survey about salt marshes with respect to your visits to the salt marshes **in the lagoon of Venice**. If no, please continue with question 7.

4. Why have you visited the salt marshes (or the waters surrounding them)?

   You can tick more than one answer.

   - ☐ To relax
   - ☐ To fish in my free time
   - ☐ To fish as part of my job
   - ☐ To hunt
   - ☐ To observe the nature
   - ☐ To lie at anchor
   - ☐ To enjoy the beauty of the area
   - ☐ I live there/I have a second home or garden there.
   - ☐ Other (please specify):________________________________

5. Where do you go when you visit salt marshes?

   Please identify your visiting spots by marking them with a circle on the map below. Salt marsh areas are displayed in green. You can identify 10 visiting spots maximum.

6. How often have you visited the salt marshes (or the waters surrounding them) in the past 12 months?

   Please tick the appropriate box.

   - ☐ I have not visited them
   - ☐ Once
   - ☐ 2-15 times
   - ☐ More than 15 times

7. In your experience, have the following environmental processes/components, decreased, increased or stayed constant in the lagoon compared to 10 years ago?

   Please indicate in the table below. If you observed changes of other environmental processes/components, please add them in the last lines.

	Increased	**Decreased**	**Constant**	**I do not know**
Erosion	☐	☐	☐	☐
Salt marsh surface (natural salt marshes only, not artificial ones)	☐	☐	☐	☐
Tidal flats surface	☐	☐	☐	☐
Depth of lagoon bottoms	☐	☐	☐	☐
Water quality	☐	☐	☐	☐
Air quality	☐	☐	☐	☐
Fish abundance	☐	☐	☐	☐
Molluscs (e.g. mussels, clams) abundance	☐	☐	☐	☐
Waves caused by vessel traffic	☐	☐	☐	☐
Length and width of natural channels	☐	☐	☐	☐
Abundance of terrestrial vegetation/plants	☐	☐	☐	☐
Abundance of aquatic vegetation/plants	☐	☐	☐	☐
Bird abundance	☐	☐	☐	☐
Waste	☐	☐	☐	☐
Water pollution	☐	☐	☐	☐
Landscape attractiveness/beauty	☐	☐	☐	☐
Other:	☐	☐	☐	☐
Other:	☐	☐	☐	☐
Other:	☐	☐	☐	☐

8. If you think salt marshes are eroding, please tell us why and mention, in the space provided below, the causes of erosion you think are most important. If you are not aware of any causes, please write “I do not know”.

   ____

   ____

   ____

9. Do you intend to visit or use the salt marshes (or the waters surrounding them) within the next two years?
   - ☐ Yes
   - ☐ No

   9 a. If yes, how do you intend to use the salt marshes (or the waters surrounding them) within the next two years?

   Please ***select*** *from the list below with a X up to three salt marsh uses. Only for the reasons you have selected with a X, please* ***rank them with a score from 1 to 3*** *(1 = least important, 3 = most important).*

Please select with a X	**Score (from 1 to 3)**	**Use of the salt marshes**
		To relax
		For fishing in my free time
		I am a fisherman and catch fish there as part of my job
		For hunting
		I go there to observe the nature (e.g. birds)
		To attend a guided tour to the salt marsh conservation works
		To lie at anchor
		To enjoy the beauty of the area
		I do not know
		I will use them in another way (please specify):________________________________

(B) Salt marshes benefits and management preferences

10. In your opinion, which of the following benefits are provided by the salt marshes to humans? How important are the benefits you have selected compared to each other?

    Please ***select*** *from the list below with a X the benefits that, in your opinion, the salt marshes provide to humans. You can select up to 6 benefits that are most important to you.*

    Only for the benefits you have selected with a X, please ***specify their importance with a score from 1 to 5*** *(1 = not important, 5 = very important).*

Please select with a X	**Score (from 1 to 5)**	**Salt marshes benefits**
		Food (for example fish, molluscs, birds)
		Filtering the air (thus, preventing health risks)
		Capturing greenhouse gases (thus, local contribution against global warming)
		Filtering the water (thus, preventing risks for human health and for the quality of water and seafood)
		Capturing sediments (thus, reduction of the amount of sediments affecting navigation)
		Preventing erosion of protected habitats (thus, saving money/efforts required for habitat protection and restoration)
		Reducing the open water areas in the lagoon thus, reducing wave energy, and protecting shores
		Support future availability of fish by maintaining the places where they live or reproduce
		Conservation of the variety of habitats and species typical of the salt marshes
		Opportunities for recreation (mooring close to salt marshes, observing flora and fauna, fishing, hunting, excursions, other)
		Inspiration for artists (paintings, music, design, other)
		Opportunities for education (environmental education)
		Contribution to the beauty and attractiveness of the lagoon
		Contribution to local communities' traditions
		Importance for local religious congregations and their spiritual traditions
		Other, please specify:

11. How important are salt marshes for the following aspects?

Please tick the appropriate boxes

	Not at all important	**Rather not important**	**I am undecided**	**Rather important**	**Very important**
Local education level					
Local/Traditional knowledge					
Local community's fellowship, trust, cooperation					
Visitor's and user's sense of care for nature and their commitment to protect nature					
Community identity (e.g. as fishermen community)					
Health and well-being of visitors and users					
Jobs in local communities					
Safety from flooding					

12. The salt marshes can change as a result of erosion and protection actions.

The first picture below represents the current situation of the salt marshes. The other pictures show three different scenarios of how the salt marshes could look like in the future. The scenarios vary in extent of salt marshes, number of birds, number and type of boats visiting them and intensity of fishing activities (the figures are sketches, we apologize if some details have not been represented in a realistic way).

In your opinion, how should the salt marshes look like in the future? When choosing, please consider also how this may affect the way you use or benefit from the salt marshes.

Please select your preferred scenario.

☐ **Current situation**

☐ **A**

☐ **B**

☐ **C**

What are **the most important reasons for your choice** in the previous question?

You can tick up to three boxes.

- ☐ The landscape/seascape is more **beautiful**
- ☐ There is more **seafood** available to **catch**
- ☐ The area is more **natural** and more suitable for **nature observation**
- ☐ The landscape is more suitable/attractive for **boating**
- ☐ The area supports the **local economy** better is a better source of **income/jobs** for people
- ☐ The landscape is part of **local traditions**
- ☐ The landscape is more suitable for **recreation**
- ☐ The landscape is more suitable for **nature education**
- ☐ **Water** will be **cleaner**
- ☐ The landscape **captures greenhouse gases** better
- ☐ Compared to the other scenarios, I expect to receive the most benefits from this landscape
- ☐ We have the **duty to protect threatened ecosystems** such as salt marshes
- ☐ I do not know
- ☐ Other (please specify):___________________________

(C) Value of salt marshes

13. In the previous questions, you have identified a number of benefits that, in your opinion, salt marshes provide. To maintain the salt marshes and the benefits associated with them, protection works should be performed over the years and a continuous maintenance of these works should be guaranteed. Without sufficient support, salt marsh protection cannot be continued.

14 a. Would you be willing to contribute to the salt marsh protection?

Please tick the appropriate box.

- ☐ Yes, I would be willing to support the maintenance work **in terms of money**
- ☐ Yes, I would be willing to support the maintenance work, but **during my free time** and not in terms of money
- ☐ Yes, I would be willing to support the maintenance work **in terms of money and during my free time**
- ☐ **Thanks but I would not be willing to contribute** to the salt marsh protection

If you indicated you would be willing to contribute during your free time,

14 b. How many hours per year would you be willing to contribute?
While choosing, please consider the benefits the salt marshes provide you with. Also consider the other activities that require your time (e.g. job, family, education, leisure, sport).

Please tick the appropriate box.

- ☐ 4 hours (= half day) per year
- ☐ 8 hours (= 1 day) per year
- ☐ 16 hours (= 2 days) per year
- ☐ Other (please specify): ________hours per year

If you indicated you would be willing to contribute in terms of money,

14 c. How much would you be willing to donate per year during the next 10 years to protect the salt marshes? Your donation would be used to fund salt marsh protection works over the years in the entire lagoon of Venice. The salt marshes of the lagoon have an extent of about 6500 football pitches. While choosing, please consider the benefits the salt marshes provide to you. Also consider your income and the expenditures you already incur (e.g. for your house, food, health, education, leisure). Without sufficient funding the salt marsh protection cannot be continued.

Please tick the appropriate box.

- ☐ 90 Euros per year (7.50 Euros per month) during the next ten years
- ☐ 70 Euros per year (about 5.80 Euros per month) during the next ten years
- ☐ 50 Euros per year (about 4.20 Euros per month) during the next ten years
- ☐ 30 Euros per year (2.50 Euros per month) during the next ten years
- ☐ 20 Euros per year (1.70 Euros per month) during the next ten years
- ☐ 15 Euros per year (1.30 Euros per month) during the next ten years
- ☐ 10 Euros per year (about 0.80 Euros per month) during the next ten years
- ☐ 5 Euros per year (about 0.40 Euros per month) during the next ten years
- ☐ Other (please specify): ________________EUR per year during the next ten years

If you indicated you would be NOT willing to contribute

14 d. Please specify below the reasons for your choice.

Please tick the boxes that are most important for your choice. You can tick up to two boxes.

- ☐ Financial or time limitations
- ☐ I do not think salt marshes are important
- ☐ I am against donations in general
- ☐ I do not trust that money would be spent appropriately
- ☐ Public authorities are responsible for nature protection
- ☐ Other (please specify): ___________________________________

(D) Knowledge of salt marshes

14. Please indicate if you agree or not with the following statements

	Agree	**Disagree**
Before taking this survey, I already knew a lot about lagoon salt marshes and the benefits they provide to humans		
The erosion issue in the lagoon of Venice was new to me before I took this survey		
I have learned a lot from this survey about the benefits salt marshes provide		
Before this survey, I was not aware of the benefits that salt marshes provide		

(E) Personal details

15. Why do you visit the city of Venice and its lagoon?

Please tick the appropriate box

- ☐ I am a resident or have a second home in the city of Venice
- ☐ I am a resident or have a second home in Burano, Mazzorbo, Torcello or neighbouring islands
- ☐ I am a resident in the Municipality of Venice, but not in the city of Venice and not in Burano, Mazzorbo, Torcello or neighbouring islands
- ☐ I own a boat in the lagoon of Venice
- ☐ I am a fisherman in the lagoon of Venice
- ☐ I am a tourist/visitor
- ☐ Other (please specify):___________________________

16. Gender:

- ☐ Female
- ☐ Male

17. What year were you born?

____

18. What is your regular occupation?

- ☐ Employed
- ☐ Freelance
- ☐ Unemployed
- ☐ Retired
- ☐ Student/in training

19. What is your profession?

____

20. What is the highest level of education you have completed?

- ☐ Elementary school
- ☐ Junior high school
- ☐ High school
- ☐ Vocational education
- ☐ University: bachelor degree
- ☐ University: master degree
- ☐ Doctoral degree

21. How many persons belong to your household?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ More than 5

22. Please specify the Municipality and Country where you live.

____

23. What is your annual household net income?

We are aware that this is a sensitive question. The survey is however fully anonymous and the information obtained with this question is required for statistical analysis so we would appreciate very much your answer.

- ☐ Below 15.000 EUR per year
- ☐ 15.000 – 30.000 EUR per year
- ☐ 30.000 – 55.000 EUR per year
- ☐ 55.000-75.000 EUR per year
- ☐ More than 75.000 EUR per year

Thank you for taking this survey.

We would like to emphasize that all the questions concerning your monetary contribution for salt marsh restoration (questions 14 a, b, c, d) are simply a scientific way to estimate the value of salt marshes and their benefits (the methodology is known as Willingness to Pay). It is actually NOT the intention to establish a salt marsh tax or fee.

PRIVACY

If you wish stay informed about activities of the LIFE VIMINE project, please fill in your contact details:

Name ______________________

Surname ______________________

Address ______________________

e-mail ______________________

Privacy agreement

I give consent to the processing of my personal data in an anonymous form for use in scientific research activities that will be carried out through the analysis of the collected questionnaires, in observance of the provisions of the Italian Legislative Decree 196/2003.

- ☐ *I AGREE*
- ☐ *I DO NOT AGREE*

I give consent to the processing of my personal data for the possible sending of information material, in observance of the provisions of the Italian Legislative Decree 196/2003.

- ☐ *I AGREE*
- ☐ *I DO NOT AGREE*

Place and date

Signature

Appendix 3.B

Trends of lagoon processes and components

Lagoon process or component	Trend *according to literature*	Targeted by education actions in VIMINE?	Comments	References
Erosion	Increase	Yes	*Data on past decades indicate strong and accelerating erosion. There is no reason to assume that this process has stopped.* *LIFE VIMINE addressed this aspect predominantly in its communication.*	D'Alpaos (2010), Sarretta et al. (2010)
Natural Salt marsh surface	Decrease	Yes	*Data over the past decades indicate a strong salt marsh surface decrease due to erosion. There is no reason to assume that erosion has stopped.* *LIFE VIMINE addressed this aspect predominantly in its communication.*	D'Alpaos (2010), Sarretta et al. (2010)
Water quality	Increase	Yes	*Nutrient discharge into the lagoon and nutrient and Chl-a concentrations in water and sediments have reduced same as anoxic events; decrease of heavy metal and organic micropollutant concentrations in sediments.* *LIFE VIMINE targeted water quality only occasionally. Concurrent project LIFE SERESTO also dealt with water quality*	Magistrato alle Acque di Venezia (2010), Solidoro et al. (2010), Bonometto et al. (2017)
Fish abundance	Decrease	Yes	*Artisanal fishery landings (characterized by a low discard rate) and landings per fisherman decreased in recent years.* *LIFE VIMINE targeted fish abundance only occasionally*, e.g. by stressing the dependence of fish on salt marsh presence.	Pranovi et al. (2013), Provincia di Venezia (2014), Clodia database (2017)
Mollusks abundance	Decrease	No	*Steady strong decline of clam and mussel production*	Provincia di Venezia (2014)
Waves caused by vessel traffic	Most likely increase	Yes	*Pleasure boats in the Northern Lagoon have increased. In Venice Port passenger traffic (including cruise traffic) increased from 1.4 to 1.9 million passengers from 2005-2014 while goods handled in Venice port decreased by 25% during that period.* *LIFE VIMINE did not deal with trends over time, but stated that motorboat waves are a problem.*	Consorzio Venezia Nuova (2016), ISPRA (2016)
Abundance of terrestrial vegetation	Decrease	Yes	*Terrestrial vegetation in the lagoon mainly comprises salt marsh plants. Data covering past decades indicate a strong salt marsh surface decrease due to erosion. There is no indication that erosion has stopped. Recently constructed artificial salt marshes are also covered with plants but do not compensate for natural salt marsh losses.* *LIFE VIMINE addressed terrestrial vegetation indirectly by telling about changes in surface of salt marshes which host halophyte vegetation.*	Carniello et al. (2009), D'Alpaos (2010), Sarretta et al. (2010)
Bird abundance	Increase	No	*Bird abundance and number of bird species in Venice Lagoon has increased recently, although some bird species have decreased.*	Scarton and Bon (2009), Basso and Bon (2016), Scarton (2017)
Water pollution	Decrease	No *see water quality*	*Nutrient discharge into the lagoon and nutrient and Chl-a concentrations in water and sediments have reduced, same as anoxic events; decrease of heavy metal and organic micropollutant concentrations in sediments.*	Magistrato alle Acque di Venezia (2010), Solidoro et al. (2010), Bonometto et al. (2017)

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Appendix 3.C

Coding scheme applied to analyse open-ended question on salt marsh erosion causes

Code	Explanation
Wave	More generally only 'waves' or unspecified currents mentioned; this code *excludes* responses specifying how waves were generated (i.e. boats/water taxi/cruise ships)
Boats	Waves caused by boats, boat traffic in general, increase in boat traffic or vessel size, too high velocity of boats, lack of compliance with speed limits; lack of enforcement of speed limits
Hydrodynamics	Alteration of lagoon hydrodynamics (dredging, jetties at lagoon inlets, increase of velocity of tidal flows, artificial channels, deepening of navigation channels, MOSE flood defense project); changes in water flow, increased currents, velocity of currents have been coded as "hydrodynamics" if respondents explicitly linked it to the altered lagoon hydrodynamics
MOSE	This project aims to protect Venice from high tides by movable barriers at each of the three lagoon inlets. The project is contested because it is expected to severely affect lagoon hydrodynamics. Where MOSE was mentioned explicitly, responses were coded both as Hydrodynamics and MOSE to understand whether and how perception of this project changed. Although VIMINE did not deal with MOSE impacts, we report it separately in the coding scheme (following its presence in the respondent's answers) given that it is a hot topic in the public debate on lagoon management in Venice.
Maintenance	Shore protection is not or not sufficiently maintained, thus causing erosion; lack of maintenance in general; lack of attention to landscape/ongoing processes, lack of monitoring
Sediment	Decrease in sediment availability and negative sediment budget, anthropogenic relocation or diversion of river beds
Wind	Wind causing waves; atmospheric/climate conditions in general (unspecified by respondents)
Vegetation	Decrease in vegetation, reduction/destruction of vegetation (both terrestrial and benthic)
Sea level	Rising sea level
pollution	Reduced water quality, contamination/pollution of water or soil, waste
Tide	High tide in general, exceptional high tides and their increased frequency, increase in tidal amplitude, tidal current with unspecified causes
fish	Fishing activities (commercial and non-commercial) destroying lagoon bottoms and salt marsh surface and unspecified fishing activities
Other	Reasons mentioned by not more than 5 respondents, e.g. subsidence, erosion, air pollution, alien species, river discharge, lack of awareness, off topic remarks

Appendix 3.D

Comparison of respondents characteristics between first and second survey and with population of Venice/Veneto region

Respondent characteristic	**2015**	**2017**	**p-value and test statistics** ***(W – Welch's two sample t-test; F – Fisher's exact test)***	**Comparison with population socio-demographic statistics for Venice/Veneto**
Sample size	109	236		
Age (mean (SD))	47.1 (15.1)	49.2 (14.4)	p=0.2171 [W]	45.9[a]
Gender (% female)	44.0	41.5	P=0.725 [F]	51.6[a]
Education level				
% High school	79.2	87.7	p=0.05038 [F]	
% Master degree	48.1	48.9	p=0.8166 [F]	
Annual HH income (EUR (SD))	29,905 (15,011)	31,149 (18,037)	p=0.5536 [W]	32,973[b]

a Data for Province of Venice, Year 2016 (latest available year); source: https://ugeo.urbistat.com/AdminStat/en/it/demografia/dati-sintesi/venezia/27/3

b Data for Veneto region, Year 2015 (latest available year); source: http://dati.istat.it/Index.aspx?lang=en&SubSessionId=78ff9fa6-9508-4cc7-a0cb-a4db20b1fffe#

Summary

Healthy marine ecosystems are essential for human well-being because they sustain livelihoods, shape traditions and identity of coastal communities, provide food, moderate extreme weather events or mitigate effects of anthropogenic climate heating by uptaking and storing carbon dioxide. These ecosystem contributions to human well-being are conceptualized as ecosystem services and certainty and scientific consensus increases that they are at risk due to globally degrading marine ecosystems.

International policies have responded to the decline of marine ecosystems. In Europe, the Marine Strategy Framework Directive sets the frame for conserving and sustainably using European seas. The directive aims at biologically diverse and dynamic seas that are clean, healthy and productive. To implement these aims, the Directive requires to adopt an Ecosystem Approach to marine management. This approach is characterized by the so-called Malawi Principles which also reflect several challenges involved in implementing this approach. For instance, human pressures that degrade marine ecosystems need to be reduced to sustainable levels, the preferences of stakeholders and society in general, need to be considered in management decisions, and management effects on ecosystem services need to be taken into account. These three challenges are addressed by my thesis which aims to develop, adapt and apply marine ecosystem service assessments and to understand how these assessments assist to achieve the policy goal of healthy seas. I approach this objective by three case studies in the Black Sea, in the Mediterranean Sea and in the North Sea. The Black Sea case study seeks to understand how the management of two important human pressures, high nutrient loads and unsustainable fisheries, affects the supply of marine ecosystem services. The Mediterranean case study analyses preferences of local residents for salt marsh management and their demand for ecosystem services in the Venice lagoon. The North Sea case study explores how the methods to analyse ecosystem service supply and stakeholder preferences and their ecosystem service demand can be combined for a more comprehensive understanding of management implications. These three case studies apply a similar marine ecosystem service typology at different spatial scales to assess management effects on marine ecosystem services.

Chapter 2 develops a marine ecosystem service typology with a particular focus on sustainable marine management that restores habitats or reduces human pressures. Such measures improve ecosystem processes and functions as prerequisites for ecosystem service supply. To reflect ecosystem service supply changes, my typology includes only those marine aspects that depend on ecosystem processes and functions. This implies to exclude from the typology marine aspects that are purely abiotic or utilize the so-called carrier function of marine ecosystems. Abiotic marine aspects are, for instance, seawater (in case its use or extraction is dependent solely on quantity), or sediments that depend on physical weathering processes. The carrier function relates to the use of marine space or abiotic components as media, like use of the sea floor to place infrastructure or surface water as ‘carrier’ for transportation (ships). My thesis applies its marine ecosystem service typology to assess marine management effects in three different case studies in the context of the EU’s Marine Strategy Framework Directive and the EU’s Habitats Directive. All three case studies assess ecosystem services at different spatial scales that range from the entire regional sea to a sub-regional part of the North Sea, to a local case study on a part of a Mediterranean lagoon. The typology proved for all these different policy contexts and

spatial scales sufficiently comprehensive and flexible but required adaptations to specific assessment conditions. For the indicator-based assessment, the typology was refined by distinguishing particular sub-ecosystem services. For the survey-based assessment, the terminology of the particular ecosystem service definitions and descriptions were re-phrased to avoid technical terms and improve comprehensibility by interviewees.

The ecosystem service typology assists in structuring and guiding the ecosystem service assessments regarding which ecosystem services to include. Moreover, a joint typology can facilitate the transfer of assessment methods (e.g. ecosystem service indicators) and the comparison of assessment results (e.g. to integrate findings from different assessments). However, even an agreed general typology leaves room for interpretation that can question the comparability of different assessments. Particularly the Black Sea case study illustrates that each ecosystem service is linked to a number of sub-services. This makes it unlikely that different assessments investigate the same and thus comparable sub-services. To apply a general, pre-defined ecosystem service typology can also involve the risk to restrict an assessment because even a comprehensive typology may fail to capture very specific local ways of how ecosystems contribute to human well-being.

To summarize, ecosystem service typologies can be a very useful tool that should be carefully applied. Even comprehensive typologies most likely need adaptation to case study conditions. Perhaps even more relevant than a general typology is to agree on what is to be considered an ecosystem service (and what not)? Particularly regarding purely abiotic ecosystem components and the carrier function, current typologies reveal large disagreement.

Chapter 3, aims to understand how nutrient and fisheries management affect marine ecosystem services in the Black Sea. This chapter also considers the cumulative effects of both management aspects. The study compares three different management scenarios that combine fishing at maximum sustainable yield with different levels of primary production (that reflects the Black Sea's eutrophication status). The study reveals trends of marine ecosystem service supply under the three management scenarios at the scale of the entire Black Sea. The study developed a set of indicators for ecosystem processes, functions and ecosystem services and mapped how these indicators are interlinked in ecosystem service supply. Results suggest that sustainable fisheries management is most favourable from an ecosystem service perspective, because it involves many ES increases and the least decreases. However, this is a rather tentative result due to remaining knowledge gaps.

This chapter concludes with recommendations for ecosystem service assessments in the context of the Marine Strategy Framework Directive and beyond: (1) To deal with knowledge gaps, marine ecosystem service assessments should combine qualitative and quantitative methods and an interdisciplinary team that includes several regional sea experts is crucial; (2) to split up ecosystem services into several sub-ecosystem services increases the specificity of the assessment; (3) to analyse cumulative management effects is relevant for identifying synergies and useful antagonistic effects. To combine such synergistic and antagonistic effects smartly can assist in alleviating negative management outcomes.

Chapter 4 analyses how participatory salt-marsh restoration affects local residents' appreciation of salt marshes and their support for conservation. This study surveyed local residents twice at an early and at the final stage of a restoration project and compared the results of both surveys. Results suggest that salt marshes are widely appreciated in the Venice lagoon region and are associated with nature conservation but also with a range of different ecosystem services and social benefits. This appreciation increased between both surveys and the participatory restoration approach is supposed to have contributed to this increase. Results further show a general understanding and acceptance that salt marsh conservation and restoration comes at a cost because they express a willingness to pay for restoration, to support restoration works in their free time and to accept restrictions in fishing and boating. Despite this overall support for restoration, a coherent, lagoon-wide and long-term funded salt marsh management scheme is lacking so far, although these protected habitats are disappearing at high rates. This chapter presents suggestions on how this pressing challenge in Venice lagoon management can be addressed: (1) Salt marsh management benefits from involving local residents. (2) Information and education measures should accompany salt marsh conservation to ensure long term conservation support. (3) Spatial zoning can be used to solve conflicts between different saltmarsh uses and conservation.

Chapter 5 applies three different methods to understand the effects of nature conservation, offshore wind farm construction and fisheries on the Dogger Bank (North Sea) and aims to understand how these different methods can be combined for a more comprehensive understanding of management implications. The three methods involve an indicator assessment to understand ecosystem service supply, a Discrete Choice Experiment to reveal ecosystem service demand and a Citizens' jury that reveals the public's management preferences for the Dogger Bank. Integrating the findings of such different methods proved challenging because they differ regarding the ecosystem services covered and regarding their output units. These differences hamper a smooth comparison of individual ecosystem services' supply and demand. Instead, findings were integrated based on their major management implications for the three management foci: conservation, fisheries and wind farms. All three methods largely agree in favouring conserving the Dogger Bank. Results for the other management foci are, however, rather mixed. Yet, even contradicting results can still provide valuable information to management decisions because they highlight management issues that require attention and can also reveal underlying reasons for management conflicts. For instance, publics' perception of fisheries as the historically legitimate use of the Dogger Bank is potentially one reason why fisheries restrictions are difficult to achieve. In contrast, insights gained from the ecosystem service-supply assessment suggest that many ecosystem services suffer from fisheries. This exemplifies that applying and integrating different methods improves the basis for decision making and is thus relevant for marine management.

My thesis shows that ecosystem service assessments provide information that is relevant for improving marine management. However, marine management decisions in Europe frequently lack consideration of ecosystem service implications. Since current management approaches failed to preserve our life-sustaining oceans the application of the ecosystem service concept offers a way forward to turn the tide in marine ecosystem management towards more healthy seas.

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About the author

Anne Böhnke-Henrichs was born in October 1981 in Magdeburg, Germany and grew up in Berlin. Observing and protecting nature and the environment always accompanied her life. Aged eleven a key moment shaped her philosophy of life: After having eaten an apple she was about throwing the apple core into the more conveniently accessible residual waste bin instead of the proper organic waste bin in about 10 meters distance. She paused when imagined the huge amount of apple cores if 1 million people behaved similarly lazy and thus made the extra effort to the proper waste bin. Since that moment this principle of what she later recognized as Kant's Categorical Imperative became the fundamental basis of her decision making.

After school and a gap year with the environmental NGO Grüne Liga, Anne studied Geoecology at the University of Potsdam. Her diploma thesis evaluated the management planning under the EU Habitats Directive in Germany. During an ERASMUS fellowship, she studied several months at Wageningen University where she took the 'Regional management course' led by Dolf de Groot and got enthusiastic about the ecosystem services concept because of its potential to improve, how nature conservation is considered in spatial planning and land- or sea-use decision making. Together with Dolf at the Environmental Systems Analysis group at Wageningen University she worked on a WWF-funded project to estimate how the re-opening of a locked distributary in the Dutch Southwestern Delta would affect ecosystem services. Afterward, she worked on the ODEMM project (https://odemm.com) and started her PhD thesis under the supervision of Rik Leemans and Dolf de Groot. She continued her work at Wageningen University during the VECTORS project (https://www.marine-vectors.eu) and switched to the Foundation for Sustainable Development for the LIFE VIMINE project (http://www.lifevimine.eu /lifevimine.eu/index.html). Since 2017 Anne works on marine conservation with the German environmental NGO NABU. There she is mainly concerned with assessing environmental impacts of offshore infrastructure projects and argues with public authorities, policymakers and at court to achieve conservation and sustainable use of the seas.

Within the Ecosystem Services Partnership (https://www.es-partnership.org) Anne was part of the first steering committee and supported the Working groups 'Marine Biome' and 'Application of ES in Planning and Management'. Together with three colleagues she is the founding mother of the Young Ecosystem Services Specialists Group (YESS) and co-led the group from 2011 to 2014. In 2017 Anne has been elected to the executive committee of the environmental NGO 'Grüne Liga Berlin' (https://www.grueneliga-berlin.de/).

Anne is a mother of three wonderful sons and lives with her family in Potsdam.

List of peer-reviewed publications

Börger, T., A. Böhnke-Henrichs, C. Hattam, J. Piwowarczyk, F. Schasfoort & M. C. Austen. 2018. The role of interdisciplinary collaboration for stated preference methods to value marine environmental goods and ecosystem services. Estuarine, Coastal and Shelf Science. 201, 140-151.

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SENSE PhD Courses

- Integrated assessment of ecosystem Services: from theory to practice (2011)
- Environmental research in context (2013)
- Research in context activity: 'Contribute to research proposals: FishConnect and ForeSEE' (2015)

Other PhD and Advanced MSc Courses

- Teaching and supervising Thesis students, Wageningen University (2013)

Management and Didactic Skills Training

- Supervising three MSc students with internship (2012-2014) and one BSc student with thesis 'Evaluation Aktueller Managementpläne von Fauna-Flora-Habitat-Gebieten in Deutschland' at University of Potsdam (2013)
- Lecturer and developer of practical for the MSc course 'Regional Management' (2012)
- Establishing (2011) and managing (2011-2014) the international network 'Young Ecosystem Services Specialists' (YESS)
- Support management of working groups of the Ecosystem Services Partnership: 'Application of ES in Planning & Management', 'Cultural services & Values' and 'Marine Systems' (2012-2015)
- Co-organising and co-hosting the workshop 'Using the ES Framework as a catalyst for restoration - opportunities and obstacles' at the Ecosystem Services Conference in Antwerp, Belgium (2016)
- Member of the Steering committee of the Ecosystem Services Partnership (2013-2017)

Selection of Oral Presentations

- *Restoration Pays! The case of the Dutch South-West Delta restoration. International ESP conference, 4-7 October 2011, Wageningen, The Netherlands*
- *Integrating Ecosystem Services in Marine Spatial Planning. VALMER Workshop, 6-8 November 2012, Brest, France*
- *Ecosystem Services in Landscape Planning. VILM Workshop AK Landschaftsplanung, 27-29 November 2014, VILM, Germany*
- *Where offsetting schemes fail to avoid biodiversity net loss - current examples from the North Sea and Baltic Sea. World ESP Conference., 21-25 October 2019, Hannover, Germany*

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