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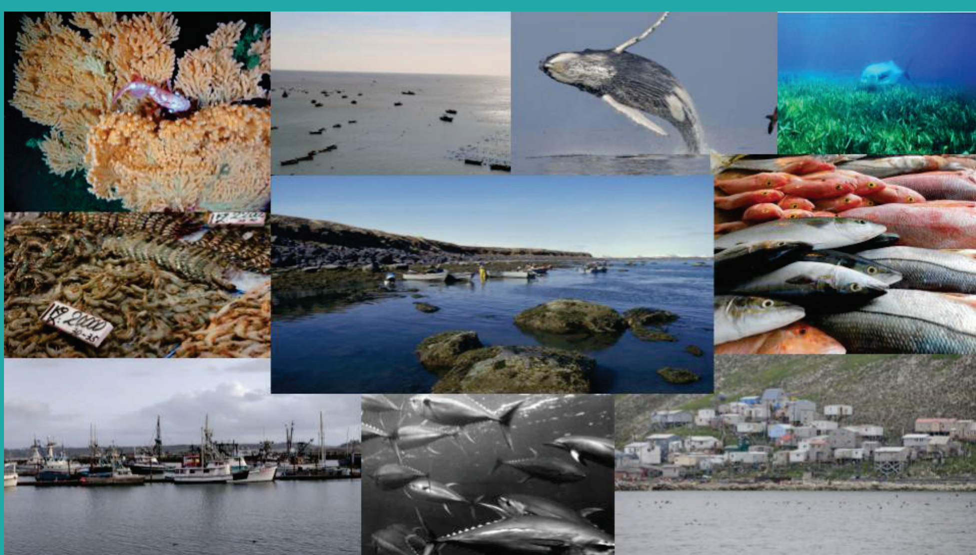

Report of Working Group 41 on Marine Ecosystem Services in the North Pacific

NORTH PACIFIC MARINE SCIENCE ORGANIZATION

PICES

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Report of Working Group 41 on Marine Ecosystem Services in the North Pacific

edited by
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Front cover:
Clockwise from top left: Soft coral *Primnoa pacifica* providing habitat for rockfish (Image credit: Ed Bowlby, NOAA/Olympic Coast NMS; NOAA/OAR/Office of Ocean Exploration); Sanggou Bay, Rongcheng City, Shandong Province (Image credit: Jingmei Li); a humpback whale in a graceful arc as it begins its descent to the sea from a near vertical breach (Image credit: Elliott Hazen NMFS/SWFSC/ERD); healthy seagrass with a jack in the background (Image credit: Heather Dine); fish market catch (https://www.rawpixel.com/); Little Diomede Island village, Alaska (Image credit: Crew and Officers of NOAA Ship *Fairweather*); Yellowfin tuna *Thunnus albacares* (Image credit: William L. High); Port of Newport, Oregon (Image credit: Dan Lew). Middle: Roe herring fishery at Summit Island, Alaska (Image credit: Allen Shimada)

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Table of Contents

Acknowledgements

We wish to acknowledge and thank all the participants who attended topic sessions, workshops, and meetings related to the PICES Working Group on *Marine Ecosystem Services* (WG 41/WG-MES). We also wish to thank the Human Dimensions (HD) committee and FUTURE program for their valuable support. Lastly, we acknowledge Study Group on *Marine Ecosystem Services* Chair and WG 41 Co-Chair, Professor Shang "Sunny" Chen, for his encouragement and leadership. Without his significant efforts, WG 41/WG-MES would not have been possible.

Executive Summary

This report is a product of the PICES Working Group on *Marine Ecosystem Services* (WG 41/WG-MES). Established in 2017, the Working Group was charged with facilitating exchange of information about marine ecosystem services (MES) in North Pacific waters in order to promote ecosystem service science and improve the consideration of MES in decision making related to marine integrated management. In coupled human and natural system models, ecosystem services (ES) serve as an important link between ecosystems' functions and human well-being. In broad terms, ecosystem services are the direct or indirect benefits to humans provided by nature. A common classification divides ES into four types: provisioning, regulating, cultural, and supporting services. Provisioning services are produced by the ecosystem and used directly by humans (*e.g*., seafood and raw materials). Regulating services are ES that benefit humans by regulating ecosystem processes and include, for example, climate regulation, water purification, and pollination. Cultural services are those that provide non-material benefits to humans, such as those that provide recreation, spiritual or religious, inspirational, educational, or cultural heritage benefits. And finally, supporting services are those services necessary for the production of all ecosystem services but are not themselves ones that directly benefit humans. The report provides an overview of MES in the North Pacific, which for our purposes are inclusive of ecosystem services associated with off-shore marine and nearshore coastal and estuarine environments.

We include sections presenting the concepts and classifications for MES, an overview of assessment methods, a review of MES literature pertaining to aquaculture ecosystem services in several North Pacific nations, and the results from surveys conducted to understand how scientists and decision-makers in PICES member countries view and use information on MES and their values. Our review of the literature of ES and MES reveals a growing literature that has accelerated in the past two decades and one in which definitions and classifications have been evolving towards ones that allow for operationalizing the concepts in analytic frameworks to inform decision-making.

The examination of ecological, economic, and sociocultural assessment approaches underscores two common themes shared between the different scientific disciplinary perspectives: (1) within each discipline, there is a diversity of approaches one can take to assess MES and (2) often multiple approaches are needed to accurately assess them. In the ecological context, the diverse ways in which biodiversity, ecosystem health and resilience, and ecosystem functions manifest dictate the need to employ a range of different ways of monitoring, mapping, modeling, and forecasting MES. In economics, this latter point translates to combining data sources in common utility-theoretic models of choice or behavior to better represent the underlying preferences and economic values. In sociocultural contexts, the diversity of types of values being assessed mandates a multifaceted approach that depends upon the particular setting being analyzed, including the particular social and cultural contexts involved and the relationships individuals and groups have with each other and with nature.

A comparison of the literatures on aquaculture-related ES in PICES member countries indicates a modest amount of research on the topic in Canada, China, and Japan, with fewer than 10 studies being found in those countries. The U.S. literature consisted of 41 studies. These bodies of literature cover an array of species and ES, but with very unequal coverage. There is significant disparity between the countries in this report in the volume of published research, and within countries geographic gaps are identified. In relation to the types of ecosystem service studied, there are large differences in the depth and breadth of the literature. Cultural ES are rarely considered, while the regulating service of eutrophication mitigation is by far the most frequently studied.

Surveys of scientists and decision-makers were conducted to collect information about attitudes and knowledge about ES and their values (ESV) in Canada, China, and the U.S. The results indicated that familiarity with ES was high in all three countries, with a majority of respondents in each country having had some experience or exposure with ES values in their work. In all three countries, respondents indicated they used ESV to support a range of activities, including information and analysis, to support decision-making. Each country's survey included opinion questions related to ESV. Respondents were asked to indicate the level to which they agreed or disagreed with a series of statements related to the use and potential limitations of ESV. The results for Canada and the U.S. were broadly similar and indicated support for ESV information for ES that are central to the mission of their respective agencies. However, responses from the survey in China indicated that some types of economic values (specifically non-use values like existence values) were not used, due in part to concerns over the uncertainty of the methods and accuracy of the estimates for these types of economic values. In general, however, the surveys indicated support for the use of ESV information in fisheries and ocean management.

The specific terms of reference (TOR) for the Working Group are the following:

1. Review MES studies of North Pacific marine ecosystems, identifying the scientific tools and methodologies employed, and the role these studies have played in policy analyses, management, or natural resource damage assessment.

2. Develop a typology of marine ecosystem services, tools and methodologies (*e.g.*, environmental accounting/natural capital, non-market values, replacement cost/Natural Resource Damage Assessment, productivity change methods, *etc*.) that can be used to analyze marine ecosystem services, and the strengths and weaknesses of those tools and methodologies.

3. Illustrate (2) by applying two or more methods to the assessment of marine ecosystem services in identical case studies in multiple regions of the North Pacific.

4. Collaborate with WG 36 (Common Ecosystem Reference Points) and WG 40 (Climate and Ecosystem Predictability) to explore development of an indicator-based framework to study the resilience of social ecological systems and to advance integration envisioned in the FUTURE science program.

5. Complete a detailed technical report on the results of the analyses detailed in TORs (1), (2), and (3) and scoping requested in (4). The report should include practical recommendations for characterizing the status and trends of marine ecosystem services in the North Pacific. In addition, the WG will contribute articles on ecosystem services to PICES Press.

This report directly addresses TOR 5, but also fulfills the other TORs. Section 1 addresses TOR 2 by reviewing typologies of ecosystem services. Section 2 focuses on TOR 1 by providing a comprehensive overview of methods to assess marine ecosystem services. Section 3 fulfills TOR 3 by presenting a comparative review of aquaculture-related ecosystem services across multiple PICES member countries. Section 4 presents the results from surveys of key participants in ecosystem service science and/or management in several PICES member countries, and thus further contributes to fulfillment of TOR 3 and our understanding of how ecosystem services and their values are viewed in the North Pacific. The collaborative elements of TOR 4 are captured through participation and contributions by Working Group on *Common Ecosystem Reference Points across PICES Member Countries* (WG 36) and Working Group on *Climate and Ecosystem Predictability* (WG 40) members in WG 41's activities.

Key recommendations

MES should be assessed from multiple disciplinary perspectives in an open and transparent way. A key area for future research is developing frameworks for the integration of MES assessments conducted from the ecological, economic, and sociocultural perspectives. There is clearly a need to more fully understand the set of values that need to be assessed (*e.g*., relational values) and how these values can be incorporated meaningfully in evaluation frameworks. This also points to open questions about the extent to which MES assessment information can and should be compared and contrasted, and when it is appropriate to do so. Viewing and evaluating MES from a variety of scientific disciplinary perspectives can provide an array of information that stakeholders and policy makers at many levels may find valuable in better understanding the relationships humans and the environment have with one another and that can be useful when considering actions and policies that affect ecosystems and their services. Maintaining an open dialogue about the benefits and limitations of the assessments used, as well as the processes to determine which one to use, is a crucial step in informed decision-making in the North Pacific.

A holistic approach should be taken with respect to MES in the North Pacific. The comparison of the published literature on aquaculture-related ecosystem services indicates a number of gaps in geographic coverage and types of ES studied. There is also a scarcity of studies presenting economic value information, even for provisioning ecosystem services for which monetizing the ES benefits is more straightforward. Moreover, sociocultural value information on MES was rarely examined in the literature. At the same time, the belief that information about many types of MES for policy and management is useful in the policy and management process was a sentiment shared by most respondents in the three countries surveyed. This suggests that MES information will be welcomed by analysts, scientists, and decision-makers and can help improve decision-making in the management of the ocean and its resources in PICES member countries. Taking a holistic approach to the study of MES to capture their diversity and their associated values and applying this information in integrated marine management can lead to a better accounting of the benefits that nature provides to people and improve ocean management decisions.

1 Marine Ecosystem Services: Concepts and Classifications

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1.1 Introduction

The relationship between the natural environment and human-based social, economic, and cultural systems has long been of academic interest to researchers in many disciplines, but a shift to formally recognize, model, and analyze human actions and environmental processes within integrated frameworks that recognize the connectivity and interdependence of these systems has been a more recent development (Daily, 1997). In the past two decades, a variety of conceptual frameworks that recognize the relationships between humans and the natural environment have arisen, many from efforts to adopt an ecosystem-based approach to management (Grumbine, 1994; Yaffee, 1996). While early frameworks generally limited inclusion of human dimensions to decision-making or socio-political processes, later models included considerations for a fuller set of human dimensions (Endter-Wada *et al*., 1998; McGinnis and Ostrom, 2014). A key feature of these coupled social–ecological system (SES) frameworks is the inclusion of feedback mechanisms between human components of the system and the natural environment (Liu *et al*., 2007). This was a natural extension to the trend in the natural sciences towards modeling natural processes within ecosystem models that recognize the biotic and abiotic processes at work and the feedback processes within them.

In these coupled human and natural system (CHANS) models, ecosystem services (ES) serve as an important link between ecosystems' functions and human well-being. In broad terms, ecosystem services are the direct or indirect benefits to humans derived from ecosystems (Costanza *et al*., 1997; MA, 2005). The term "ecosystem services" generally embodies both goods and services produced by ecosystems through ecological structures and ecosystem functions (MA, 2005). They include a wide variety of things, from ecosystem goods that are used directly by humans for food, medicine, and raw materials to ecosystem services such as habitat for species, minimizing climate variability, filtering air and water pollution, and providing opportunities for recreational, scenic, spiritual, and cultural benefits. A common way of organizing ecosystem services by functional grouping was proposed by the United Nations (UN)'s Millennium Ecosystem Assessment (MA). The MA classified ecosystem services into four types: provisioning, regulating, cultural, and supporting services (MA, 2005). Provisioning services are produced by the ecosystem and used directly by humans. For example, provisioning ecosystem services include food, fuel, genetic resources, fresh water, and other raw materials. Regulating services are ecosystem services that benefit humans by regulating ecosystem processes and include, for example, climate regulation, water purification, and pollination. Cultural services are those that provide non-material benefits to humans, such as those that provide recreation, spiritual or religious, inspirational, educational, or cultural heritage benefits. And finally, supporting services are those services necessary for the production of all ecosystem services but are not themselves ones that directly benefit humans. These include things like nutrient cycling, soil formation and cycling, water cycling, and habitat services.

The ecosystem services concept has been broadly recognized as an important means for facilitating environmental assessments at local, regional, and global scales (Gómez-Baggethun and Barton, 2013; Kumar *et al*., 2013). It is central to payment for ecosystem services (PES) programs (Bulte *et al.*, 2008; Jack *et al*., 2008; Farley and Costanza, 2010) and efforts to develop the United Nations-led System of Environmental-Economic Accounting (SEEA), a framework that integrates economic and environmental data to provide a comprehensive view of the interrelationships between the economy and environment and the stocks and flows of environmental assets (La Notte and Rhodes, 2020; UN, 2016).

This section focuses on marine ecosystem services (MES), which for our purposes are inclusive of ecosystem services associated with off-shore marine and nearshore coastal and estuarine environments. Ocean and coastal ecosystems provide human populations with a variety of ecosystem services. The desire to account for values of these services in policy and management decisions at the local, regional, and international scale, and in global efforts to understand trends in natural capital (*e.g*., https://seea.un.org/content/projects), has not only made understanding and assessing ecosystem services an emergent issue recognized as critical from a social, economic, and cultural perspective, but also one that poses challenges both from a policy and scientific perspective.

Given the growing interest in ecosystem-based approaches to managing the environment, MES has become an important topic for intergovernmental bodies and other international organizations. For instance, the UN-sponsored MA study (www.millenniumassessment.org) focused on the change of global ecosystem services' status and trends (MA, 2005), while the more recent World Ocean Assessment focused on an assessment of MES in the world's oceans and emphasized the importance of all types of MES, not just those that have a market value to humans or those that are easily quantified or observable (UN, 2016). The United Nations Environmental Programme (UNEP) also recently established the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to develop and use knowledge about ecosystem services and biodiversity to improve ecosystem-based management at national, regional, and global scales (Díaz *et al*., 2015). Other intergovernmental marine science organizations like the International Council for the Exploration of the Sea (ICES) and North Pacific Marine Science Organization (PICES) have also formed working groups to study MES.

This section presents key concepts and definitions needed to understand what MES are. In this way, it serves as an introduction to a PICES Scientific Report that is a primary product of the PICES Working Group on *Marine Ecosystem Services* (WG 41 or WG-MES).[1] The work described within the broader report is intended to contribute to PICES' integrative science program, **F**orecasting and **U**nderstanding **T**rends, **U**ncertainty and **R**esponses of North Pacific Marine **E**cosystems (FUTURE), which is the Organization's SES-based conceptual framework meant to understand and predict how marine ecosystems in the North Pacific are affected by climate change and human activities (Bograd *et al*., 2019). In the FUTURE SES-based framework, MES are represented by service flows from the marine ecosystem to the human system (Fig. 1.1). By providing a framework for assessment, MES generally,

[1] See https://meetings.pices.int/members/working-groups/wg41.

and the Working Group and this report specifically, indirectly contribute to three objectives of the FUTURE Product Matrix:

2.5 How are human uses of marine resources affected by changes in ecosystem structure and function?

2.7. What are the consequences of projected climate changes for the ecosystems and their goods and services?

3.4. What will be the consequences of projected coastal ecosystem changes and what is the predictability and uncertainty of forecasted changes?

It is important to bear in mind that the concept of MES, and ES generally, involves the flow of benefits society receives from the natural environment and does not embody human behavioral effects on the natural systems (represented by the "pressures" in Figure 1.1). While clearly important for a full understanding of the role of humans in any SES framework, a focus on anthropogenic impacts on nature is outside the scope of this report.

The remainder of this section is organized as follows: Section 1.2 briefly illustrates the growing interest in ES and MES by researchers by presenting a bibliometric analysis of the scholarly literature. Section 1.3 discusses in more detail how MES are defined and classified. Section 1.4 concludes section 1 and provides an outline of the remainder of the report.

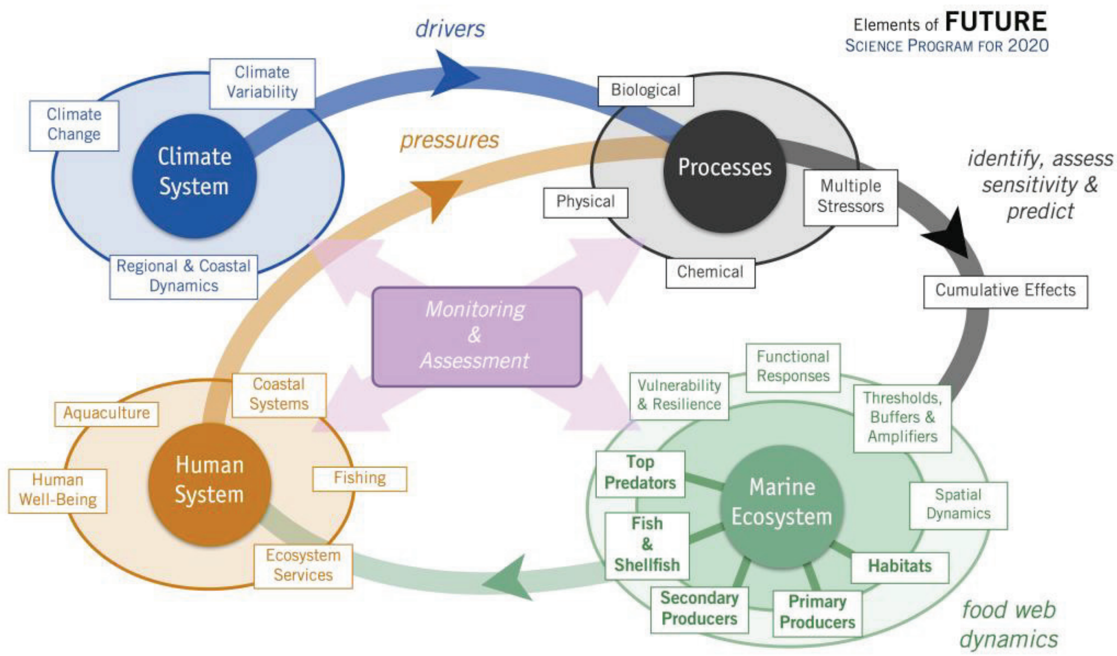

Fig. 1.1 PICES' FUTURE social–ecological system (SES)-based conceptual framework.

1.2 *Growth in scholarly research on MES and ecosystem services generally*

Academic interest in ES is widespread and continues to grow. To illustrate, we conducted a bibliometric search of the Web of Science Core Collection (WoS), which indexes publications in over 21,100 journals and books spanning 250 disciplines.[2] Publications in WoS include journal articles, reviews, proceeding papers, editorials, book chapters, meeting abstracts, data papers, letters, and other published documents that appear in academic journals and book compilations.

Using the WoS search function, two searches were conducted on June 30, 2020. First, we searched topics that included the keywords “ecosystem service*” to identify all published documents that had “ecosystem service” or “ecosystem services” in the title, keywords, or abstract. We found a total of 25,623 documents published between 1983 and 2020. Of principal interest is the period from the end of the 1990s to the present, after the seminal ES work by Daily (1997) and Costanza *et al*. (1997) served to mainstream the concept in the academic literature.[3]

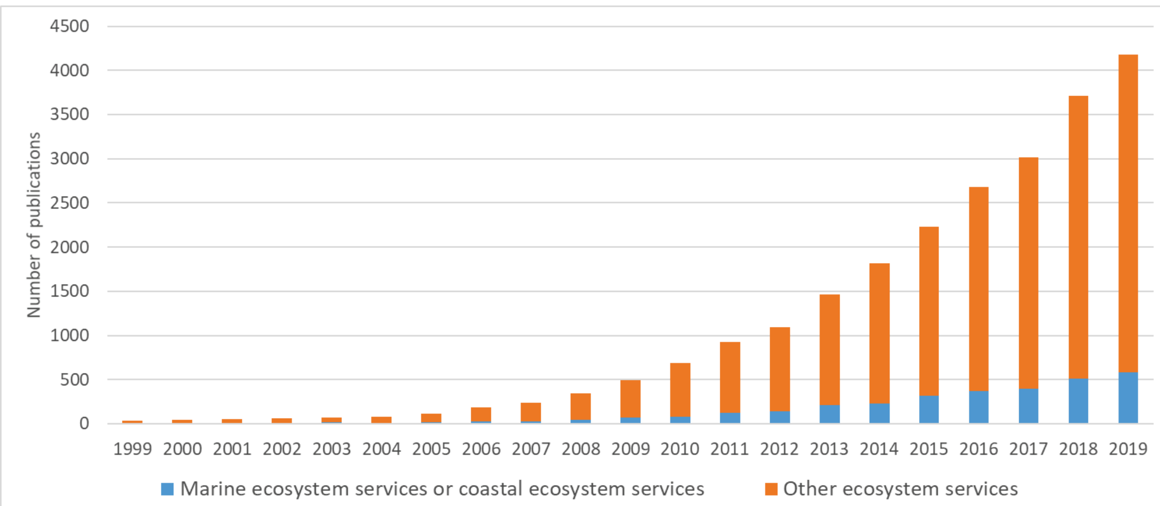

Fig. 1.2 Comparison of the growth of the general ecosystem services literature and the coastal and marine ecosystem service literature, 1999–2019. Number of publications by year resulting from a search of the Web of Science Core Collection (WoS, http://apps.webofknowledge.com) using the keywords “ecosystem service*” to identify general ecosystem service publications, and “ecosystem service*” in combination with “coast*” or “marine*” to identify the subset of the literature focusing on coastal and marine ecosystem services.

Over the period 1999–2019, the number of published ecosystem service documents grew steadily each year (Fig. 1.2), and does not appear to be slowing. In fact, the average annual growth rate over the most recent five years is 18%. Overall, the largest proportion of these studies appeared in journals

[2] See https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/ for more details.
[3] See Gómez-Baggethun *et al*. (2010) for a useful history of the early ES literature.

categorized under the "environmental science" WoS category (45.3%). The next largest number of studies were in journals categorized as "ecology" (33.4%) and "environmental studies" (16.7%).[4]

The second search was more refined and focused on identifying studies involving coastal ecosystem service and marine ecosystem service. The keywords we searched were the union of "ecosystem service*" with either "coast*" or "marine*". This resulted in 3,493 published documents, representing only 13.6% of all ecosystem services documents. The average rate of growth in the coastal and marine ecosystem services literature in the most recent five year period has been 21%, which slightly exceeds the average growth rate for the general ecosystem services literature. At the same time, however, the size of this sub-literature relative to the general ecosystem services literature has remained fairly steady at about 14% over the past decade. Similarly to the larger ecosystem services literature, the top two WoS categories were "environmental science" (46.6%) and "ecology" (28.3%). The third largest number of studies was classified under the "marine freshwater biology" WoS category. Taken as a whole, this brief bibliometric analysis is indicative of the rapid and continued growth of the ES and MES literatures.

1.3 Marine ecosystem services: Definitions and classifications

The concept of ES has been viewed as a unifying one that provides a role for multiple disciplines to contribute towards an improved understanding of the valuable role ecosystems play in human life. As such, there are both positive (descriptive) and normative (prescriptive) aspects of the concept. ES has been described as a boundary object (Abson *et al*., 2014; Schröter *et al*., 2014), which is an analytic concept that is flexible enough to be adapted to differing contexts and worldviews, but robust enough to have a common identity across them (Star and Griesemer, 1989; Schroter *et al*., 2014; Ainscough *et al*., 2019). As such, it provides a means for fostering communication between social scientists and natural scientists, as well as policy makers and researchers, and facilitates cooperation in the scientific and policy community towards furthering the concept and its application.

While generally accepted as a useful concept for thinking about a key set of relationships between ecosystems and human well-being, there has been less agreement about how to operationalize the definition of ES to enable more concrete, quantitative inquiries. Two of the earliest definitions for ES were put forth by Costanza *et al*. (1997) and Daily (1997). Daily (1997) described ecosystem services as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (page 3). On the other hand, Costanza *et al*. (1997) referred to the combination of ecosystem goods and services as "the benefits human populations derive, directly or indirectly, from ecosystem function" (page 253). Another commonly used definition comes from the Millennium Ecosystem Assessment (MA, 2005), which defines ecosystem services more generally as "the benefits people obtain from ecosystems." These definitions generally refer to "benefits" as improvements in human well-being. Well-being, as defined in the MA, is multi-faceted and includes "basic material for a good life, freedom and choice, health, good social relations, and security…and is on the opposite end of a continuum from poverty" (Leemans and de Groot, 2003, page 3). While all of these definitions suggest ES are intrinsically anthropocentric and relate to the benefits humans derive

[4] Note that every journal and book in WoS is assigned to at least one category, with many being assigned to several. As a result, the percentages of published documents in each category when summed are greater than 100%. For a full list of categories, see https://images.webofknowledge.com/images/help/WOS/hp_subject_category_terms_tasca.html.

from nature, they differ in important ways. The last two define ES (and ecosystem goods) as equal to the benefits provided to humans, while the first suggests that ES both facilitate the production of ecosystem goods that are valuable to humans and more directly benefit humans in the case of life-supporting functions.

These early definitions for ES tended to be vague and require further interpretation (Nahlik *et al*., 2012). As a consequence, subsequent authors have proposed variants of these definitions (*e.g.*, Boyd and Banzhaf, 2007; Fisher *et al*., 2008; Nahlik *et al*., 2012) that help narrow the definition in ways that allow it to be more operational and to facilitate measurement and valuation. To this end, for example, Boyd and Banzhaf (2007) proposed narrowing the focus from all ecosystem goods and services to "final" ecosystem goods and services (FEGS), which they defined as "components of nature, directly enjoyed, consumed, or used to yield human well-being." Ringold *et al*. (2013) further articulated this FEGS definition, noting that FEGS are "biophysical features, quantities, and qualities that require little further translation to make clear their relevance to human well-being" (page 98). The FEGS definition is based on an economic view: that it is only the end-products of nature that directly affect the well-being of humans. Instead of rejecting the large number of ES that are not FEGS, Fisher *et al*. (2008) proposed distinguishing between FEGS and "intermediate ecosystem services," which are ES that contribute to the production of FEGS but do not directly affect human well-being. For example, in the context of MES, coastal and marine habitats provide a variety of intermediate ecosystem services (and interact with other non-habitat intermediate ecosystem services) that help support fish populations. These populations are targeted and caught by recreational anglers who benefit directly from catching and consuming the fish as a FEGS, both as part of a recreational fishing experience that they enjoy and for the sustenance the fish provides as food. These authors note that in valuation and accounting exercises, the focus should only be on the FEGS to avoid double-counting.

Nahlik *et al*. (2012) discussed how these differing definitions and those that followed them have, taken as a whole, provided an inconsistent set of definitions that have generally hindered efforts to move toward operationalizing the concept. Their work builds off Fisher *et al*. (2009) who advocated for an ES classification system that includes a "clear, consistent and operational definition of what ecosystem services are" and is informed by the "characteristics of the ecosystem or ecosystem services under investigation…and the decision context or motivation for which ecosystem services are being considered" (page 644). Nahlik *et al*. (2012) proposed a set of four guiding principles for developing a definition and classification scheme for ES (pages 29–30):

1. Measuring, quantifying, valuing, and/or accounting for ecosystem services requires a wholly collaborative effort among natural scientists, social scientists, and decision-makers.

2. Ecosystem processes and functions produce ecosystem services, while people, groups, or individuals actualize ecosystem services by using them in consumptive and non-consumptive ways.

3. Defining, identifying, and classifying a complete, but non-duplicative, set of ecosystem services is the foundation of a transdisciplinary approach.

4. Because individuals actualize ecosystem services, their involvement (either direct or indirectly) in identifying ecosystem services and contributing to the framing of the research and the implementation plan is crucial.

These principles are used to guide the ES definition they adopt, which is based on the FEGS terminology proposed by Boyd and Banzhaf (2007). Importantly, their adoption of the FEGS concept involves a further articulation of the importance of "beneficiaries"—those who benefit from the ecosystem services—in the FEGS definition. Specifically, they noted that individuals can benefit from (final) ecosystem goods and services, either actively (physically interacting with the ecosystem through an activity) or passively (individual benefits without direct interaction with the ecosystem). They viewed the FEGS definition as having four strengths relative to others, specifically that it (1) avoids ambiguity by being restricted to the ES that directly interact with beneficiaries; (2) eliminates double-counting of ES that have both a direct and indirect impact on beneficiaries; (3) encourages natural scientists and social scientists to collaborate by connecting ecosystem services to both ecological features and beneficiaries; and (4) is more easily understood by the public because of the focus on beneficiaries (Nahlik *et al*., 2012). They further proposed to take a "beneficiary approach", one where beneficiaries are defined as categories of ways people benefit from the ecosystem (Nahlik *et al*., 2012). In this beneficiary approach, an individual person, organization, household, or firm is viewed as a potential beneficiary to multiple FEGS. For example, one person may be a farmer who benefits from water from a nearby river used to irrigate the farm's fields and also likes to fish recreationally in the river, which she does for the experience of catching fish, for the enjoyment of nature, and for providing fish to eat. This example suggests that the same individual benefits from several FEGS that the river environment provides that include water used for irrigation in her agricultural business, fish in the river available for angling, and sights and sounds of the riverine environment that provide an aesthetic experience while fishing.

The above discussion can be summarized with the help of Figure 1.3, which is a conceptual diagram of the relationship between the ecosystem, intermediate and final ecosystem services, and humans. On the left are the ecosystem structures and ecosystem processes and functions that represent the ecosystem. The bidirectional arrow between them represents the feedback mechanisms that occur between the ecosystem structures, processes, and functions. In the middle are ecosystem services, which represent a bridge between the ecosystem and humans. The ecosystem produces ecosystem goods and services (measured in biophysical units), some of which are used directly by humans—the final ecosystem goods and services (FEGS)—and others that are intermediate ES in the sense that they contribute to the production of FEGS. On the right are the human dimensions, represented by individuals and groups in the lower box and productive processes in the upper box that take FEGS and combine them with human capital and labor to produce goods and services that are then used or enjoyed by humans. Thus, humans benefit from FEGS either directly or indirectly. Human benefits (well-being) can be measured using tools from economics or other social sciences. Figure 1.3 emphasizes the basic pathways through which nature contributes to human well-being. Note that this conceptual diagram is only a portion of a fuller SES model, one in which the role of individual and collective human actions on the natural environment is accounted for, *i.e*., the "pressures" referred to in the FUTURE SES-based framework (Fig. 1.1). This relationship could be captured in a more complete SES model that highlights how individual and collective human actions serve as (positive or negative) stressors on the natural environment.

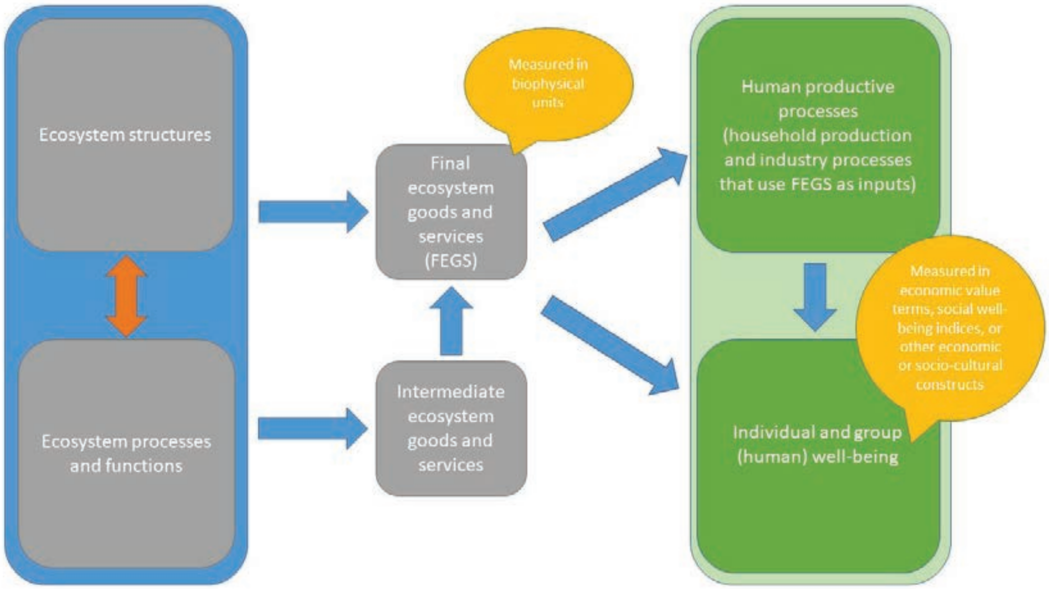

Fig. 1.3 Conceptual diagram of the relationship between the ecosystem, intermediate and final ecosystem services, and humans.

It is important to note that the FEGS view of the relationship between humans and the environment depicted in Figure 1.1 is utilitarian and instrumental in nature. This is consistent with an economic view, but less so with a broader sociocultural view in which relational values (Chan *et al.*, 2018; Stålhammar and Thorén, 2019) are viewed as central or with a biocentric view emphasizing intrinsic values (Brennan, 2007). However, it can be generalized to include other sociocultural (often non-material yet still instrumental) benefits provided by ecosystems by more directly linking the biophysical components of the ecosystem (the ecosystem structures, processes, and functions in the figure) with human well-being. This can also be achieved by relaxing the definition of FEGS to embody more generally the "biophysical components" of the ecosystem that convey value or benefits to humans. The recognition of different worldviews is an explicit part of the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework (Diaz *et al.*, 2015; Pascual *et al.*, 2017) and is discussed from the perspective of assessing MES later in this report.

1.3.1 Classifying ecosystem services

Numerous typologies, or classification systems, have been developed to categorize ES. In large part, these typologies have been put forth to aid in conceptually organizing ES in ways that capture the scope of what is meant by ecosystem services. For example, as noted in the introduction, the Millennium Ecosystem Assessment divides ES into four types: provisioning, cultural, regulating, and supporting (MA, 2005). Provisioning ES include the products obtained and used from ecosystems, including food, fresh water, fuel materials, fiber, and biochemical and genetic resources. Cultural ES are non-material benefits obtained from ecosystems, like those related to recreation and ecotourism, spiritual, religious, aesthetic, and inspirational benefits; educational benefits, cultural heritage, and providing a sense of place. Regulating ES are those obtained from regulating ecosystem processes and include climate regulation, disease regulation, water regulation, and water purification. Supporting ES are those that are necessary for the production of the other categories of ES. Soil formation, nutrient cycling, and primary production are included in this category.

The Economics of Ecosystems and Biodiversity (TEEB) (http://teebweb.org), another global initiative with a focus on the valuation of ES, uses a similar ecosystem services definition to MA, but is slightly more general by focusing on "contributions" rather than "benefits" (de Groot *et al*., 2010). The ES typology they use divides ecosystem services into four main categories: provisioning, cultural, regulating, and habitat. Thus, a notable difference from the MA typology is the exclusion of supporting services and inclusion of a separate category for habitat services. In the TEEB framework, supporting ecosystem services are considered a subset of ecological processes rather than distinct ecosystem services that directly or indirectly benefit humans. Habitat services, on the other hand, are included as a separate category "to highlight the importance of ecosystems to provide habitat for migratory species (*e.g*., as nurseries) and gene-pool "protectors" (*e.g*., natural habitats allowing natural selection processes to maintain the vitality of the gene pool)" (de Groot *et al*., 2010, page 19).

Another ES typology explicitly maps its ES categories to those used by MA and TEEB. It was created by the European Environment Agency's Common International Classification of Ecosystem Services (CICES) project (https://cices.eu). The CICES classification scheme is based on the cascade model of Potschin and Haines-Young (2011, 2016), which itself builds from TEEB's conceptual foundations (de Groot *et al*., 2010), and illustrates how ES follow a "pathway" from ecological structures and functions to the well-being of people (similar to the conceptual model in Figure 1.1). CICES is a hierarchical classification system with three of the four MA classes at the highest level—provisioning, cultural, and regulating ecosystem services[5]—and increasingly more specific sub-categories in four lower levels. The lower levels, from high to low, are "division," "group," "class," and "class type." At any level, the categories are mutually exclusive. The increasing specificity leads to increasingly detailed descriptions of ES, with the lowest levels indicative of the specific uses of the ES by people (similar in function to the "beneficiary" dimension of the FEGS). The latest version of CICES (version 5.1) includes 90 class types (the lowest level): 42 provisioning, 31 regulating, and 17 cultural ES. This hierarchical structure allows users to determine the most appropriate level of ES detail for a given application (Haines-Young and Potschin, 2018).

Beyond providing a functional organization for types of ES to capture the full scope of ES, another purpose for these typologies is to provide a framework from which to operationalize the concept of ES and allow for integration into quantitative-oriented analyses. Standardizing the set of ES can aid in guiding measurement and valuation for environmental assessments. As discussed earlier, Nahlik *et al*. (2012) reviewed the ES definitions to evaluate how useful they are for guiding operationalization and advocated for the use of the FEGS concept using a beneficiary approach to avoid double-counting ES and as a means of facilitating a standardization of ES with measurement and valuation in mind generally. Landers and Nahlik (2013) developed an ES typology based on FEGS called the Final Ecosystem Goods and Services Classification Scheme (FEGS-CS) and provide an on-line web tool to facilitate its usage (available at https://www.epa.gov/eco-research/final-ecosystem-goods-and-services-classification-system-fegs-cs). The FEGS-CS includes 342 specific types of measurable FEGS. These 342 FEGS types are defined in terms of the environmental class (and subclass) in which they fall, as well as the class (and subclass) of beneficiary. These classes and subclasses were identified through a series of workshops with natural and social scientists.

[5] These three MA classes are also in the TEEB system.

The FEGS-CS classification scheme has three environmental classes and 15 environmental subclasses. The three environmental classes are “aquatic,” “terrestrial,” and “atmospheric.” The aquatic environmental class includes six subclasses:

(1) rivers and streams
(2) wetlands
(3) lakes and ponds
(4) estuaries and near coastal and marine waters
(5) open oceans and seas
(6) groundwater.

Groundwater was included as an aquatic environmental subclass since it is a vital FEGS for those relying on well water. The terrestrial environmental class has eight subclasses:

(1) forests
(2) agroecosystems
(3) created greenspace
(4) grasslands
(5) scrubland/shrubland
(6) barren/rock and sand
(7) tundra
(8) ice and snow.

The atmospheric class has only one subclass, atmosphere.

Most of these environmental subclasses were determined in part due to consideration for the feasibility of mapping them with existing satellite data, though Landers and Nahlik (2013) acknowledge that atmosphere and groundwater are not ones likely to be mapped using satellite data. Each of the 15 environmental subclasses are assigned a two-digit code. The first digit is the environmental class (1 = aquatic, 2 = terrestrial, and 3 = atmospheric) and the second digit corresponds to the environmental subclass number, *e.g.*, “11” denotes aquatic (1), rivers and streams (1) and “31” denotes atmospheric (3), atmosphere (1).

The FEGS definition is distinguished from most other ways of defining ES by an explicit accounting of who receives the benefit from the ecosystem—the beneficiary. In the FEGS-CS, there are 10 beneficiary classes and 38 beneficiary subclasses. The 10 beneficiary classes are the following:

(01) agricultural
(02) commercial/industrial
(03) government, municipal, and residential
(04) commercial/military transportation
(05) subsistence
(06) recreational
(07) inspirational
(08) learning
(09) non-use
(10) humanity.

The subclasses differ by beneficiary class and represent different types of individuals or groups of individuals who benefit in distinct ways. Each beneficiary class and subclass combination is identified by a 4-digit code with the 2-digit beneficiary class code (above) first, followed by the 2-digit beneficiary subclass code. The beneficiary classes and subclasses are presented in Annex Table A1.1. For example, drawing from the earlier example of the farmer who uses river water for her farm, her use of river water in her farming business to water her crops (environmental class/subclass = 11) suggests for this particular FEGS the beneficiary class designation would be agriculture (01) and farmer (06), which is coded as ".0106".

Each beneficiary class interacts with the environment differently, depending on the type of environmental class. To reflect this, the FEGS-CS identifies each FEGS by the environmental class and subclass (XX) and beneficiary class and subclass (.YYYY) with a unique code (XX.YYYY). For instance, in our farmer example, the full FEGS-CS code is "11.0106," which captures the FEGS for the farmer's use of river water for agricultural purposes. Other FEGS-CS codes could be determined for the other FEGS associated with the benefits the river provides to the farmer. The feasible combinations of environmental classes and subclasses with beneficiary classes and subclasses result in a matrix containing 342 specific FEGS (Landers and Nahlik, 2013). This excludes certain combinations of beneficiaries and environmental class types that do not exist.

To our knowledge, the FEGS-CS is the most detailed formal classification scheme for organizing ES. Note that the latest version of CICES (version 5.1) is similar in that it notes the importance of beneficiaries, but does not explicitly identify beneficiary types and instead uses examples and a "use clause" to illustrate elements of this dimension (Haines-Young and Potschin, 2018).

While this discussion has described a range of ES definitions and classification systems, including ones that are specifically designed to minimize problems when a quantitative assessment is desired, we acknowledge that the specific definition employed in a given study is necessarily context-dependent. It will be driven by the study goals and characteristics of the human and natural systems involved (*e.g*., temporal and spatial scale), the composition and expertise of those conducting the application, political feasibility, data availability, and time and resource constraints. Thus, it is not advocated that a specific definition or classification system be used in all studies, but the flexibility of the CICES framework (since it embodies elements of MA and TEEB) and more holistic approach and detail of the FEGS-CS framework make these two systems attractive ones to work from. However, it is important to recognize that neither of these frameworks are wholly satisfactory in terms of accounting for some types of cultural ecosystem service values, particularly ones that are non-instrumental in nature, like relational values (Chan *et al*., 2018).

1.3.2 Types of marine ecosystem services

Coastal and marine ecosystems provide myriad indirect and direct goods and services that benefit humans. Table 1.1 includes a list of common coastal and marine ecosystem services occurring in PICES member countries and how they map into the MA ES typology and FEGS-CS. The specific MES are grouped into six categories: food source, source of non-food materials, supporting functions, recreational benefits; social, cultural, and religious benefits, and nonuse benefits.

1. **Food source**: This category includes flora and fauna used by humans for consumption and as intermediate inputs for production processes (home production or industrial processes). This category of MES is provisioning services under the MA classification.

2. **Source of non-food materials**: This includes inorganic materials from the environment that are mined, dredged, or harvested for industrial or commercial purposes, including for pharmaceuticals, as well as water for non-drinking purposes, flora and fauna harvested for non-food purposes (*e.g.*, for the pet industry or for ornamental purposes), and the harvest of wind and wave energy. These MES are provisioning services under the MA classification.

3. **Supporting and regulating functions**: This category includes a wide variety of mostly intermediate ES that support other ecosystem functions and services, including carbon sequestration, habitat functions, and biodiversity. However, it also includes several regulating functions that more directly benefit humans, such as shoreline protection, pollution filtration, and acting as a medium for transportation of goods and people, and atmospheric processes like weather. These functions are generally associated with the supporting or regulatory MA categories of ecosystem services.

4. **Recreational benefits**: This category includes a variety of recreational benefits provided by the coastal and marine environment, including various types of direct and indirect water recreation (scuba diving, swimming, surfing, boating, *etc*.), sport fishing and hunting, wildlife and nature viewing, and coastal recreation activities (beachgoing, tide pooling, *etc*.). This category of MES falls under the class of cultural ES in the MA classification scheme.

5. **Social, cultural, and religious benefits**: This category includes the uses for the environment people have that are related to their cultural heritage; spiritual, religious, or inspirational motivations, educational opportunities, and provision of a sense of place or identity. Like recreational benefits, this category of MES falls under the class of cultural ES in the MA classification scheme.

6. **Nonuse benefits**: Nonuse benefits include the benefits people get from knowing the environment exists (existence value) and knowing that the environment will be available to future generations (bequest value). These are cultural ES under the MA classification scheme.

For each type of MES in these groups, Table 1.1 indicates the FEGS-CS beneficiary class and specific FEGS associated it. Note that in general, there are three applicable environmental classes associated with MES: estuaries and nearshore marine (Environmental Class 14 in FEGS-CS), open seas and oceans (Environmental Class 15), and wetlands (Environmental Class 12) (that include estuarine wetlands and mangroves). The exception, of course, is Environmental Class 31, Atmosphere, which is included in the supporting functions group. Annex Table A1.2 provides the MES classified under the CICES classification system.

Table 1.1 Common marine ecosystem services and mapping to the Millennium Ecosystem Assessment (MA) and Final Ecosystem Goods and Services Classification Scheme (FEGS-CS).

Ecosystem Services (MA classification)	**FEGS-CS Environmental classes: Estuaries and nearshore marine (14) and open seas and oceans (15)**	
Description	**Beneficiary class**	**FEGS type**
Food source (provisioning)		
Fish, other animals, and plants harvested for human consumption via commercial fishing, aquaculture, hunting, and subsistence/artisanal fishing	Aquaculture (.01), commercial fishing (.02), subsistence (.05), hunting (.06)	Flora and fauna
Fish, other animals, and plants used as inputs in human production process (*e.g.*, bait, feed used in agriculture) or other ecosystem production processes (*e.g.*, forage fish)	Food extractors (.02), no match for forage fish	Flora and fauna
Source of non-food materials (provisioning)		
Minerals, rare earth elements, petroleum/oil, natural gas, and other valuable materials that can be mined, dredged, or harvested	Resource-dependent businesses and other resource extractors (.02)	Natural materials, fibers
Materials needed for, or potentially useful for, medicine or pharmaceuticals	Pharmaceutical and food supplement suppliers (.02)	Natural materials, flora, fauna, fibers
Water for industrial processes and other non-drinking purposes	Industrial dischargers, industrial processors, resource-dependent businesses (.02)	Water
Wave and wind energy that can be harnessed	Electric and other energy generators (.02)	Presence of environment, water
Fish, other animals, and plants harvested for ornamental use (*e.g.*, aquariums)	Hunters or trappers (.02)	Flora and fauna
Supporting and regulating functions (supporting/regulating)		
Carbon sink (*i.e.*, carbon sequestration) and climate regulation	*Not in FEGS-CS*	n/a
Pollutant filtration and remediation	*Not in FEGS-CS*	n/a
Shoreline protection, storm buffering, and erosion control	Presence of environment: residential property owners (.03), resource-dependent businesses (.02)	Presence of environment
Habitat for marine and coastal plants and animals	*Not in FEGS-CS*	n/a
Medium for transportation of goods and people	Transporters of people and goods (.04)	Presence of environment, water
Biodiversity	*Not in FEGS-CS*	n/a
Atmospheric processes, including weather (*e.g.*, rain and wind), breathable air, *etc.*	Wide range of beneficiaries	Water, presence of environment, air, weather, viewscapes, wind, atmospheric phenomena, open space, sounds and scents

Table 1.1 Continued.

Ecosystem Services (MA classification)	FEGS-CS Environmental classes: Estuaries and nearshore marine (14) and open seas and oceans (15)	
Description	**Beneficiary class**	**FEGS type**
Recreational benefits (cultural)		
Water recreation (*e.g.*, scuba diving, snorkeling, swimming, surfing, paddle boarding, kayaking, sailing, motor-boating,)	Swimmers, divers, boaters, and other water-based recreationists (.06)	Water, presence of environment, sounds and scents, viewscapes, fauna, flora
Sport fishing and hunting opportunities	Hunters, anglers (.06)	Fauna
Wildlife and scenic viewing opportunities	Experiencers and viewers (.06)	Water, presence of environment, sounds and scents, viewscapes, fauna, flora
Onshore/coastal recreation activities (*e.g.*, tide pooling, sunbathing)	Tide poolers, sunbathers, beachgoers, exercisers, and other coastal recreationists (.06)	Water, presence of environment, sounds and scents, viewscapes, fauna, flora
Social, cultural, and religious benefits (cultural)		
Cultural heritage	Anyone using coast or ocean for traditional or cultural ceremonies or other purposes rooted in culture or history (.07–.09)	Presence of environment, sounds and scents, viewscapes, natural materials
Spiritual or religious importance, inspirational	Anyone using coast or ocean for spiritual or religious purposes or for inspirational purposes (*e.g.*, artists) (.07–.09)	Presence of environment, sounds and scents, viewscapes, natural materials
Sense of place/identity	Anyone for whom the coast or ocean provides a sense of identity or place (*e.g.*, communities, residents) (.07–.09)	Presence of environment
Educational opportunities	Educators and students, researchers (.08)	Presence of environment, natural materials
Nonuse benefits (cultural)		
Existence benefits (knowing that something exists even if it is never visited or used personally)	People who care (.09)	Presence of environment
Bequest benefits (knowing that something will be available for future generations of people)	People who care (.09)	Presence of environment

1.4 Summary and road map

Over the past two decades, the concept of ecosystem services has grown in usage and acceptance as a principal vehicle for describing the benefits nature provides to humans in numerous conceptual coupled SES frameworks. This section illustrated the growth of the MES literature, reviewed several common definitions and classifications of ES generally, and identified a number of MES common in the North Pacific.

This section sought to provide an answer to the question, "What are marine ecosystem services?" Subsequent sections in this report focus on other key questions about MES. This includes a review of the assessment methods used to measure and value MES from multiple disciplinary perspectives—in particular, ecological, economic, and sociocultural ones (section 2). Another section compares how the MES concept is applied and researched in relation to aquaculture in PICES member countries (section 3). The final section reports on how MES and MES values are viewed by researchers and policy analysts, using results from a survey conducted in three PICES member countries (section 4). Appendices 1 to 3 provide WG 41's TOR, membership, and workshop and topic session summaries and meeting reports from PICES Annual Meetings. Taken together, the WG 41 report represents a first step towards a fuller understanding of MES in the North Pacific.

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Annex Table A1.1 Final Ecosystem Goods and Services (FEGS) beneficiary categories. Reproduced from Landers and Nahlik (2013).

Beneficiary class		Beneficiary subclass			Beneficiary class		Beneficiary subclass		
Code	Name	Code	Name	Beneficiary code	Code	Name	Code	Name	Beneficiary code
01	Agricultural	01	Irrigators	0101	04	Commercial/military transportation	01	Transporters of goods	0401
		02	CAFO (animal feeding) operators	0102			02	Transporters of people	0402
		03	Livestock grazers	0103	05	Subsistence	01	Water subsisters	0501
		04	Agricultural processors	0104			02	Food subsisters	0502
		05	Aquaculturists	0105			03	Timber, fiber, and fur/hide subsisters	0503
		06	Farmers	0106			04	Building material subsisters	0504
		07	Foresters	0107	06	Recreational	01	Experiencers and viewers	0601
02	Commercial/industrial	01	Food extractors	0201			02	Food pickers and gatherers	0602
		02	Timber, fiber, and ornamental extractors	0202			03	Hunters	0603
		03	Industrial processors	0203			04	Anglers	0604
		04	Industrial dischargers	0204			05	Waders, swimmers, and divers	0605
		05	Electric and other energy generators	0205			06	Boaters	0606
		06	Resource-dependent businesses	0206	07	Inspirational	01	Spiritual and ceremonial participants and participants of celebration	0701
		07	Pharmaceutical and food supplement suppliers	0207			02	Artists	0702
		08	Fur/hide trappers and hunters	0208	08	Learning	01	Educators and students	0801
03	Government, municipal, and residential	01	Municipal drinking water plant operators	0301			02	Researchers	0802
		02	Waste water treatment plant operators	0302	09	Non-use	01	People who care (existence)	0901
		03	Residential property owners	0303			02	People who care (option/bequest)	0902
		04	Military/coast guard	0304	10	Humanity	01	All humans	1001

Annex Table A1.2 Marine ecosystem services in the Common International Classification of Ecosystem Services (CICES) classification scheme linked to the Millennium Ecosystem Assessment (MA) and Economics of Ecosystems and Biodiversity (TEEB) classifications. Derived from CICES version 5.1. (Available at https://cices.eu/)

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by *in situ* aquaculture grown for nutritional purposes	1.1.2.1	*Plants, algae by amount, type*	*Plants that are cultivated in fresh or salt water that we eat*	Food	Food
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Fibres and other materials from *in situ* aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2	*Plants, algae by amount, type*	*Plants that are cultivated in fresh or salt water that we can use as a material*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by *in situ* aquaculture grown as an energy source	1.1.2.3	*Plants, algae by amount, type*	*Plants that are cultivated in fresh or salt water that we can use as an energy source*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by *in situ* aquaculture for nutritional purposes	1.1.4.1	*Animals by amount, type*	*Animals that are cultivated in fresh or salt water that we eat*	Food	Food
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by *in situ* aquaculture for direct use or processing	1.1.4.2	*Animals by amount, type*	*Animals that are cultivated in fresh or salt water that we can use as a material*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by *in situ* aquaculture as an energy source	1.1.4.3	*Animals by amount, type*	*Animals that are cultivated in fresh or salt water that we can use as a source of energy*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	1.1.5.1	*Plants, algae by amount, type*	*Food from wild plants*	Food	Food
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2	*Plants, algae by amount, type*	*Materials from wild plants*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	1.1.5.3	*Materials by type/source*	*Materials from wild plants, fungi and algae used for energy*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources

Annex Table A1.2 Continued.

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	1.1.6.1	*Animals by amount, type*	*Food from wild animals*	Food	Food
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild animals for direct used or processing (excluding genetic materials)	1.1.6.2	*Materials by type/source*	*Materials from wild animals*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used as a source of energy	1.1.6.3	*By amount, type, source*	*Materials from wild animals that can be used as a source of energy*	Fibre, timber, ornamental, biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	*By species or varieties*	*Seed collection*	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Higher and lower plants (whole organisms) used to breed new strains or varieties	1.2.1.2	*By species or varieties*	*Plants, fungi or algae that we can use for breeding*	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1.2.1.3	*Material by type*	*Genetic material from wild plants, fungi or algae that we can use*	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	1.2.2.1	*By species or varieties*	*Animals used for replenishing stock*	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	Wild animals (whole organisms) used to breed new strains or varieties	1.2.2.2	*By species or varieties*	*Wild animals that we can use for breeding*	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from organisms	Individual genes extracted from organisms for the design and construction of new biological entities	1.2.2.3	*Material by type*	*The genetic information that is stored in wild animals that we can use*	Genetic materials	Genetic materials

Annex Table A1.2 Continued.

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
Provisioning (Biotic)	Other types of provisioning service from biotic sources	Other	Other	1.3.X.X	*Use nested codes to allocate other provisioning services from living systems to appropriate Groups and Classes*		No equivalent	No equivalent
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by macro-organisms, algae, plants, and animals	2.1.1.1	*By type of living system or by waste or subsistence type*	*Decomposing wastes*	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration /storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	*By type of living system, or by water or subsistence type*	*Filtering wastes*	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Smell reduction	2.1.2.1	*By type of living system*	*Reducing smells*	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Visual screening	2.1.2.3	*By type of living system*	*Screening unsightly things*	Water purification and water treatment, air quality regulation?	Water purification and water treatment, air quality regulation?
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	2.2.1.1	*By reduction in risk, area protected*	*Controlling or preventing soil loss*	Erosion regulation	Erosion prevention
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	2.2.1.2	*By reduction in risk, area protected*	*Stopping landslides and avalanches harming people*	Erosion regulation	Erosion prevention

Annex Table A1.2 Continued.

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (including flood control and coastal protection)	2.2.1.3	*By depth/volumes*	*Regulating the flow of water in our environment*	Water regulation	Regulation of water flows, regulation of extreme events
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	*By amount and pollinator*	*Pollinating our fruit trees and other plants*	Pollination	Pollination
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	2.2.2.2	*By amount and dispersal agent*	*Spreading the seeds of wild plants*	No equivalent	Biological control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (including gene pool protection)	2.2.2.3	*By amount and source*	*Providing habitats for wild plants and animals that can be useful to us*	No equivalent	Biological control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	2.2.3.1	*By reduction in incidence, risk, area protected by type of living system*	*Controlling pests and invasive species*	Pest regulation	Biological control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	2.2.3.2	*By reduction in incidence, risk, area protected by type of living system*	*Controlling disease*	Disease regulation	Biological control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	2.2.4.2	*By amount/ concentration and source*	*Ensuring the organic matter in our soils is maintained*	Soil formation (supporting service)	Maintenance of soil fertility
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	*By type of living system*	*Controlling the chemical quality of salt water*	Water regulation	Water
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	*By contribution of type of living system to amount, concentration or climatic parameter*	*Regulating our global climate*	Atmospheric regulation	Climate regulation
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	*By contribution of type of living system to amount, concentration or climatic parameter*	*Regulating the physical quality of air for people*	Atmospheric regulation	Climate regulation

Annex Table A1.2 Continued.

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
Regulation & Maintenance (Biotic)	Other types of regulation and maintenance service by living processes	Other	Other	2.3.X.X	*Use nested codes to allocate other regulating and maintenance services from living systems to appropriate Groups and Classes*		No equivalent	No equivalent
Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	3.1.1.1	*By type of living system or environmental setting*	*Using the environment for sport and recreation; using nature to help stay fit*	Recreation and ecotourism	Recreation and ecotourism
Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	3.1.1.2	*By type of living system or environmental setting*	*Watching plants and animals where they live, using nature to destress*	Recreation and ecotourism	Recreation and ecotourism
Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	3.1.2.1	*By type of living system or environmental setting*	*Researching nature*	Knowledge systems and educational values, cultural diversity, aesthetic values	Information and cognitive development
Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	3.1.2.2	*By type of living system or environmental setting*	*Studying nature*	Knowledge systems and educational values, cultural diversity, aesthetic values	Information and cognitive development
Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	*By type of living system or environmental setting*	*The things in nature that help people identify with the history or culture of where they live or come from*	Knowledge systems and educational values, cultural diversity, aesthetic values	Inspiration for culture, art and design, aesthetic information

Annex Table A1.2 Continued.

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
Cultural (Biotic)	Direct, *in situ* and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	3.1.2.4	*By type of living system or environmental setting*	*The beauty of nature*	Knowledge systems and educational values, cultural diversity, aesthetic values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	3.2.1.1	*By type of living system or environmental setting*	*Using nature as a national or local emblem*	Spiritual and religious values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	3.2.1.2	*By type of living system or environmental setting*	*The things in nature that have spiritual importance for people*	Spiritual and religious values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	3.2.1.3	*By type of living system or environmental setting*	*The things in nature used to make films or to write books*	Spiritual and religious values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	3.2.2.1	*By type of living system or environmental setting*	*The things in nature that we think should be conserved*	No equivalent	No equivalent
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	3.2.2.2	*By type of living system or environmental setting*	*The things in nature that we want future generations to enjoy or use*	No equivalent	No equivalent
Cultural (Biotic)	Other characteristics of living systems that have cultural significance	Other	Other	3.3.X.X	*Use nested codes to allocate other cultural services from living systems to appropriate Groups and Classes*		No equivalent	No equivalent

2 Assessing Marine Ecosystem Services in the North Pacific: An Overview of Approaches

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2.1 Introduction

This section examines the diverse approaches used to assess ecosystem services (ES), with a particular focus on marine ecosystem services (MES). The term MES, as used here, is interpreted broadly to include all types of coastal and marine ecosystem services. Separate subsections present ES assessment approaches for three broad scientific disciplinary perspectives that see the world through different lenses: the *ecological* sciences perspective (subsection 2.2), the *economic* perspective (subsection 2.3), and the *sociocultural* perspective (subsection 2.4).

As illustrated in Figure 2.1, we differentiate the assessment approaches of different scientific disciplinary perspectives along several dimensions: (1) foci of value, (2) primary analytic objective, (3) measurement or assessment approaches, and (4) examples of assessment methods. The foci of value indicate what the focus of the assessment is directed at. In the case of ecological assessments, for example, which embodies all physical, chemical, and biological disciplines, the focus is on the processes and functions of nature and the relationships between, and production of, various stocks or flows interpreted as ES. The analytic objective of ES measurement in this perspective is generally to gauge the health and resilience of the ecosystem. Since this disciplinary perspective is inclusive of many scientific disciplines, there are many types of approaches one can take to measure, model, or map ES. This is in contrast to the economic worldview, which has a very specific focus in evaluating ES—specifically focusing on the benefits to human well-being provided by the ES (foci of interest), which can be revealed and valued through human preferences and behavior (primary analytic objective) using a set of fairly well-defined quantitative approaches. While similarly interested in human well-being, the sociocultural worldview is more expansive in the types of values of interest, and consequently utilizes a wider assortment of approaches to understand values for ES. For example, both individual well-being and community well-being (as a separate and distinct object) are a focus, as are interactions of ES with culture and traditions. The types of sociocultural assessment methods reflect this diversity and include a variety of qualitative and quantitative approaches that are focused on both individuals and groups.

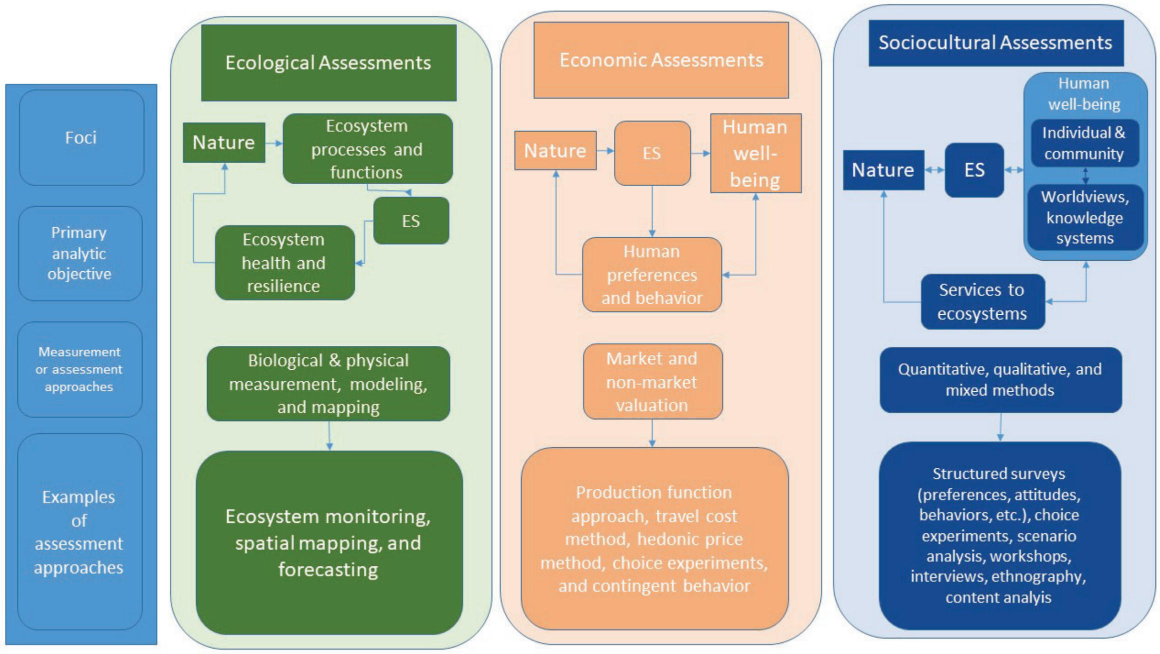

Fig. 2.1 Different disciplinary perspectives influence what aspects of marine ecosystem services are focused on and how to assess them.

The following subsections provide an overview of the different approaches for assessing ES from the ecological, economic and sociocultural perspectives.

2.2 Ecological assessment

Ecologically, ecosystem services are the physical, chemical, and biological processes provided by the natural environment. As ES broadly encapsulate the direct or indirect benefits to humans derived from ecosystems, ecological ES result from the organisms that form the biotic community and the abiotic habitat they occupy (Lindeman, 1942; Costanza *et al.*, 1997; MA, 2005; Mace *et al.*, 2012; Eastwood *et al.*, 2020). These services support a vast range of ecological processes, including preserving biological communities, climatic regulation, population persistence, and maintaining abiotic conditions and are often classified as provisioning, regulating, supporting, or cultural (Table 2.1, MA, 2005). A notable portion of these services is evident within, and vital to the preservation of, marine ecosystems, especially coastal zones. These services have been termed “marine ecosystem services” (MES) (Costanza *et al.*, 1997b; Martínez *et al.*, 2007; Liquete *et al.*, 2013). For example, nearshore shellfish populations provide a vital food source for coastal human populations (Cox *et al.*, 2020). Similarly, reef fish community diversity correlates with fish biomass, allowing artisanal and commercial fisheries to extract more protein while increasing the resilience of reef fish communities to changing climatic conditions (Duffy *et al.*, 2016).

Evaluating the MES provided to society by an ecosystem, the services’ processes and function, and the regulator mechanism(s) by which the services and thus the ecosystem are maintained, requires an array of techniques (Liquete *et al.*, 2013). Effectively examining these ecological services is more challenging within marine ecosystems than terrestrial equivalents due to the marine system’s ambiguous boundaries, broad spatial scales, three-dimensional habitats, and nonlinear system dynamics (Agardy, 2000; Portman, 2013). Despite this complexity and the relatively recent awareness of the importance of MES, an effective combination of adaptable methodologies has emerged that integrate scientific monitoring, mathematical modelling, mapping, and forecasting.

Evaluating the ecological component of ES requires the application of several techniques due to the diversity of services that sustain natural environments (Nahlik *et al.*, 2012; Fig. 2.2). Finite resources and external processes that disrupt services at varying spatial and temporal scales usually prevent marine ecosystems from achieving a state that provides services continuously while conserving the internal stability of the ecosystem (DeFries and Nagendra, 2017; Eastwood *et al.*, 2020). Therefore, it is vital to monitor select components and mechanisms that create MES. In many regards, this causes evaluations of MES to be analogous to examining an ecosystem's function. The fundamental biophysical unit of measure is biological diversity, or alternatively, the diversity and abundance of biological units (*e.g.,* individuals of each species), and by extension, the functions each unit provides. Monitoring biophysical units can be done selectively or holistically by targeting specific individuals, species, or the whole community. Specifically, MES metrics include the number of species, endangered taxa, functional diversity or redundancy, ecological connectivity, ecosystem or habitat area, climate regulation, and adaptive capacity (Annex Table 2.1). Monitoring these and other metrics allows for ES to be assessed. Based on the emergent idea that biophysical units, directly and indirectly, affect MES, the combination of these metrics allows for higher order processes, such as ES, health, and resilience to be examined.

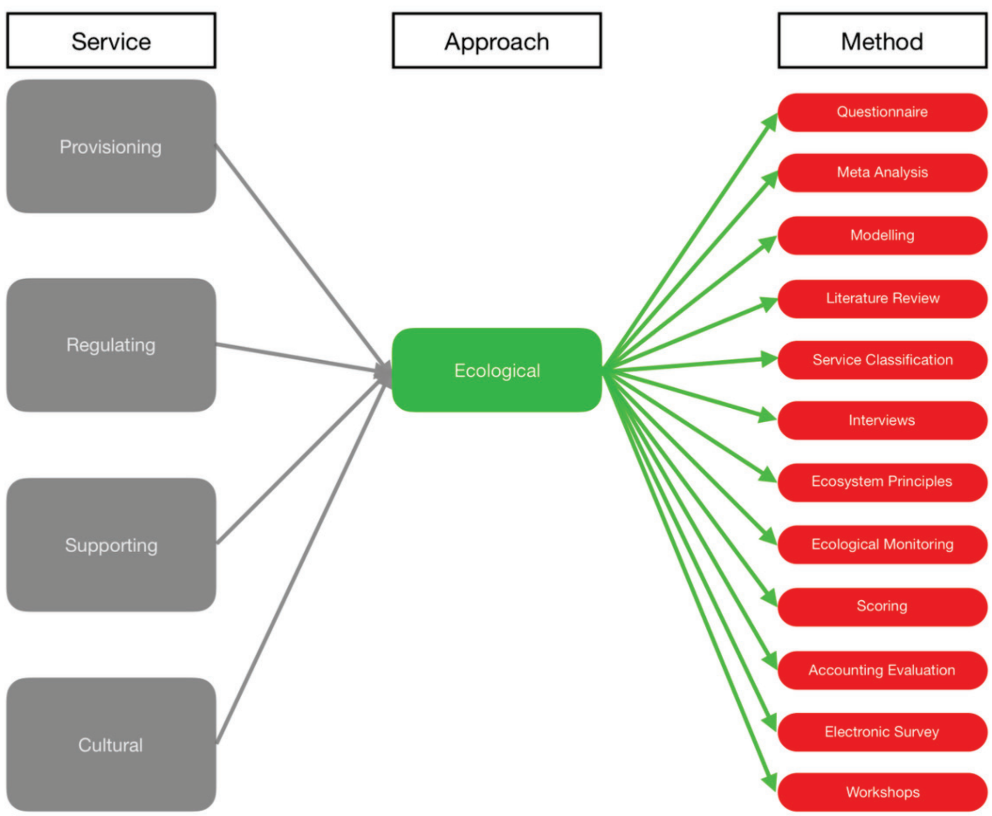

Fig. 2.2 An illustration of the connection between the ecosystem service assessed, the approach taken for the assessment, and the method utilized.

Assessments of ecological services can also examine abiotic conditions as they are integral to ecosystems, ecological functions, and thus MES (Atkins *et al.*, 2011; Cooper, 2013; Hattam *et al.*, 2015). However, abiotic conditions should generally be considered secondarily to biological units as MES are inherently derived from living entities (Fisher *et al.*, 2009). Still, biological units and abiotic conditions underlie every MES, allowing evaluations to consider their intrinsic value and the complex processes they support, as well as to forecast how deviations may alter services and recipient ecological systems (Palumbi *et al.*, 2009; Cardinale *et al.*, 2012; Teixeira *et al.*, 2019). This substantiates using an array of MES assessment metrics that are convertible, based on a common denominator (*i.e*., biological diversity) when examining ecological services.

2.2.1 Monitoring ecological marine ecosystem services

Monitoring the ecological components of MES poses several challenges for elucidating their long-term sustainability and predictability. An ecosystem's biotic and abiotic components can change incrementally or rapidly across a range of spatial scales. Both incremental and rapid modifications can alter the availability of MES, and generally the more extensive and sudden the change, the less likely the ecosystem is to recover (Scheffer *et al.*, 2001; Carpenter *et al.*, 2006; Jentsch *et al.*, 2007; Hawkins *et al.*, 2009). Furthermore, while gradual changes are less likely to alter MES irreversibly, they can signal deviations that will have downstream consequences for the ecosystem and the services it provides (Jentsch *et al.*, 2007; Hawkins *et al.*, 2009; Liquete *et al.*, 2013; Teixeira *et al.*, 2019). Monitoring one or several biophysical units can detect changes of varying severities if survey efforts measure the appropriate indicator(s) at the correct spatial scale(s) (Folke *et al.*, 2004; Walker and Meyer, 2004; Carpenter *et al.*, 2006; Liquete *et al.*, 2013). The selection of the monitoring technique(s) has a considerable influence on the survey's ability to detect ecologically relevant changes due to the plethora of available MES indicators and the spatial scales they occupy (Fig. 2.2; Table 2.1) (Liquete *et al.*, 2013; Portman, 2013). Some techniques employed include ecological monitoring (*e.g.*, counting biophysical units), workshops, meta-analysis, mathematical models, and questionnaires (Fig. 2.2). All of these can assess the ecological aspects of provisioning, regulating, supporting, and cultural ecosystem services (Fig. 2.2). Determining how to monitor ES should be based on the specifics of the service(s) being measured and the best available information on how to quantify it most effectively and accurately. Generally, decades of surveys have established connections between ES, assessment approach, and response metrics (Table 2.1; Annex Table 2.1). For example, examining ES that stem from fisheries, such as life cycle maintenance or fish biomass, should consider assessment approaches like estimating recruitment biomass, spawning stock size, and spawning area (Table 2.1). Examinations of this nature can use a series of metrics, including fish catch, spatial distribution, nursery area, juvenile and spawning fish density (Annex Table 2.1).

A resource-intensive multi-method approach is commonly required to survey MES effectively, as accurately monitoring ecosystems involves detecting a wide variety of ecological changes ranging from variations in species diversity to fluctuations in climatic processes (Liquete *et al.*, 2013; Teixeira *et al.*, 2019). Methods that monitor MES at broad spatial scales allow for geographic information systems and remote sensing techniques to illustrate relevant ecosystem-level trends whereas mathematical models can utilize MES surveys to examine the ecosystem components' connectivity, indicators' validity, and how changing ecosystems influence MES (Mooney *et al.*, 2009; Borja *et al.*, 2016). For example, changing ocean chlorophyll levels are detectable from satellites, while surveying ecological communities *in situ* and modelling biological interactions provides insight into changing MES, allowing for changes in chlorophyll levels to be attributed to biological interactions. If the data are robust enough, mathematical models can examine these relationships under theoretical conditions (Stow *et al.*, 2009; Liquete *et al.*, 2013; Canonico *et al.*, 2019). This forecasting allows for future MES to be predicted. Consistent application of multi-method approaches suggests that assessments of MES benefit considerably if a combination of scientific monitoring, mathematical modelling, mapping, and forecasting is employed (Fig. 2.3).

Table 2.1 Summary of ecological services, assessment categories, and approaches utilized when examining the ecological aspects of marine ecosystem services (MES).*

Ecological service	Assessment category	Assessment approach
Biodiversity	Biodiversity maintenance	Zooplankton biomass, benthic biomass, flagship species, species diversity, nursery habitats
	Community composition	Indicator diversity, community composition, phytoplankton diversity, zooplankton diversity, benthic diversity, pelagic diversity, species and communities condition, functionality index
	Functional diversity	Ecosystem function
	Genetic diversity	Gene pool maintenance, population genetic diversity, phylogenetic diversity
	Genetic resources	Gene pool maintenance, extracted genetics
	Indicator species	Indicator populations, sensitive or tolerant species
	Non-indigenous species	Non-indigenous species diversity, non-indigenous species impact
	Resilience	Ecosystem resistance and recovery
	Nursery populations	Spawners and recruits
	Species distributions	Distributional pattern, species distribution within a habitat, distribution limit
	Species diversity	Species Density Index, Biodiversity Index
Climate	Carbon sequestration	Carbon sequestration, carbon turnover, carbon movement and regulation
	Climate regulation	Habitats regulate climate, mediate air flow, biotic climate regulation, carbon and carbon dioxide fluxes, greenhouse gases fluxes
	Temperature	Sea surface temperatures
Fish and fisheries	Fish biomass	Landed biomass, annual biomass, regional biomass, spawning stock biomass, overflow biomass, biomass and trophic level
	Fish mortality	Mortality
	Fishing capacity	Annual fishing intensity, maximum sustainable yield
	Foraging area	Fish foraging potential
	Life cycle maintenance	Recruit biomass, nursery habitats, spawning and nursery area
	Population composition	Commercial populations composition, population size and biomass, fish length, fish size, species density
	Seafood quality	Mercury, polychlorinated biphenyls, lead, and petroleum hydrocarbon, concentrations

Table 2.1 Continued.

Ecological service	Assessment category	Assessment approach
Habitat	Biogenic habitats	Community use of biogenic habitats
	Coastal stability	Index for erosion control, shoreline protection, biogenic structures disturbance dampening, coastal erosion prevention, coastal protection model
	Habitat provisions	Abiotic conditions, characterization, quality, flagship species, impacted habitat area, refuge habitat
	Migration support	Migratory population support
	Oxygen demand	Oxygen concentration
	Sediment quality	Organic carbon concentration, soil formation and composition, acid volatile sulfide concentration
	Water quality	Water quality maintenance, quality days, extracted seawater, dissolved silicates concentration, habitat mediated flow, sediment transport, annual runoff, sea level rise, species distribution limit, suspended particles concentration
Nutrients	Filtration	Water filtration
	Nutrient density, regulation, and cycling	Inorganic nitrogen concentration, index of nutrient recycling, oxygen concentration, denitrification, nutrient concentrations, benthic eutrophication, biotic nutrient cycling, stored nitrogen and phosphorus, chlorophyll a concentration, flagship species, nitrogen and phosphorus accumulation, nutrient biomass, nitrogen assimilation
	Primary production	Biotic nutrient abundance, algae and plant production, phytoplankton and zooplankton concentrations, phytoplankton biomass
	Water quality	Water quality indicators, pollutants, capacity of water purification, diatom to dinoflagellate index, material transport
Pollution mitigation	Ecotoxicology	Pathogen, toxicity levels within species, harmful algae blooms
Raw material	Biotic resources	Extracted biotic resources, nutritional biomass, biotic biomass density, extracted mangroves, extracted seaweed
Renewable energy	Energy production	Potential wind energy area

* Reference sources, metrics, and ecosystem service types (*e.g.*, provisioning, regulating) relating to these data can be found in Annex Table 2.1.

2.2.1.1 Measuring ecological MES

A positive correlation between biological diversity and ecosystem function has emerged in recent decades (Cardinale *et al.*, 2012). Therefore, elevated biodiversity levels, expressed in terms of unique taxa, genetic variability, or functional diversity, increase ecosystem function, and thus resultant ecosystem services (Cardinale *et al.*, 2012). This association is more evident within provisioning (*e.g.*, population biomass) and regulating (*e.g.*, waste remediation) services (Cardinale *et al.*, 2012; Eastwood *et al.*, 2020). However, the influence of biological diversity on ecosystem function and services is not consistent across taxonomic units (Mooney *et al.*, 2009). Generally, dominant or abundant taxa have a disproportionate impact on ES, except in the case of keystone species and ecosystem engineers, which, by definition, have a substantial influence even if scarce (Lyons *et al.*, 2005; Mooney *et al.*, 2009). Nonetheless, less abundant taxa contribute to ecosystem processes that sustain ecological services, including functional redundancy and invasion resistance (Yachi and Loreau, 1999; Lyons and Schwartz, 2001). For example, increases in the diversity of functional traits and stress responses within an ecological community can elevate an ecosystem's resilience to environmental changes and its ability to consistently provide services despite changing climatic conditions (Elmqvist *et al.*, 2003; Duffy *et al.*, 2016). Therefore, measuring less abundant and dominant taxa concurrently may provide a more holistic understanding of MES.

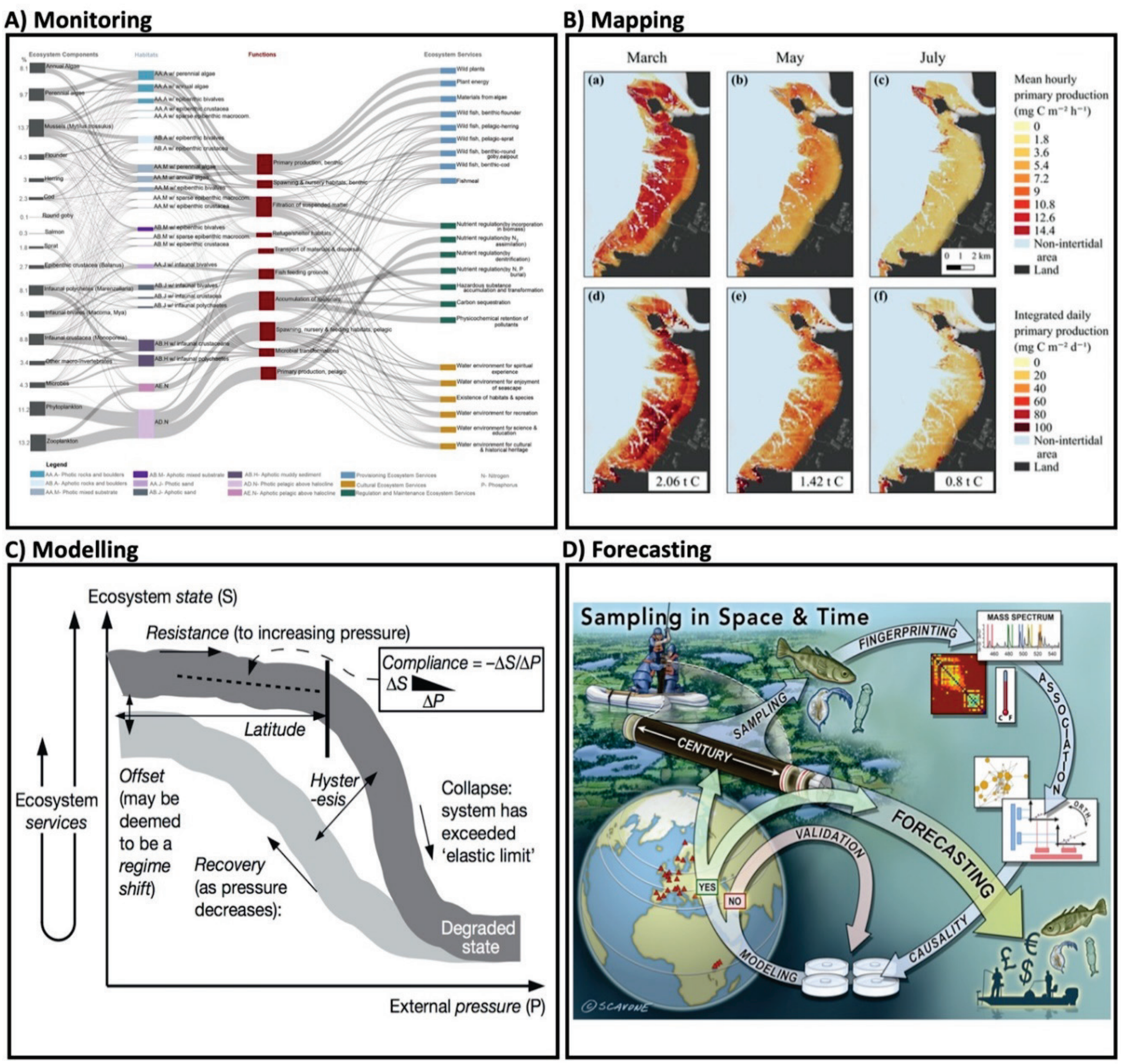

Fig. 2.3 Graphical depictions of monitoring, mapping, modelling, and forecasting the ecological attributes of marine ecosystem services (MES). A) Armoškaitė *et al.* (2020), B) Méléder *et al.* (2020), C) Tett *et al.* (2013), D) Eastwood *et al.* (2020). All figures are open-access adapted from open-access articles distributed under the terms of the Creative Commons Attribution License.

The ecological importance of monitoring more than species diversity has expanded the biological metrics surveyed when quantifying MES to include taxonomic richness, genetic diversity, community structure and composition, and species functions (Cadotte, 2013; Spaak *et al.*, 2017; Eastwood *et al.*, 2020). This approach can provide additional insight into MES (Rice, 2003; Liquete *et al.*, 2013; Rombouts *et al.*, 2013). Generally, an indicator should exhibit several quantities to describe a MES effectively and should (1) be adequately sensitive to provide prompt warnings of environmental changes that will impact MES, (2) have broad spatial and temporal distributions that overlap the focal MES, (3) be responsive to a range of MES stressors, (4) be cost-effective to measure and collect, (5) display distinguishable responses to anthropogenic stressors and natural cycles, (6) be coupled with ecological phenomena or services, and (7) occur independently of sample size (Noss, 1990; Rombouts *et al.*, 2013). Currently, more than 430 indicators exist to describe marine and coastal ecosystems, many of which are directly applicable to measuring MES (Rice, 2003; Liquete *et al.*, 2013). Selecting the appropriate indicator can be challenging as many fail to capture the complexity of MES adequately. Büchs (2003) recommends using a combination of indicators that collectively captures ecosystem structure, activities (*e.g.*, nutrient cycling), and ecological processes (*e.g.*, resilience) (Rombouts *et al.*, 2013). An additional advantage to utilizing a combination of indicators to quantify MES is that many indicators allow for complex and dynamic ecosystem processes to be expressed on a simplified numerical scale. However, the extent to which biological diversity and other indicators describe and predict MES varies considerably. Therefore, successfully detecting changes in MES through measuring one or several biophysical units commonly requires the integration of spatial assessments of the habitats or ecosystems that complement these survey efforts (Worm *et al.*, 2006; Burkhard *et al.*, 2012; Culhane *et al.*, 2020).

2.2.1.2 Mapping ecological MES

Marine ecosystem services exhibit heterogeneous distributions across ecosystems, with the abundance of services varying temporally. Dynamic interactions between variable biotic populations and fluctuating abiotic conditions create complex species distribution and resource availability patterns that decrease the likelihood that survey efforts with limited spatial coverage adequately capture MES (Teixeira *et al.*, 2019). Mapping MES, however, allows for multiple sites, gradients, or focal habitats to be surveyed over a large geographic area. Furthermore, mapping can integrate varying levels of human activities, ecological stressors, and environmental protection mechanisms (Worm *et al.*, 2006). If mapped accurately, the impact of biophysical units on MES can be characterized across a continuum of ecosystems, possibly identifying each biotic and abiotic component's role in facilitating ecosystem processes (Jax, 2005; Teixeira *et al.*, 2019). For example, increasing the spatial coverage beyond the limits of traditional measuring techniques (*e.g.*, local monitoring) has led to the identification of several novel ecological links, including the mounting awareness of the need to consider mobile biota in the spatial assessment of habitats (Lundberg and Moberg, 2003; Teixeira *et al.*, 2019). Several mapping studies have also examined how anthropogenic activities may disrupt MES. Mapping benthic habitat features over broad spatial scales allowed Hooper *et al.* (2017) to examine how changes in fishing pressure might impact remediation of waste, the provision of nursery habitats, carbon sequestration, and other ecosystem services.

Mapping marine ecosystems, their services, and their spatial distribution is a complex and expensive exercise that often involves exploring data-poor areas that require the use of advanced geospatial and remote sensing techniques (Portman, 2013). Unfortunately, many of the satellite or flyover techniques that have been applied successfully to terrestrial ecosystems (*e.g.*, Normalized Difference Vegetation

Index) are more complex and cumbersome for marine environments (Nunes *et al.*, 2011; Portman, 2013). Consequently, the use of Geographic Information Systems (GIS) and spatial analyses for examining MES has recently begun expanding, driven by innovations in remote sensing, photometric image analysis, digital cartography, and more recently, simulation visualization and augmented reality (Portman, 2013). These innovations have been aided by advancements in computing hardware, software, and spatial databases, allowing for more complex analyses of MES (Portman, 2013). For example, Integrated Valuation of Ecosystem Services and Tradeoffs (InVest), developed by the Natural Capital Project at Stanford University (Sharp *et al.*, 2020), includes distinct ecosystems for freshwater, marine, and coastal environments and develops spatially explicit models to determine how changes in an ecosystem's structure or function will affect ecosystem services. Models report outcomes in biophysical terms (*e.g*., tons of carbon sequestered), allowing for MES to be directly quantified (Portman, 2013; Cong *et al.*, 2020). Despite these advancements, constructing integrated maps that illustrate the abundance and fluctuations of MES at multiple scales is still uncommon. This deficiency is due to a lack of adequate marine data (*e.g.*, heterogeneous sampling, poor spatiotemporal coverage) and a limited understanding of the appropriate scale to map MES (Mooney *et al.*, 2009; Cognetti and Maltagliati, 2010; Portman, 2013). A quantitative synthesis by Liquete *et al*. (2013) determined that only four of the 145 papers on marine and coastal ecosystem services used mapping approaches, with all of them focused on the coastal zone (*i.e*., nearshore marine ecosystems). Consequently, integrating MES into conservation measures that aim to preserve ecosystem health (*e.g.*, marine protected areas) is insufficient and commonly relies on complex statistical methods to address data limitations (Mooney *et al.*, 2009; Manea *et al.*, 2019)**.**

2.2.1.3 Modelling ecological MES

The majority of marine ecosystems are composed of nonlinear relationships, limiting the capability of monitoring, mapping, and other techniques that assume linear associations between ecosystem components (Worm *et al.*, 2006; Chen *et al.*, 2013). Mathematical models allow for the intrinsic interactions between components to be examined while accounting for the complexity of these relationships. These models can integrate a range of relevant indices or broad ecosystem metrics such as MES, health, or resilience (Worm *et al.*, 2006; Chen *et al.*, 2013). Model variables can also be weighted to incorporate preexisting information on the ecological importance of specific factors or expert knowledge (usually as rank importance), making this technique especially effective when working with limited data. For example, Chen *et al*. (2013) utilized an ecosystem coordination index to match ecosystem structure and services levels before incorporating this data into an index that denotes the health of the Pearl River Estuary, China. This analysis effectively examined a range of weighted indicators for regulating, provisioning, and supporting services, biological communities, and habitat structure. Chen *et al*. (2013) determined the region's health index was 3–16% lower than that calculated using more traditional ecosystem assessment methods that did not consider ecosystem coordination. Chen *et al*. (2013) also determined that over the last three decades, the estuary's ecosystem health index decreased from 0.91 to 0.50, indicating deterioration from healthy to unhealthy status. Despite the evident advantages of this and similar approaches, the majority of MES models describe static systems due to limited analyses integrating spatial or temporal aspects of ecosystems (Liquete *et al.*, 2013). Three techniques can advance MES models to address this limitation: (1) extrapolate primary data collected through ecological or mapping surveys, (2) utilize habitat maps as a proxy for MES abundance based on scoring factors, or (3) use models specifically developed to examine MES (Liquete *et al.*, 2016).

Mathematical models have vast applications when examining the ecological aspects of biological populations and species-specific contributions to MES. Ecological niche models, for example, develop spatially explicit models for select taxa that are able to predict distributions in space and time, given their ecological requirements (Liquete *et al.*, 2016). Analogous terms for this modelling technique include species distribution models, predictive habitat distribution modelling, environmental niche modelling, and climate envelope models (Mooney *et al.*, 2009; Liquete *et al.*, 2016). A range of MES can be integrated and predicted using ecological niche models, especially those that focus on services that pertain to lifecycle maintenance, including recruit biomass and occurrence of spawning habitat (Liquete *et al.*, 2016). The predictive element of these models allows examiners to consider how environmental changes (*e.g.*, changing climatic conditions) will influence species distributions and population persistence (Mooney *et al.*, 2009). For example, Thomas *et al.* (2004) were able to predict that intermediate climate warming would drive 15–37% of species to extinction by 2050. These and other ecosystem models address single-species models' inability to inadequately capture the complex aspects of ecological communities by constructing models that represent the state of an ecosystem and its underlying processes (Rombouts *et al.*, 2013). Ecosystem models can then be used to calculate indicators for the system's physical attributes, trophic levels, integrity, resilience, and services (Rombouts *et al.*, 2013). This framework allows models to extend to abstract concepts such as "ecosystem health", by addressing a significant challenge when examining marine ecosystems—simplifying complex systems.

2.2.1.4 Forecasting ecological MES

The forefront of modelling MES is the ability to use data collected through measuring and mapping efforts to predict future conditions, ecological impacts, or the consequences of different management actions. These forecasting analyses address a prevailing constraint embedded within the majority of current MES models, which is their limited ability to extend beyond hindcasting (Liquete *et al.*, 2016; Eastwood *et al.*, 2020). Forecasted MES can utilize ecological niche models to predict populations distributions, given theoretical ecological conditions (Mooney *et al.*, 2009). Additionally, whole ecosystems models can use ecosystem state–space approaches that relate Euclidian distances from a reference state to ecological resilience (Tett *et al.*, 2013). Emerging applications within machine learning proposed by Eastwood *et al.* (2020) suggest it is possible to integrate biochemical and environmental data using fingerprinting with biological archives that span centuries. The associations obtained from this process can be run through a machine learning pipeline to identify cause–effect relations between environmental change and biodiversity dynamics. This approach allows for predictive models to be tested using hindcasting and forecast the future of ES under different ecological scenarios (Eastwood *et al.*, 2020). These vital developments within the study of ES have demonstrated the influence that anthropogenic activities, changing climate conditions, and mismanagement of ecosystems can have on MES (Rapport *et al.*, 1998; Worm *et al.*, 2006; Mooney *et al.*, 2009; Wernberg *et al.*, 2013). Consequently, accurate forecasts of MES are becoming increasingly important.

2.2.1.5 Ecosystem services and resilience

Ecologically, resilience is an ecosystem's capacity to resist and recover from disturbances, which allows the system to maintain its function, structure, and services (Folke *et al.*, 2004; Vallina and Le Quéré, 2011). Resilient ecosystems are able to maintain internal stability and prevent shifting into an alternative state (*i.e.*, regime shift) and subsequently maintain their ES. When the aim is to quantify services, stability, or resilience, biological units, and to a lesser extent abiotic conditions, are then the system components that warrant monitoring. However, despite the established importance of MES, mounting scientific interest in ecosystem resilience, and societal concerns surrounding declining ecosystem health, considerable uncertainty exists surrounding how to effectively classify and monitor system components. Liquete *et al*. (2013), for example, reviewed 145 papers that assessed marine and coastal ecosystem services represented by 476 indicators and determined that 68% of the papers did not follow or mention any standard classification system. The Millennium Ecosystem Assessment (MA) classification system was only used by 15% of the papers. The limited consistent use of classification systems likely stems, at least in part, from the multidimensionality of ecosystem processes, which requires assessment methods to be particularly robust and informative (Table 2.1, Annex Table 2.1, Fig. 2.1). Furthermore, as this approach views ecosystems as the services they provide to society and how human actions alter them, it has limited applications when solely considering the ecological components of ES (Carpenter *et al.*, 2009; Liquete *et al.*, 2013). Consequently, the study of MES must prioritize multidimensional investigations that combine field surveys, mathematic models, spatiotemporally robust mapping, and forecasting when seeking to contribute to examinations of ecosystem resilience and other higher-level environmental processes.

2.3 Economic assessment

In economics, ecosystem goods and services are valuable because of what they do for people, either directly or indirectly as inputs to their utility (a measure of well-being or satisfaction), or through their contribution to productive processes (such as their use in the production of other goods and services). Thus, by construction, economic values are inherently anthropocentric in nature. Economic values are also instrumental and utilitarian values (NRC, 2005) since the values of goods and services are derived from the role they play towards achieving a goal—increasing human well-being. In other words, they do not have value in their own right (intrinsic value); rather, they have value from being a means to an end (*e.g*., Brennan, 2007).

Economic value information of ES can be useful in policy and management contexts in which decision-makers are faced with balancing ecological, economic, and sociocultural priorities. This information provides a means for formal and quantitative trade-off analyses by facilitating comparisons across different types of ES and human activities. This is possible since economic values are measured in a common metric, usually a monetary currency. As a result, one can use these values to apply formal policy analytic approaches like benefit-cost analysis (BCA) to evaluate alternative policies or management actions in relation to fisheries, coastal protection, biodiversity, marine protected areas, off-shore energy, or other coastal and marine issues involving multiple stakeholders and a diversity of ecosystem services. In their evaluation of the ES economic valuation literature, Torres and Hanley (2017) identified eight specific management areas for which economic values for coastal and marine ES can potentially be utilized: wetland management, beach management, coastal area management, freshwater resource management, coastal water management, coral reef management, marine protected areas management, and general protection strategies for the open seas.

TEEB (2010) and Gómez-Baggethun and Barton (2013) highlight several other uses for economic value information of ES besides facilitating evaluation of trade-offs: awareness raising, green accounting, instrument design, and litigation. Awareness raising relates to the fact that knowledge of the economic value of an ecosystem service can highlight its importance to society. Green accounting refers to both private and public efforts to account for natural capital and environmental costs. For example, the United Nations' System of Environmental Economic Accounting (SEEA) (https://seea.un.org/)

represents an effort to provide a more comprehensive view of the relationship between national-level economies and the natural environment to enable tracking natural capital values change over time. Instrument design refers to the use of economic value information to inform policy makers in their efforts to design management programs that may involve payments for ecosystem services like user or access fees or determining a project or program budget that does not exceed the value it would have for the public. Lastly, economic values of ES are often desired in litigation involving natural resource damages (Kopp and Smith, 1993; Barbier, 2013).

2.3.1 Economic values of market and non-market goods

In economics, individuals are assumed to choose between bundles of goods and services that maximize their well-being (or satisfaction), referred to as "utility". This bundle includes private and government-provided goods and services, as well as quantities and qualities of ecosystem goods and services that are not bought or sold in explicit markets. These latter goods and services are generally referred to as "non-market goods and services" since they cannot be observed to be bought and sold in explicit markets. The trade-offs between different bundles of goods and services individuals make provide an indication of the value people place on them. For example, for "market goods and services," the prices people pay indicate that the value they place on these goods and services is at least equal to what they paid.

The theoretically appropriate measures of economic value are willingness to pay (WTP) and willingness to accept (WTA). WTP and WTA correspond to compensating measures of welfare change (see Mas-Colell *et al*. (1995); Freeman *et al*. (2014)).[6] Which of the two is appropriate depends upon property rights—who owns the resource. For a decrease in the quality or quantity of an environmental good or service, the WTP is the maximum amount that the individual would pay to avoid the change, whereas the WTA is the minimum amount that would need to be given to the individual to make the individual as well off after the change as they were before. For an increase in an environmental good or service, WTP is the maximum amount an individual would pay to bring about the change, while WTA is the minimum amount one would accept to not have the change occur.

A common typology (Fig. 2.4) of economic values often made in discussions of non-market goods and services, and ecosystem goods and services specifically, is based on the concept of total economic value (TEV) (MA, 2005; NRC, 2005; Freeman *et al*., 2014). A common decomposition of the TEV of a good or service is into use and nonuse values (Freeman *et al*., 2014). "Use values", as the name implies, are those values or benefits derived from the use of the good or service and can be either direct (*e.g*., consumption of seafood) or indirect (*e.g*., coastal erosion protection, pollution filtration). "Direct use values" involve direct interaction with the environment and can either reflect "consumptive uses" involving the extraction of a component of the ecosystem (*e.g*., harvesting fish or hunting wildlife) or a "non-consumptive activity" that involves direct contact but no extraction (*e.g*., recreational activities like swimming). "Indirect use values" are derived from ecosystem services that provide regulatory functions in the ecosystem (*e.g*., coastal erosion protection) but do not require direct interaction with the ecosystem. These types of values also include those associated with learning about or studying the

[6] There are four exact welfare measures that differ in the utility level assumed (before the change or after the change) and the type of change being valued (price or quality/quantity change). Compensating variation and equivalent variation are the exact welfare measures associated with price changes, and compensating surplus and equivalent surplus correspond to quality or quantity changes. Compensating welfare measures assume the initial level of utility (well-being) is the basis of comparison, while equivalent welfare measures assume the level of utility to base the changes upon is the level achieved after the change.

good or service, but not directly interacting with it. Another type of use value is "option value," which is the value placed on the good or service being available for one's own future use (either consumptive or non-consumptive). On the other hand, "nonuse value" is the value independent of any use of the good or service and generally is attached to ecosystem goods and services that are unique or special and subject to irreversible loss or injury (Freeman *et al*., 2014). The concept of nonuse value is generally attributed to Krutilla (1967), who made the seminal observation that many people may hold value for unique natural resources simply because they exist. Types of nonuse values include "existence value" (the value of simply knowing the good or service exists), "bequest value" (the value of knowing it will exist for future generations), and "altruistic value" (the value of knowing it will exist for others in the current generation) (*e.g*., van Beukering *et al*., 2015).

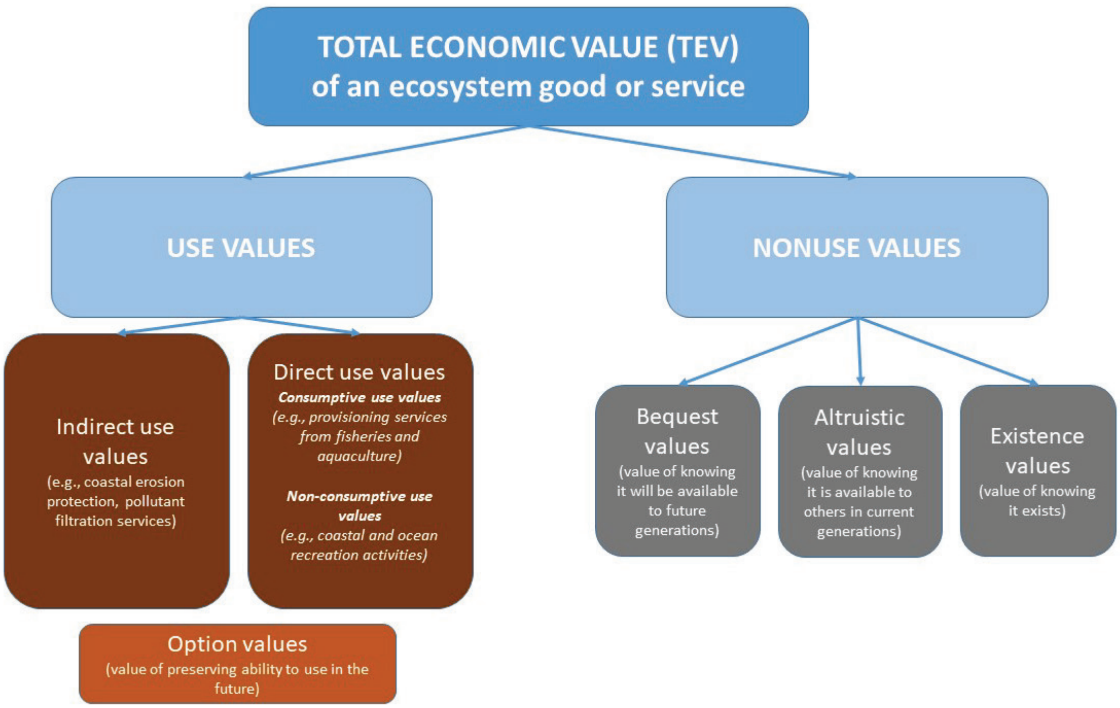

Fig. 2.4 Total Economic Value (TEV) and its constituent values.

2.3.2 Measuring economic values of MES

2.3.2.1 Market valuation approaches

While most ES are not bought or sold in explicit markets, some like seafood are. When explicit markets exist for an ecosystem service, market prices provide a signal of the value people place on it and analysis of market behavior (transactions between buyers and sellers) can be used to directly reveal economic values. In "market valuation" of ES (assuming the market is competitive),[7] economists are

[7] Competitive markets are ones where there are many buyers and sellers, and both buyers and sellers are price-takers (they cannot individually exert influence over the price).

most interested in measures of economic surplus, which, for a given amount of a market good or service, is the WTP net of the costs of providing the good or service. This economic surplus is the sum of the consumer's surplus, which is the consumer's WTP minus the amount paid, and the producer surplus, which is the total revenue (price times quantity) from the transaction minus the variable costs of producing the good or service.

When ES are used as inputs in the production of a related market good or service, "production function-based approaches" can be used to estimate economic values (Barbier, 2007). If the relationship between the ecosystem service and how it is used in the production of the related market good or service can be measured, the value of changes in the level of the ES will be reflected in associated changes in the value of the market good or service. Therefore, analyzing the market for the related good or service provides an avenue for understanding the economic value of the ES.

"Cost-based approaches" use information about what people spend to avoid or mitigate the loss of an ecosystem service or to substitute or replace it. The former type of cost-based approach is generally called the averting expenditures method and the latter is the replacement cost method. These approaches, while commonly used, do not generate theoretically consistent measures of economic value. They work under the assumption that the amount of money people spend in mitigation or to substitute or replace the ecosystem service is a lower bound on its economic value. Unfortunately, this is not likely to hold in many cases. To illustrate, consider a market good. The economic value to a consumer of the market good can be measured by the consumer's surplus. Cost-based methods measure the cost (the amount paid), not the consumer's surplus. As a result, economic values derived from cost-based approaches should be viewed with skepticism.

2.3.2.2 Non-market valuation approaches

Values for non-market goods and services are estimated using either revealed preference (RP) or stated preference (SP) valuation approaches (Fig. 2.5). RP valuation methods use information on observed behavior to infer the preferences for, and value of, the non-market good or service (Boyle, 2003; Bockstael and McConnell, 2007). As such, these methods require data on observable behavior to be linked to the non-market good in question, such as information on a market good that is consumed in conjunction with the non-market good (complement) or, instead, of the non-market good (substitute). SP methods, on the other hand, involve asking individuals carefully worded hypothetical market questions to either directly or indirectly infer the value they place on a non-market good or service (Mitchell and Carson, 1993; Carson *et al*., 2001). Thus, the principal difference between the RP and SP methods is the type of data used. RP methods use data on observed behavior to infer economic values, while SP methods use data on stated or intended behavior to infer economic values. Due to its reliance on observable behavior, RP methods are generally not able to estimate nonuse values, which, by definition, are not tied directly to observable behavior. Thus, researchers must use SP methods to estimate nonuse values.

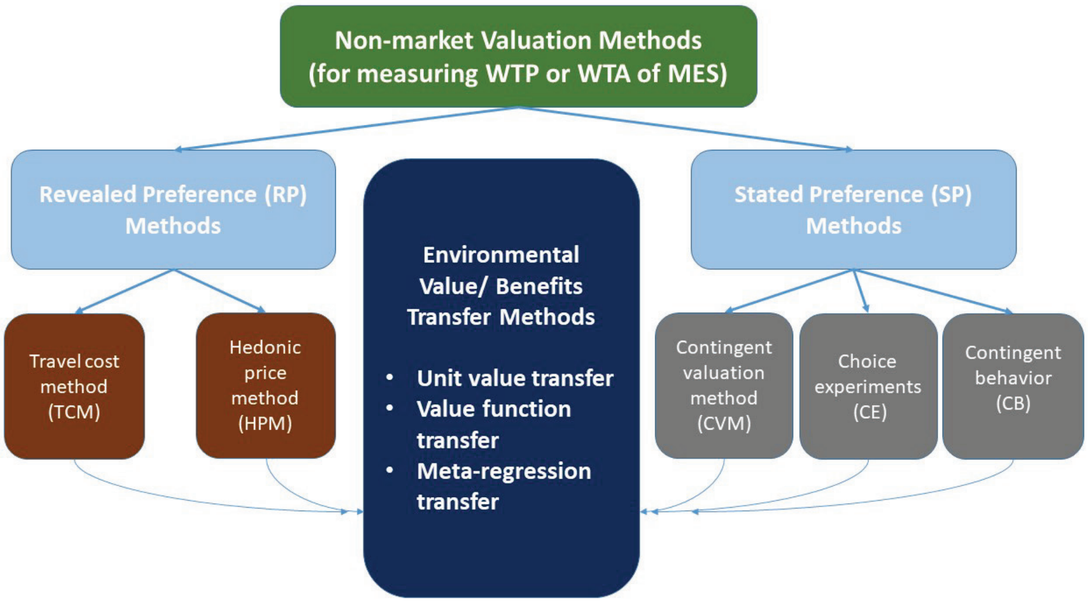

Fig. 2.5 Non-market valuation approaches. WTP = willingness to pay, WTA = willingness to accept.

2.3.2.3 Revealed preference methods

The two most common RP approaches are the travel cost method and hedonic price method. The travel cost method (TCM), or recreation demand modeling approach, is a RP approach often used to value recreational resources (Parsons 2003; Lupi *et al*., 2020). TCM models assume that the costs of travel to and from recreation sites are the implicit price of the visit. Although there are a number of variants of this approach, TCM studies have in common the use of trip expenditure and visitation data for visitors to a natural resource area (*e.g*., a beach, coastal wetland area, coral reef, or marine protected area) to extrapolate the associated value of the area. TCM models are limited to valuing the use values associated with recreational amenities. Contemporary TCM models generally focus on analyzing individual-level recreational decisions and require data on individual recreationists' trip-making behavior, trip expenditures, and socio-economic information. A common variant of the TCM is the random utility maximization (RUM) travel cost model, which is used to model the individual's choices between different recreation opportunities, such as the choice between fishing at different locations (*e.g*., Lew and Larson, 2011).

The hedonic price method (HPM) is useful for valuing ecosystem services that are attributes of quality-differentiated market goods. Some relevant quality-differentiated market goods in this context are coastal properties and many types of seafood. In general, HPMs assume that the price of a market good is a function of its attributes (Taylor, 2003). For example, the hedonic property value model assumes the price consumers pay for a house in a given location embodies features of the house (number of rooms, square footage, *etc*.), locational amenity characteristics (proximity to schools, parks, shopping, *etc*.), and certain ES, such as the scenic ocean view (or lack thereof) from that house. Estimates of the value of these ES (and other characteristics) can be derived by an analysis of price differentials across property sales using statistical methods (*e.g*., Sander and Haight, 2012). Hedonic price methods have also been applied to seafood markets to identify the marginal value of sustainable harvesting practices (evidenced through ecolabels) and other characteristics (Bronnmann and Asche, 2016; Asche *et al*., 2021). Two recent alternatives to hedonic methods include discrete choice models and sorting models that focus on analyzing individual decisions from a structural (economic theory-motivated) perspective (*e.g.*, Sieg *et al*., 2004). See Phaneuf and Requate (2016) and Kuminoff *et al*. (2013) for useful overviews of these recent approaches.

2.3.2.4 Stated preference methods

Perhaps the best known stated preference method is the contingent valuation method (CVM). In CVM, economic values for a non-market good or service are revealed through survey questions that set up hypothetical markets for a non-market good or service. These CVM questions involve asking the respondent questions to indicate their WTP (or WTA) for the good or service. In a typical CVM survey, a good is described, such as a program or policy, and respondents are asked questions to elicit their WTP for it through a payment vehicle, like taxes or contributions to a trust fund (Mitchell and Carson, 1989; Johnston *et al*., 2017). Contingent valuation methods are differentiated by the way they elicit WTP. Respondents are commonly asked to directly state their maximum WTP (open-ended CVM question), choose the amount they are willing to pay from a list of values (payment card CVM question), or accept or reject a specific amount (referendum CVM question).

Like the CVM, the choice experiment (CE) approach relies on using carefully constructed survey questions to elicit economic values. Due in part to the flexibility of the CE approach in valuing a wide range of non-market goods and services, its use has increased considerably over the past two decades (Hanley *et al*., 1998; Alpízar *et al*., 2001; Johnston *et al*., 2017). In this approach, respondents are asked questions in which they must choose between two or more alternatives that differ in one or more attributes, including cost. By decomposing environmental goods, in the form of choice alternatives (*e.g*., policies or programs), into measurable attributes (*e.g*., specific outcomes of ecosystem service levels under each alternative, costs to the respondent, and other impacts), value can be estimated from an analysis of choices between different alternatives. Since choice alternatives are described by their attributes, and the effects of these attributes on choice are estimated in the model, it is possible to estimate economic values for alternatives not originally included in the CE questions seen by respondents. Variants of the CE approach include contingent rating and contingent ranking, where the respondent rates or ranks each choice alternative, respectively, instead of choosing between them (Boyle *et al*., 2001; Siikamäki and Layton, 2007).

Another type of SP approach is the contingent behavior (CB) method. In this method, respondents are asked questions about what they would do in a counterfactual situation in which one or more conditions (*e.g*., ES levels) have changed. In the context of CB questions about recreational decisions, responses to these questions are often combined with RP data (observed recreational decisions) within a combined data TCM model (Englin and Cameron 1996; Whitehead *et al*., 2008; Whitehead and Lew, 2020). Combining CB data with RP data can be used to overcome a limitation of RP approaches—that preferences and values can only be measured within the range of observed behavior. Thus, if the value of a change in an ecosystem service is desired but is outside the current set of experience revealed through RP data, SP methods like CB are often employed.

2.3.2.5 Benefits transfer/Environmental value transfer

A growing field of study in economic valuation is concerned with how to transfer economic value information from one or more previously completed studies to a new application (which we refer to as the "policy application"). This process is called benefits transfer, or environmental value transfer (Smith, 2018; Johnston *et al*., 2021). There are three common techniques for transferring economic benefit information from an existing study to a new policy application:

1. *Unit value transfer:* This typically involves using the mean or median economic value estimate from an existing study directly in the new policy application (Boyle and Bergstrom, 1992; Desvousges *et al*., 1992). No adjustments are made to the value estimate to account for differences in the population of interest that may arise due to income or demographic, resource use, or behavioral differences.

2. *Value function transfer*: Instead of transferring values from an existing study, this approach involves directly using the estimated function from an existing study that was used to calculate economic values, instead of the values themselves (Loomis, 1992). Adjustments to the value estimate arise by inserting information about the new policy application into the transferred value function. For example, if in the original study a WTP function was estimated as a function of demographics of the sample, a new WTP estimate could be calculated from the function by inserting the demographics of the population of interest into the new policy application.

3. *Meta-regression transfer*: Meta-analyses have been used to synthesize and summarize existing valuation studies of ES (Quintas-Soriano *et al*., 2016; Lara-Pulido *et al*., 2018; Grammatikopoulou and Vačkářová, 2021). Meta-analyses of this type involve conducting regression analysis to understand how economic values from existing studies vary by the characteristics of the goods being valued in each study and on features of the studies themselves. The resulting summary value function can then be used in the same manner as in the value function transfer to provide a customized estimate of economic value for the new policy application.

Regardless of the method used, benefits transfer is only useful if it provides valid estimates of value for the new policy application. The existing literature seems to support the idea that the more closely the researcher can customize the value estimate to the new policy application, the more accurate the transferred value will be to the value that would be generated if a primary study had been done (Johnston and Rosenberger, 2010; Johnston *et al*., 2021). Moreover, the use of benefits transfer methods presupposes one or more high-quality valuation studies exist with values or value functions that are appropriate to transfer to the new policy application. Concerns about temporal stability of preferences and values suggest ES economic values may not be static over long time periods, limiting the available studies available to draw upon to more recent studies (Lew and Wallmo, 2017). Another concern relates to the fact that in non-market valuation studies economic values are estimated for a sample of individuals representing a particular population. Given differences in cultural values and attitudes toward ES and socio-economic characteristics in different countries, a natural question that arises is whether one could reasonably transfer values for an ecosystem service from one country to another. Studies suggest that doing so can lead to significant transfer errors (Lindhjem and Navrud, 2008; Londoño and Johnston, 2012). These and other issues (Johnston *et al*., 2021) point to challenges of using benefits transfer methods to value ES instead of conducting a primary (*de novo*) study. However, given the high cost, limited budgets, required expertise in valuation methods, and short timeframes often faced by those seeking economic values for ES, benefits transfer methods are often the only feasible option.

2.3.2.6 Economic valuation of MES

Table 2.2 presents the types of economic values and the economic valuation methods used to measure them by common MES type from Table 1.1 in section 1. In Table 2.2, only ES types that can be valued using economic valuation are included. Absent are the cultural ES associated with social, cultural, and religious benefits that are generally outside of scope of economic valuation or are components of nonuse benefits that cannot be separately measured. In general, SP valuation methods are used to value many cultural ecosystem services, like recreational and nonuse benefits. RP methods can be used to value recreational benefits and some supporting/regulating ES. Direct market valuation can be used to value many provisioning ES, while the production function approach can be used to value some provisioning and supporting/regulating ES.

Table 2.2 Marine ecosystem services and economic valuation (similar to Goulder and Kennedy (2011)).

Ecosystem services*	Type of economic value	Valuation method(s)
Food source (provisioning)	Direct use values • Consumptive use values	Direct market valuation Production function approach
Source of non-food materials (provisioning) Supporting and regulating functions (supporting and regulating)	Direct use values Indirect use values	Hedonic price methods Production function approach
Recreational benefits (cultural)	Direct use values • Non-consumptive use values Indirect use values	Travel cost method Hedonic price method Choice experiments Contingent valuation Contingent behavior
Nonuse benefits (cultural)	Existence values Bequest values Altruistic values	Choice experiments Contingent valuation

* Millennium Ecosystem Assessment classification

2.4 Sociocultural assessment

Sociocultural analyses aim to understand how people create knowledge and meaning about ecological components of the physical environment (Ciftcioglu, 2017; Pascua *et al*., 2017; Sterling *et al*., 2017; Morishige *et al*., 2018). All social science inquiry assumes a degree of relativism and constructivism, which recognizes that reality is constructed within the human mind and is influenced by social and cultural contexts such as social norms, traditions, and history (Tashakkori and Teddlie, 1998; Moon and Blackman, 2014). Individuals from different backgrounds engaging in similar activities can experience different ecosystem services or well-being outcomes. For example, when fish are harvested, the fish may be consumed by the fisher, shared within social networks, or provided for cultural or religious events. While the fish are eaten in each instance (a provisioning ecosystem service), the sociocultural benefit can be diverse and multiplicative. Together, these interactions and relationships between people and nature affect how individuals and communities interpret ecosystem services.

From a sociocultural perspective, MES are shaped by people's perceptions and interactions with the environment (Díaz *et al*., 2015; Christie *et al*., 2019). Sociocultural ES assessments have typically focused on non-material goods and services derived from the biotic and abiotic components of an ecosystem (MA, 2005; Chan *et al*., 2012; Comberti *et al*., 2015; Fish *et al*., 2016; Pascua *et al*., 2017). While the existence of non-material goods and services depend on the presence of the biophysical units, their derived value depends on the diverse meanings people create and assign for them (Ingram *et al*., 2020). These meanings are experienced at varying levels and scales, depending on an individual's or community's unique interactions with the environment and each other (Raymond *et al*., 2014; Kenter *et al*., 2015, 2019; van Riper *et al*., 2019).

In addition, sociocultural analyses seek to include multiple value and knowledge systems, also known as worldviews or paradigms (Chan *et al*., 2012; Comberti *et al*., 2015; Calcagni *et al*., 2019). Since stakeholders think about and interact with marine resources in a variety of ways, understanding these diverse perspectives is critical to achieving an equitable analysis (Ives and Kendal, 2014; Horcea-Milcu *et al*., 2019; Kronenberg and Andersson, 2019). Sociocultural assessments investigate how worldviews influence and are influenced by culture, traditions, and socialized meanings of interactions with the environment. Worldviews can range from dominant natural resource management culture, with fishing viewed as a commodity in a predominantly capitalist society, to local fishing cultures with long histories of community reliance on fishing for livelihood and community cohesion, to Indigenous cultures where marine resources may be more appropriately thought of as relational responsibilities that require care and foster stewardship.

In addition to a wide range of worldviews, sociocultural analyses consider the value of what nature does for people (instrumental values), the inherent value of nature (intrinsic values), and the preferences, principles, and virtues related to human–nature relationships (relational values, Chan *et al*., 2018; Gould *et al*., 2019). In alignment with economic definitions, instrumental values evaluate how nature contributes to humans in a utilitarian aspect through both direct and indirect use (TEEB, 2010). Intrinsic values consider nature as inherently valuable in its own right, regardless of human use. Importantly, in sociocultural considerations, the meaning of intrinsic values can vary slightly depending on whether a person's worldview includes humans as separate from or existing alongside/within nature, which will influence a person's interactions with nature (Batavia and Nelson, 2017). Relational values expand on instrumental and intrinsic values by recognizing the existence and meaning of reciprocal relationships between humans and nature (Comberti *et al*., 2015; Chan *et al*., 2018; Gould *et al*., 2019). Dominant scientific conceptual frameworks commonly depict human interactions with nature in terms of negative impacts and stressors (Leong *et al*., 2019). The concept of relational values was created in an attempt to name and capture the many diverse influences humans have on and with nature. Some have termed these relationships "services to ecosystems," to acknowledge that people can enhance (*e.g.*, *via* stewardship), as well as modify or degrade nature and its related services (Comberti *et al*., 2015; Ingram *et al*., 2020). For example, taro farming in Hawaiʻi, along or within natural waterways, helps to provide flood protection and a food source to people and helps to clean waterways, put nutrients back into the soil, and provide habitat protection for different plant and animal species (Bremer *et al*., 2018; Winter *et al*., 2020).

A common framework used to assess sociocultural aspects of ES comes from the Millennium Ecosystem Assessment (MA, 2005). Within this framework, sociocultural considerations are categorized as cultural ecosystem services (CES) and limited to non-material services and benefits (MA, 2005), which has been noted as a shortcoming (*e.g.*, Fish *et al*., 2016). Other difficulties include a reliance on quantification and monetization within the ES framework (Chan *et al*., 2012; Fish *et al*., 2016; Calcagni *et al*., 2019), the incommensurable nature of CES (Calcagni *et al*., 2019), the conceptualization of CES as a one-way linear flow (Comberti *et al*., 2015; Chan *et al*., 2018; Calcagni *et al*., 2019), the intangibility of CES (Chan *et al*., 2012; Fish *et al*., 2016; Gould *et al*., 2019), and the lack of inclusion of diverse worldviews in ES conceptualization and management implementation (Comberti *et al*., 2015). Other sociocultural methods besides quantification and monetary valuation can be inclusive of a diversity of values and knowledge systems but are often either place-specific or value/situation specific (Fish *et al*., 2016; Pascua *et al*., 2017; Gould *et al*., 2019).

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has attempted to broaden this limited framing by acknowledging and including relational values, but faces the challenges of value intangibility and the limits of sociocultural methods (Stokland *et al*., 2022), which is explored in this section. There is a promising movement to increase inclusivity of sociocultural connections to, relations with, and influences on the environment (Ciftcioglu, 2017; Pascua *et al*., 2017; Sterling *et al*., 2017; Morishige *et al*., 2018). The IPBES approach to valuing nature's contribution to people is founded on acknowledging the diversity of values that serve as a conduit between nature and achieving a good quality of life, which includes human well-being outcomes (Díaz *et al*., 2015; Pascual *et al*., 2017). This approach expanded the ES framing to make room to acknowledge and include relational values. Bringing relational values into an ES framework helps to move away from perceiving ES as strictly "goods and services" that benefit humans and instead, bring in the many ways humans influence and are influenced by nature, an inherently multidirectional understanding.

2.4.1 Assessment approaches

Sociocultural assessments of MES investigate the instrumental, intrinsic, and relational connections between humans and the marine environment using monetary and non-monetary valuation metrics to signify importance. Section 2.3 covered economic, often monetary approaches, whereas in this section, we focus more on non-monetary approaches. Several recent publications have systematically reviewed the specific mechanics and nuances of sociocultural assessment methods and the frameworks they are often encompassed in (*e.g.*, Huynh *et al*., 2022; IPBES, 2022). Whereas those studies are valuable for understanding discourses and refining methods, we focus on detailing the broader methodological realms surrounding approaches to sociocultural assessments of MES. Activities related to MES (*e.g.*, fishing) can be measured directly (*e.g.*, number of recreational fishing trips). Yet, assessing perceived benefits and connections from those activities first requires defining the concepts of interest and then developing ways to systematically document them. Approaches can be quantitative, such as psychometric scales that use structured questions to quantify pre-determined dimensions of concepts like social cohesion or sense of place. Qualitative assessments often start with a more inductive approach, where the important dimensions of concepts emerge from the data itself. In practice, most studies employ mixed methods that apply both quantitative and qualitative approaches to understand different aspects of the issue and confirm results. The objective of each study will determine the type of method(s) employed. Below, we discuss examples of common approaches that have been used to assess sociocultural ecosystem services.

2.4.1.1 Quantitative assessments

Quantitative methodologies are often used in sociocultural assessments when research questions are focused on understanding the distribution of user/stakeholder preferences or the degrees of such preferences across predetermined categories. Quantitative methods typically involve deductive approaches and produce measurable data. Approaches commonly used for ES assessments include structured surveys, choice experiments, and scenario analysis. Quantitative methods usually seek larger sample sizes, which can allow for more robust statistical analyses when appropriate. Data are typically collected from individuals and pooled to gain a better understanding at the population level. Due to the deductive and commensurable nature of quantitative methods, these approaches are better suited to study established indices of instrumental and intrinsic values. They could also be used for relational values, but as relational values are a fairly new concept, there are few established measurement typologies (Christie *et al*., 2019; IPBES, 2022).

Structured surveys are a common method used in quantitative sociocultural assessments. Structured surveys rely on closed-ended questions with specific response categories (*e.g*., yes/no, check all that apply, response scales such as level of agreement or disagreement). Structured surveys can help to understand broad participant preferences, demographics, and attitudes. Surveys are typically collected at the individual or household level and aim to look at population preferences. Respondents can be asked directly about their perception of benefits by presence–absence assessments or can use rating or ranking scales. The questions asked in surveys can contain non-numeric or even qualitative aspects, but respondents must select from structured response categories or assign numeric values. For example, van Riper *et al*. (2017) surveyed visitors to a national park to understand how people perceive benefits of the park. Specifically, they asked participants to allocate points to different types of values to show preferences and trade-offs between them. The survey included values such as recreational activities of the park, opportunities for scientific observations and experimentation, and the ability for future generations to experience the park.

Choice experiments look at respondent preferences based on choice attributes and choice behavior, thus aiming to reveal the motivations behind their behaviors. In addition to their role in economic valuation (subsection 2.3), these experiments have proven valuable in including preferences for non-material concepts (Barnes-Mauthe *et al*., 2015). From an economic disciplinary lens, choice experiments typically are used to infer respondents' willingness-to-pay for certain attributes (Barbier *et al*., 2011). However, choice experiments have also been used to estimate the relative value of attributes compared to other attributes based on preferences and willingness or lack of willingness to trade between attributes directly, not *via* monetary proxy. Ament *et al*. (2017), for example, looked at the tradeoffs and synergies between different bundles of CES: natural history, recreation, sense of place, safari experiences, and outdoor lifestyles.

Scenario analysis can be seen as a narrow focus under the broader umbrella of choice experiments. However, scenario analysis evaluates different scenario options (rather than attributes) that often mimic management interventions in order to inform policy and decision making. Scenario analysis assesses possible alternatives and outcomes and can show the preferred scenario based on attribute preferences (Adams *et al.*, 2016). For example, Kalantari *et al*. (2017) examined different types of scenarios of travel methods to access water-related CES. This approach could also be applied to changes in numbers or abundance. While scenario analysis and choice experiments are similar, the main differences are the objectives and framing, particularly in regard to comparing attribute preferences directly to each other (choice experiments) or understanding how attribute preferences change across different possible futures (scenario analysis).

A common quantitative approach has been to conduct benefit-cost analyses of CES, that is, the monetary valuation of benefits derived from CES in comparison to the monetary costs of maintaining that CES and any foregone alternative benefits that might be a tradeoff with the CES at hand (Daily *et* *al*., 2009). Such approaches have followed the logic that CES, as with other ecosystem services, have been either devalued or unvalued on the market, and so by attaching monetary estimates of the perpetuation or loss of certain CES, decision makers will be better able to properly account for these aspects, therefore advancing sustainability goals (Carpenter *et al*., 2009; Daily *et al*., 2009). However, when viewed through a sociocultural lens a number of critiques of benefit-cost analyses have surfaced related to sociocultural assessments of ecosystem services, especially with respect to more sensitive cultural facets. For one, there are methodological concerns around whether benefit-cost analyses of CES accurately capture the underlying dynamics, particularly given the pluralistic and often intangible nature of human relations with the environment (Fish *et al*., 2016). Furthermore, such benefit-cost analyses place monetary values on cultural values and run the risk of obscuring people's worldviews and misrepresenting their embodied values, particularly regarding Indigenous cultures. In these cultures, many facets are understood to be integral to sense of identity and therefore invaluable (Gould *et al*., 2014). Lastly, many cultural paradigms, particularly Indigenous kincentric modalities of relating with the environment, are incommensurable with capitalist norms and market logics, such that the benefit-cost valuation mechanisms would insufficiently embody the cultural values and possibly alter the very cultural fabric itself (Fish *et al*., 2016; Salmón, 2000). Therefore, rather than conducting benefit-cost analyses of CES, particularly in regard to more sensitive cultural dynamics, a more culturally sound and efficacious approach is to conduct choice experiments or scenario analyses as described above. This type of approach is particularly robust when researchers collaborate closely with communities to understand sociocultural assessments without reducing culture to monetary metrics.

2.4.1.2 Qualitative assessments

Qualitative methodologies are largely inductive approaches that rely on narrative data and interpretation-based analysis. They are typically employed when seeking to establish a new framework or typology through which to understand a concept, such as when engaging with new stakeholder groups who may bring different worldviews to their relationship with resources, or to identify appropriate response categories for structured surveys that can assess population-level perceptions. In contrast to quantitative methods that focus on breadth and generalizability of results across populations, qualitative assessments focus on in-depth understanding of concepts from specific perspectives. Common data collection approaches include workshops, interviews (semi-structured and unstructured), and ethnography. Qualitative methods typically have smaller sample sizes, and generalization to a population is rarely a research goal. For sociocultural assessments of MES, qualitative studies strive to provide data that illuminate the intricacies, complexities, and juxtapositions regarding instrumental, intrinsic, and relational values. These methods are increasingly common in ecosystem assessments as a complement to quantitative assessments. Qualitative methods allow for more discussion to understand the reasoning and deeper meaning behind perceptions and concepts. Deliberative processes include dialogue between participants who learn from each other. These processes can create space that can recognize diverse values and perspectives (Kenter *et al*., 2015; Lopes and Videira, 2018). However, these methods are time-consuming, and results are dependent on both the researchers and the participants. Researchers depend on participants to give full and honest responses, while participants depend on researchers to accurately and adequately interpret and reflect their perspectives. As such, there needs to be trust and comfort between participants and researchers to get honest and meaningful feedback, as well as continual collaboration to cross-validate all results and their interpretations. Due to the nature of qualitative methods, these methods are best suited to inspect in-depth reasonings and perceptions of instrumental, intrinsic, and relational values.

Unstructured or semi-structured interviews aim to understand the reasoning and beliefs of individuals and groups (Neef *et al*., 2018; Fordham and Robinson, 2019). Interview guides may include only opening questions about the topic (unstructured), or a set of open-ended questions or topics to help guide the discussion (semi-structured). Both methods allow the interviewee to guide the discussion and include space for related questions and topics that are important to them. Interviews can be conducted at the individual or group level to understand the reasonings and beliefs of people, families, or other collectives. Interviews can create a space for conversation, reflection, understanding, and mutual discovery between the participants and researchers (Tracy, 2013). They can provide more depth and insight about the reasons people assign certain meanings to ecological components than can be gleaned from closed-ended responses on structured surveys. For example, Gould *et al*. (2015) conducted interviews to characterize cultural, social, and ethical values associated with ecosystems in Hawai‘i and British Columbia. When conducting interviews, it is critical to keep in mind that the interviewer can control the conversation direction and topics (either intentionally or not), creating a potential power imbalance (Tracy, 2013). The interviewer has an obligation to recognize that power imbalance, ensure that the respondent is heard and comfortable to respond with their own thoughts and beliefs, and that the resulting data are treated ethically throughout the entire research process. They must also ensure that the respondents feel comfortable, safe, and trusting enough to be able to share freely and honestly. Analysis of interviews can be time-consuming and difficult, and research conclusions may not necessarily be representative of larger groups.

Workshops are used to illuminate and understand group ideas, preferences, and values while also creating a safe space for discussion and deliberation among participants (Amberson *et al*., 2016; Pascua *et al*., 2017). They often include activities or exercises that facilitate opportunities to challenge assumptions and biases that stem from differing backgrounds. In this way, workshops can be transformative, resulting in collective learning (Kenter *et al*., 2015; Eriksson *et al*., 2019; Zimmermann *et al*., 2021). Pascua *et al*. (2017) conducted workshops in Hawai‘i to examine how Indigenous groups interact with their environment to cultivate and maintain their well-being, and identified concepts not yet captured in dominant typologies. However, challenges to using workshops as a research method can include poor or inadequate facilitation, with participants not feeling comfortable or safe enough to participate fully, participants not trusting that results will be treated respectfully, risks of one or few participant voices overshadowing or dominating others, and the possibility that experiences of those within the workshop are not representative of wider groups.

Ethnography is a method that studies people through interaction and observation. Ethnography involves an immersion into other people’s lives and worlds to understand their experiences and what is meaningful and important to them (Emerson *et al*., 2011). Ethnography is usually conducted at a cultural level, involving the study of an entire cultural group through participant observation, although the exact scale can range from a small sub-cultural group within a specific community to broader cultural groups across entire geographic regions (Spradley, 1979; Clifford, 1998; Creswell and Poth, 2016). It allows for a deep understanding of customs, behavior, and interactions. Wynne-Jones (2012) used ethnography to understand the role conservationists play in accepting and advancing market style governance through the development of payments for ES in the United Kingdom. Ethnographic research faces some challenges, including the tendency to produce narratives that are best suited for a storytelling approach, which can limit its applicability to diverse audiences (Creswell and Poth, 2016). Additionally, ethnographers have a responsibility to enter into typically unfamiliar cultures, assimilate, demonstrate sensitivity to ongoing issues and cultural norms, address their own research questions, and fairly and accurately represent the cultures being studied. This is a significant burden on the researcher that can also result in great harm and misrepresentation to the culture studied if not done well (Smith *et al*., 2013). While navigating this insider-outsider dynamic can be challenging, people are often not overtly aware of cultural practices and paradigms they engage in regularly. Therefore, an outsider seeking to understand these practices and paradigms can help make explicit the important cultural norms and traditions that otherwise might not be described by insider researchers or understood externally.

Once data are collected, analysis is conducted to identify patterns and insights. Content analysis, or qualitative data analysis, is often used to understand the meanings underlying the observations. It can be applied to interview transcripts, oral histories, and field notes, as well as documents, drawings, artifacts, historical articles, images, social media posts, or other collections of primary sources (*e.g.*, Lincoln *et al*., 1985; Miles and Huberman, 1994; Strauss and Corbin, 1998; Miles *et al*., 2014). Thematic codes are attached to segments of text or areas of images with relevant meaning (Miles *et al*., 2014). Through this process, the analytical structure is revealed based on the content of the data, rather than assumed *a priori*. This inductive approach can lead to a deeper understanding using the respondents' own words. However, it is incumbent on the researcher to ensure that they are not imposing their own worldviews when interpreting the meaning of the content. For example, Ingram *et al*. (2020) conducted interviews to better understand dimensions of human well-being related to CES in West Hawaiʻi. To ensure the interviewees' responses were accurately reflected, the authors confirmed the appropriateness of the way results were described with the interviewees numerous times during the analysis and writing processes.

2.4.1.3 Applied mixed methods

Due to the enormous breadth of perceptions and values related to ES, researchers often employ multi-step processes or mixed methods to have a more holistic and diverse understanding of them. In these studies, multiple methods are used to collect data and compare results. This comparison is known as triangulation or convergent validity, which can enhance the credibility or validity of a concept or phenomenon when different sources or data converge on similar results. There is a diversity of worldviews among peoples and across times, and multiple methods that can accurately represent and understand them are needed. Even within various disciplines, the methods used express and conceptualize values differently. Thus, using mixed methods and increasing diverse perspectives and interdisciplinary objectives help to provide more holistic understandings of values and relationships (Raymond *et al*., 2014; Kenter *et al*., 2019; Kronenberg and Andersson, 2019). Examples of mixed-method socioecological assessments of ES include Iniesta-Arandia *et al*. (2014), Bremer *et al*. (2018), and Eriksson *et al*. (2019). Bremer *et al*. (2018) used workshops, interviews, and scenario and content analysis to evaluate tradeoffs and synergies in ecosystem services over land-use scenarios and climate change with regard to the restoration of traditional agriculture on O'ahu. Eriksson *et al*. (2019) used surveys and workshops, particularly investigated through an analytic known as network analysis (Scott, 1988), to highlight the relations and connections between participants and social-environmental facets, in order to understand how social learning through deliberation and social capital may influence social values. Iniesta-Arandia *et al*. (2014) used participant observations, interviews, and in-person surveys to analyze stakeholders' perceptions of ES, well-being, and drivers of environmental change in southeastern Spain.

Some methods used in sociocultural assessments explicitly involve qualitative and quantitative steps. Q method typically starts with qualitative research to determine a set of concepts to be ranked and prioritized by variables, and includes in-depth discussion during the ranking exercise to reveal preferences and reasonings (Pike *et al*., 2015). Often, Q method will use cards that contain various interactions with the environment (such as different types of CES), environmental quality, and other experiences and resources. Respondents (either individually or in groups) will sort, rank, or place cards in hierarchical clusters. The aim of the Q method is to identify population, community, and/or stakeholder preferences. For example, Peck and Khirfan (2021) discussed local experts' competing values of urban surface waters to better understand management decisions for water scarcity in Jordan. Participants in this study ranked preferences creating a context-specific scale of values; deliberation aided in this process by streamlining the interpretation of concepts and clarifying participant meanings.

Many of the methods described above have also been used together to understand how sociocultural ES are perceived spatially. Social value mapping methods integrate a mapping exercise to add location data to perceptions of ES, including sociocultural ES. Spatial representations are beneficial for spatial analysis and decision making, particularly when regulations and uses are largely area- and place-specific. This method is commonly included in tandem with other methods, such as surveys, interviews, or photo elicitation. When included in surveys, respondents are often asked to quantify and rank preferences for ES and then identify on a map where these services are located and/or preferred (Sherrouse *et al*., 2011, 2014; van Riper *et al*., 2017; Zhang *et al*., 2019). Semi-structured interviews with a mapping component allow for deeper understandings of why people associate certain sociocultural benefits with specific locations (Plieninger *et al*., 2013; Gould *et al*., 2015; Levine and Feinholz, 2015; Nahuelhual *et al*., 2016). Photo elicitation has also been used as a tool to bring out or understand the benefits, preferences, perceptions, or values of ES at particular locations (Berbés-Blázquez, 2012; Angradi *et al*., 2018; Keeler *et al*., 2019; Sun *et al*., 2019). In this method, participants share photos that are personally meaningful and researchers compare the types of meanings shared across the study participants. Locations of photos can be linked to spatial assessments of ES. Maps are then created from data collected by these various approaches, with a focus on user group, community, and/or population uses and perceptions. Although spatial analysis outputs quantify important places as points or polygons, or *via* raster datasets, the attributes of these places and their interpretations can be informed by qualitative analyses, as outlined above. Spatial approaches are not without their own challenges. For one, resulting maps may not reflect the deeper meanings and reasonings behind participant choices. Participants may have completely different or even contradictory ideas and perceptions of the concepts being explored, so care must be taken in the development of mapping exercises to ensure validity (*e.g*., *via* the more participant-driven methods, such as interviews and photo elicitation). Further, participants may be hesitant to share culturally sensitive areas on maps, just as biological resource managers are hesitant to identify populations of endangered species or other ecologically sensitive features. Special attention must be paid to cultural discretion and data sovereignty (Kukutai and Taylor, 2016) in order to actively address and alleviate any such concerns of participants.

2.4.2 Discussion

As ecosystem service approaches to research and management grow and gain popularity, a variety of methodologies are being developed and employed to try to gain more comprehensive and detailed understandings of the connections and feedbacks between social and ecological systems. Regarding the sociocultural dynamics of ES, methods were grouped into three types—quantitative, qualitative, and mixed methods—in order to provide clarity about the nature of the methods being discussed. In practice, mixed methods are usually needed for robust sociocultural assessments due to the sensitive and subjective nature of sociocultural dynamics of human practices involving the environment and their relationships with it.

Ecological and economic assessments focus on capturing intrinsic and instrumental values of ES, but sociocultural assessments are the only means of understanding relational values within social–environmental systems (Chan *et al*., 2018). Such relational values influence our valuations of the intrinsic and instrumental nature of ES while also interweaving within broader tapestries of paradigms and therefore, often are overlooked. Because of the high degree of specificity and multiplicity surrounding these relational values and their encompassing paradigms—being shaped by history, geography, culture, sociopolitical contexts, and so on—CES cannot be studied or understood in a vacuum and instead must be understood within their contextualities. For this reason, sociocultural assessments of ES heavily rely on overlapping social science fields, such as Indigenous theory and feminist theory, in order to situate and illuminate the nuances and shared threads surrounding CES, particularly in order to handle diverse and often contradicting worldviews within certain settings (Fish *et al*., 2016). These multiple worldviews can often be incommensurable with each other, adding further complication for studying and operationalizing CES (Fish *et al*., 2016). This is particularly true within (neo-)colonial settings where different paradigms shape and are shaped by power differentials that quietly and overtly control patterns of how people relate with and are allowed to relate with the environment, as well as the governance modalities surrounding these relationships (Povinelli, 2021).

Because of the rich complexities surrounding CES, there is no singular, universally accepted or adaptable framework for conducting sociocultural assessments of ES or even broader typologies for social–environmental systems in general. The Millennium Ecosystem Assessment, then IPBES, have attempted to create frameworks for defining and understanding sociocultural values of the environment, situating them within broader social and environmental currents, and structuring research and management around them. However, such frameworks have not been without ample criticisms (*e.g*., Díaz *et al*., 2018), and there has been scant guidance around assessing and creating valuations of sociocultural dimensions of ES, particularly in a standardized manner that accounts for multiple worldviews. As a result, there has been a proliferation of more context-specific frameworks and approaches for studying and operationalizing relationships with the environment. However, these too run the risk of misrepresenting how individuals and communities understand their own relationships and values.

Given the absence of a widely agreed upon framework for contextualizing and assessing the sociocultural dimensions of ES and the desire for CES assessments to fit within frameworks designed to assess ecological and economic ecosystem services, sociocultural researchers face a number of key responsibilities when assessing MES. They include:

1) Paying special attention to relational values, their encompassing paradigms, and their sociopolitical contexts so as to not unwittingly distort or misrepresent sociocultural aspects of ES and environmental relationalities, especially with regard to how new understandings can be operationalized within management arrangements in place-based manners.

2) Seeking methodologies and analyses that highlight their generalizable aspects and implement-shared terminologies to facilitate mutual intelligibility across research approaches, even as the exact frameworks may differ, particularly to increase the ease and efficacy of collaboration across geographies and cultural landscapes.

These two responsibilities favor qualitative and quantitative assessments of sociocultural ES, respectively, illustrating the need for mixed method approaches to ensure the power of future investigations into, and assessments of, sociocultural aspects of ES.

2.5 Discussion

As research on ecosystem services (ES) has grown and diversified across a number of fields, a variety of methods have been developed and employed to try to understand the connections and feedback between human and ecological systems. In this section, we examined the diverse approaches for assessing marine ecosystem services (MES). Assessment methods were presented from three broad scientific disciplinary perspectives—ecological, economic, and sociocultural—each with differing foci and analytic objectives. This has led to different assessment methods being employed from different disciplinary perspectives. However, the section has also highlighted that within each of these disciplinary lenses, multiple methods may be used to assess MES.

This overview underscores two common themes shared between the different scientific disciplinary perspectives: (1) within each discipline, there is a diversity of approaches one can take to assess MES and (2) often multiple approaches are needed to accurately assess them. In the ecological context, the diverse ways in which biodiversity, ecosystem health and resilience, and ecosystem functions manifest dictate the need to employ a range of different ways of monitoring, mapping, modelling, and forecasting MES. In economics, this latter point translates to combining data sources in common utility-theoretic models of choice or behavior to better represent the underlying preferences and economic values. In sociocultural contexts, the diversity of types of values being assessed mandates a multifaceted approach that depends upon the particular setting being analyzed, including the particular social and cultural contexts involved and the relationships individuals and groups have with each other and with nature.

A key area for future research is developing frameworks for the integration of MES assessments from these distinct perspectives. The IPBES framework is one such effort (Diaz *et al*., 2018; IPBES, 2022), but much of the effort to date appears oriented at acknowledging the importance of the different perspectives and what they bring to the framework rather than guidance on how to operationalize the framework in particular settings where overall synthesis and evaluation are desired. In part, this may be due to the need to more fully understand the set of values that need to be assessed (*e.g.*, relational values) and how these values can be incorporated meaningfully in evaluation frameworks. This also points to open questions about the extent to which MES assessment information can and should be compared and contrasted, and when it is appropriate to do so.

While this section has not answered those questions, it does underscore the need for transparency in assessing MES. Viewing and evaluating MES from a variety of scientific disciplinary perspectives can provide an array of information that stakeholders and policy makers at many levels may find valuable in better understanding the relationships humans and the environment have with one another and that can be useful when considering actions and policies that affect ecosystems and their services. Open dialogue about the benefits and limitations of the assessments used, as well as the processes to determine which one to use, is a crucial step in informed decision-making.

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Annex Table 2.1 Marine and coastal ecosystem services (MCES) indicators identified by Liquete *et al.* (2013) using a cascade scheme. Adapted from Liquete *et al*. (2013).

MCES	Ecological assessment	Metric
Food provision	Relative fish abundance based on catch per unit effort (CPUE) [1]	Artisanal fishery catch [2]
	Density of fish (weighting factor) [3]	Shrimp landings (t/yr) [4]
	Coral size, substrate cover, fish diversity and biomass [5]	Harvested mussels (n°) [6]
	Fish abundance per site [7]	Fish catch (kg/yr) [8]
	Distribution of fish or larvae [9]	Landings of commercial and recreational fishing (t, USD) [10]
	Fish biomass (standing stock) (t) [11]	Commercial fishery landings data [9]
	Estimates of species abundance (fish, shellfish, marine mammals and birds) [12]	Fish catch per household (kg/household/yr) [13]
	Proportion of fish stock overexploited, depleted or recovered (%) [14]	Fish catch (t) [15]
	Presence of reef-associated fish [16]	Fisheries production and non-marketed catch [17]
	Food web structure and robustness (various properties) [18]	Fish harvested by capture fisheries or produced in aquaculture [19]
	Marine food chain [20]	Composition of local fisheries (harvest and catch size) [21]
	Presence of fry preys [22]	Predicted fish landings up to 2050 (t) [23]
	Composition and relative importance of predators along a gradient of fishing intensities [24]	Fish production [25]
	Functional variation of predatory performance (frequency of predation, ingestion time, urchin size selection) [24]	Landings (t) [26]
	Mangrove extent as habitat for fisheries (ha) [27]	Amount of fish from certified fisheries (t) [14]
	State of the seagrass meadows [28]	Global landings from marine fisheries (t) [14]
	Diverging trends between area and productivity of mangrove forests [29]	Harvesting parameters [30]
	Area of marine protected areas (km^2) [14]	Harvested fish and its consequences in the food web (USD/km^2) [31]
	Area of no take zones (km^2) [14]	Fishery products (energy exports from social-ecological systems) (J/yr) [32]
	Areas to support seafood production (ha) [33]	Spatial distribution of squid harvests (ranking) [34]
	Carbon:nitrogen ratio [35]	Degree of specialization of fishing activities [29]
	Primary production (gross, respiration and net) ($mgC/m^2/h$) [35]	Marine farming [36]
	Sea food productivity [36]	Reduction discard (%) [14]
	Sea food quality [36]	Depletion in the number of viable (non-collapsed) fisheries (%) [37]
	Fish food indicator [38]	Importance of mangroves for food (ranking)[39]
		Spatial appropriation of marine ecosystems (ecological footprint) (m^2) [40]
		Importance and specificity of food based on expert knowledge with reference to rabbits, asparagus, wild food, rare breed cattle, meat and miscellaneous crops in dunes (scores 0-3) [41]

Water storage and provision		Importance and specificity of freshwater based on expert knowledge with reference to drinking water and irrigation (scores 0-3) [41]
		Importance and specificity based on expert knowledge with reference to drinking water and groundwater (scores 0-3) [41]
		Importance and specificity of water storage based on expert knowledge (scores 0-3) [41]
Biotic materials and biofuels	Sponge diversity and abundance (weighting factor) [3]	Generation of sand and mangrove wood (weighting factor) [3]
	Biomass production over stem diameter classes (tC/ha) [42]	Importance and specificity of fiber and fuel based on expert knowledge with reference to grass/reeds, wool and timber (scores 0-3) [41]
		Importance and specificity of mineral extraction based on expert knowledge with reference to sand and minerals (scores 0-3) [41]
		Importance and specificity of genetic resources based on expert knowledge with reference to breeding stock and biochemicals (scores 0-3) [41]
		Importance of mangroves for wood (ranking) [39]
		Importance of mangroves for construction (ranking) [39]
		Importance of mangroves for medicinal resources (ranking) [39]
		Change in the use of mangroves as household fuel (%) [43]
		Sand and gravel extraction (t) [44]
		Household effort to collect firewood (h/week) [45]
Water purification	Ammonium and phosphate concentration (microM) [46]	Oxygen concentration (mg/l) [46]
	Particulate organic carbon (POC) and nitrogen (PON) (mg/l) [46]	Seston uptake or Chl-a removal (%) [47]
	Suspended matter [48]	Nitrogen uptake (mmol N/m^3/yr) [49]
	Bottom irradiance (micromol/m^2/s) [46]	Quantity of nitrogen and phosphorus fixed by phytoplankton and kelp [50]
	Presence of nitrophilous macroalgae in catchment basin [22]	Change in bioremediation capacity by algae and bivalves [51]
	Ecological risk indicator under different euthrophication scenarios [52]	Nitrogen removal rate (kgN/ha/yr) [4]
	Depletion in the number of suspension feeders, submerged vegetation and wetlands to filter water (%) [37]	Nitrogen and phosphorus retention (microg/l) [53]
	Presence of floodplains, wetlands, estuaries, mangroves, benthic invertebrate species [10]	Nutrient abatement (t/yr) [54]
	Number of dead zones [14]	Bacterial denitrification within the sediments [20]
	Plant tissue nitrogen concentration (%) [55]	Removal of total nutrient content (kg/ha) [56]
	Water circulation [57]	Nitrogen, phosphorus and heavy metals concentration and rate (kg, kg/yr) [58]
	Sedimentation and accumulation of organic matter [57]	Nitrogen accumulation (t/yr) [59]
	Ammonium and nitrate (mg ion/g resin) [55]	Denitrification (t/yr) [59]
	Total soil nitrogen in a salt marsh (% dry weight) [55]	Oxygen levels in water and sediment [57]

	Abundance of suspension and surface deposit feeder [57]	Particulate organic matter (POM) and photosynthetically active radiation (PAR) (mg AFDM/l, umol/m^2/s)[35]
	Presence of bioturbator organisms [22]	Chemical oxygen demand (COD) and biological oxygen demand (BOD) (mg/l) [60]
	Nitrogen concentration (microM/l) [61]	Enhanced fishery catch through reduced eutrophication [62]
	Presence of degrading microorganisms [22]	Spatial appropriation of marine ecosystems (ecological footprint) (m^2) [40]
	Distribution of *Phragmites australis* [63]	Emergy flow accounting for environmental and economic inputs (solar emergy, sej/yr) [60]
	Presence of suspension feeders [20]	Fecal coliform [48]
	Feeding modes and impact on certain pollutants [20]	
	Seston reduction (mg/l) [6]	
Air quality regulation		Importance and specificity of air quality regulation based on expert knowledge (scores 0-3) [41]
Coastal protection	Healthy growing coral reefs, mangroves and wetlands (%, USD) [10]	Surge reduction (cm/km) [4]
	Coral size and substrate cover [5]	Vulnerability index based on relaxation time and return interval [64]
	Plant cover (%) [65]	Importance and specificity of storm protection based on expert knowledge (scores 0-3) [41]
	Vegetation properties (marsh width, species, biomass production, density, stiffness, height) [66]	Loss rates of experimental equipment in the coast (no. equipment lost) [67]
	Vegetation density (shoots/ha, g/m^2, t/ha) [68]	Wave attenuation (m) [69]
	Temporal changes in mangrove extent (ha) [70]	Wave attenuation (m, %) [68]
	Mangrove extent (ha) [27]	Sediment deposition (%) [71]
	Presence of seagrass meadow [22]	
	Kelp occurrence adjacent to human property (%) [34]	
	Coverage of semi-altered land use type (%) [72]	
	Hydrodynamics (hydroperiod, distance to a sediment supply) [66]	
	Aboveground biomass (g DW/ha) [68]	
	Hurricane frequency [72]	
	Health of wetland ecosystem [62]	
	Sediment accretion (mm) [73]	
	Change in erosion protection capacity [51]	
Climate regulation	Standing carbon and nitrogen stock (mg/m^2) [35]	Soil carbon accumulation (MgC/ha/yr) [4]
	Carbon and nitrogen concentration (g/m^2) [71]	Carbon flow (TgC/yr) [74]
	Carbon stock (t/ha) [75]	Net photosynthetic rate (kgC/ha/yr) [17]
	Estimates of the global pools of carbon and fluxes between them (Pg C, Pg C/yr) [76]	Primary production (gC/m^2/yr) [49]
	Aboveground biomass and dissolved organic matter (gC/m^2/yr) [77]	Carbon sequestration rate (gC/m^2/yr) [78]
	Dissolved organic and inorganic matter (gC/m^2/yr)[77]	Oceanic uptake of carbon (Pg C/yr) [76]
	Carbon biomass (t/ha) [79]	Microbial breakdown and deposit feeders activity in the sediments [20]
	Carbon stock in the soil (kgC/ha) [17]	Leaf litter production (t DW/ha/yr) [69]

	Carbon fixed by phytoplankton, mariculture kelp and cultured shellfish (t) [50]	Importance and specificity of climate regulation based on expert knowledge (scores 0-3) [41]
	Sediment carbon density (t/ha) [80]	Soil/sediment exchange of carbon monoxide, methane and nitrous oxide (microgC/m^2/h) [80]
	Carbon sequestration potential (gC/yr) [78]	
	Carbon and nitrogen storage in canopies (kg/m^2) [18]	
	Carbon cycling indicator [38]	
	Macrophyte biomass and carbon content (g/m^2) [81]	
Ocean nourishment	Nutrients stored in the sediments (mmol N/m^3/yr) [49]	Importance and specificity of soil formation based on expert knowledge (scores 0-3) [41]
	Nutrient transport to adjacent areas (mmol N/m^3/yr) [49]	Importance and specificity of nutrient cycling based on expert knowledge (scores 0-3) [41]
	Presence of four coralline algae [10]	Decomposition of dissolved and particulate organic matter by bacteria and funghi in the sediments [20]
	Nitrogen flux (mol N/yr) [82]	Oxygen emitted by primary production and kelp production (t) [50]
	Environmental measurements: tidal inundation time (g/m^2/h), net flux (g/m^2/h), tidal height, salinity, nutrient concentrations (mg/l), nitrogen:phosphorus ratio [83]	
	Soil chemical properties (pH, organic carbon, total nitrogen, available phosphorus, potassium) (kg/ha) [84]	
	Nitrogen and phosphorus aboveground and in soil (g/m^2) [81]	
	Silica fluxes (mol/h) [85]	
	Nutrient regeneration indicator [38]	
	Relationship between fish, bioturbation, bottom conditions and nutrients release [19]	
	Function of fish as active or passive transporters and distributors of energy and materials [19]	
Life cycle maintenance	Substrate character [8]	Juvenile fish density (t) [86]
	Structural complexity, nursery and feeding areas [10]	Juvenile density (abundance/m^2) [87]
	Connectivity, diversity, trophic composition [10]	Postlarvae production per hatchery (no.postlarvae/yr) [88]
	Total coral cover (m^2) [89]	Effect of mangrove coverage on the total fishery value [90]
	Composite metrics using percent cover of corals [89]	Annual production of fish juveniles (g/m^2/yr) [91]
	Size-frequency distributions of corals [89]	Foraging efficiency for fish [57]
	Topographic complexity of corals [89]	Importance and specificity of the provision of habitat based on expert knowledge (scores 0-3) [41]
	Coral extent and condition (km^2) [14]	Importance and specificity of pollination in dunes based on expert knowledge (scores 0-3) [41]
	Diversity and abundance of cold-water corals [12]	
	Nursery area (km^2) [86]	
	Eelgrass productivity (cm^2/m^2/d) [71]	
	Natural size of mangroves and density progression [69]	
	Mangrove and seagrass extent (km^2) [14]	

	Mangrove biomass (t/yr) [59]	
	Abundance of seagrasses (indiv/m^2) [35]	
	Macrophyte species richness (no. species/m^2) [81]	
	Distribution of *Phragmites australis* [63]	
	Depletion in the number of oyster reefs, sea grass beds and wetlands to provide nursery (%)[37]	
	Protected area designated for its diversed habitat and abundant seabird colonies [44]	
	Habitat change (km^2) [59]	
	Species abundance and richness (indiv/m^2, spp/m^2) [18]	
	Intertidal biodiversity [69]	
	Mechanical prevention of larval immigration [57]	
	Abundance of food organisms [57]	
	Consumption of organisms by fish/ foodchain relationships [19]	
	Biomass of sessile epifauna (g/m^2) [92]	
	Oxygen level in water column [57]	
Biological regulation		Control of aquatic disease bearing invertebrates and plants by fish [19]
		Importance and specificity of pest regulation based on expert knowledge (scores 0-3) [41]
		Importance and specificity of disease regulation based on expert knowledge (scores 0-3) [41]
All MCES together	Hydrological regime affecting all ecosystem services [21]	
	Coverage of mangrove forests affecting all ecosystem services [21]	
	Species richness [93]	
	Species diversity [94]	
	Species turnover [93]	
	Marine vertebrates living planet index (score 0-1.2) [14]	
	Pelagic seabird red list index (score 0.7-0.8) [14]	
	Local extinctions [93]	
	Invasions intensity [93]	
	Extent of terrestrial and marine ecosystems (%) [95]	
	Importance of mangroves for biodiversity (ranking) [39]	
	Ecosystem natural state [25]	
	Habitat loss and degradation [96]	
	Species abundance and community structure [96]	
	Shifts in the distribution of species and biomes [96]	
	Species extinctions [96]	

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3 Aquaculture-related Ecosystem Services in PICES Member Countries

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3.1 Introduction

3.1.1 Overview of ecosystem services and aquaculture

The relationship between aquaculture and marine ecosystem services (MES) is complex. Aquaculture can serve to augment existing ecosystem services (ES) or to degrade them, with widely varying results for different cultured species, methods of culture, and bodies of water. The Millennium Ecosystem Assessment (MA, 2005) categorized ES into provisioning, regulating, cultural, and supporting services. Some examples of the provisioning services associated with aquaculture are the meat from cultured finfish and mollusks and the shell material of farmed mollusks. The regulating services associated with aquaculture include carbon and nitrogen uptake by mollusks and kelp. Aquaculture's relationship with cultural ecosystem services (CES) includes tourism and the "sense of place/identity" benefits associated with aquaculture employment and the production/consumption of local food. Although supporting services are not considered under some frameworks due to their intermediate nature, the relationship between aquaculture and supporting services, particularly the impact on flora and fauna in the vicinity of the aquaculture site, have received some attention in the literature.

The toolkit for valuing ES from aquaculture is not perfect, but even imperfect estimates of these ecosystem service values can help in making important policy and management decisions. Efforts to measure ecosystem service values should be encouraged, but the limitations should also be acknowledged. Several methods are available to estimate the economic value of these ES. The most straightforward approach is the market-value approach, utilizing known market prices and information on market transactions to determine the value of a service. For example, where there is a tradable permit market for nitrogen, the price of a permit may be used to compute the value of nitrogen uptake by a shellfish farm. Similarly, the market price for crab can be used to value the habitat/refugia provided by a shellfish farm. Unfortunately, this method is unlikely to provide an accurate valuation. In our examples above, the market price for a nitrogen permit only accurately measures the benefits of nitrogen removal if the economically optimal number of permits is issued, which is a challenge for researchers and policy makers. As a further example, valuing a crab species based on its market value ignores other life cycle effects such as reproduction and ecosystem effects, including predator–prey relationships. Another frequently used approach to valuing MES is the "replacement cost" or "avoided cost" approach, in which the cost of replacing those services by other means is assumed to be their value. For instance, the nitrogen uptake of shellfish could be replaced by improvements in wastewater treatment plants. Therefore, according to this cost-based approach the economic value of shellfish aquaculture can be approximated by measuring the cost of reducing nitrogen emissions from the wastewater treatment plant. This method is also unlikely to produce an accurate measure of the benefits because it focuses solely on costs. Furthermore, the method is situationally specific, as the resulting costs are unique to the available technologies, the current emissions levels, and the proposed amount of abatement. The final class of methods commonly used for valuing ES is stated preference methods, such as contingent valuation. These methods are particularly useful to value the CES for which intangible human benefits are the major factor.

It is important to take a holistic view of the role of aquaculture in the ecosystem, but the "ecosystem services" verbiage tends to lead to a focus on the positives. Although the negative impacts of aquaculture could be viewed through the lens of lost/damaged ES, this verbiage is usually eschewed in favor of negative terms such as "pollution", "escapes", or "external damages". However, it should be clear that if the nitrogen removed by shellfish aquaculture is an environmental service, for example, then the addition of nitrogen to the local waters by finfish aquaculture should likewise be accounted for. The true impact of aquaculture on ES is the net effect of benefits and damages, but this has not received sufficient attention in the literature. As the research into MES and aquaculture continues, it will be important for these negative effects to be included. This will also mean incorporating the ES framework into research on external damages from aquaculture.

With many fisheries fully exploited or overexploited, growth in seafood supply is coming from growth in aquaculture production rather than increased wild capture (Anderson *et al*., 2019). This highlights the importance of decisions about aquaculture policy being made throughout the world. The research into non-fed aquaculture, such as shellfish and kelp, indicate that there are significant external benefits—benefits that accrue to the environment or to those besides the aquaculture operators themselves—which will lead to under-investment in these operations if the benefits are not internalized (Barrett *et al*., 2022). Efforts are underway to include non-fed aquaculture in nutrient permit trading programs to begin internalizing some of these benefits (Rose *et al*., 2014; Racine *et al*., 2021). On the other hand, the culture of carnivorous finfish has been recognized to have a number of negative impacts on the surrounding environment (Naylor and Burke, 2005). Optimally managing the expansion of aquaculture will require incorporating the existing state of knowledge about ES into decision-making, as well as encouraging further research.

This section summarizes the existing body of knowledge along with the notable gaps with respect to the MES provided by aquaculture in PICES member countries. There are several recently published literature surveys on the topic of marine aquaculture ecosystem services (Alleway *et al*., 2019; Weitzman, 2019; Gentry *et al*., 2020; Barrett *et al*., 2022), but these provide only a broad overview of the topic and its associated literature. This section includes a systematic literature review and gap analysis for each member country, going into more detail than the published surveys and particularly noting the country-specific knowledge and gaps.

3.1.2 General literature search methodology

The goal of the literature search is to identify the state of knowledge regarding aquaculture and MES in the PICES member countries of Canada, China, Japan, and USA. In addition to identifying what ES are assessed and the employed methodologies, the project aims to identify what gaps exist in the literature. The search is restricted to only studies published in peer-reviewed journals, excluding government reports, book chapters, theses/dissertations, working papers, and conference proceedings. Because the focus is on the quantification of ES associated with aquaculture, only studies which produce new quantified measures of ES are included. This excludes meta-analyses, conceptual and methodological papers, and papers using quantities published in other papers for a new purpose. However, where such papers appeared in the literature search, they were mined for relevant primary sources.

For the USA, Canada, and Japan, the Web of Science search database was used, while for China the China National Knowledge Infrastructure database was searched. Researchers for each country were free to modify the search query as needed, but the initial query framework was

> (“marine” or “coast*” or “ocean” or “sea”) and (“aquacultur*” or “maricultur*” or “farm*”) and “ecosystem service*” and (“economic” or “ecological” or “cultur*”) and (“valu*” or “assess*” or “measur*” or “quantif*”) and (terms to isolate country/region)

where * indicates a wildcard and terms to isolate country/region could include the name of the country, individual states or provinces, or particular bodies of water. The abstracts of the search results were reviewed and inclusion/exclusion criteria applied to determine the initial batch of results. The researchers then employed backwards reference searches (looking for relevant papers in the citations of the initially identified studies) and forward reference searches (looking for relevant papers that cite the initially identified studies). In some cases, this process identified branches of the literature with additional keywords which were added to the query and the process repeated. For instance, in the USA the required keyword “ecosystem services” appears in only 13 of the 21 identified studies estimating the impact of shellfish and kelp aquaculture on nitrogen, so terms like “bioextraction” and “nitrogen removal” were added to the query. Due to the nature of the literature search, with the specific keywords and limitation to peer-reviewed papers, our results can be expected to present an incomplete picture of the full state of knowledge regarding aquaculture and MES in the participating countries. In particular, the relative frequency of articles for different countries may be due to a prevalence of government reports rather than peer-reviewed publications, or simply due to language/terminology differences resulting in studies not being returned by the query.

3.1.3 Overview of findings

Across the four participating countries in this search, there was a large difference in the number of included studies. In descending order, the search for the USA turned up 41 studies, China identified nine studies, Canada located six studies, and Japan uncovered five studies. There were notable differences with respect to the types of aquaculture analyzed in each country, with research in the USA and Canada focused heavily on shellfish culture, Japan focused on kelp, and the research in China often considered multiple species cultured together in the same area.

Likewise, the ES being measured vary across the participating countries. Studies in China are broadly focused, considering ES across several of the Millennium Ecosystem Assessment categories, including provisioning services. Conversely, studies in the USA are narrowly focused, with only a single study of the 41 quantifying the service provision across two categories.[8] Most of the U.S. studies are focused on regulating services related to nutrient removal (primarily nitrogen), with impacts on other species of flora and fauna (supporting service) being the next most common. Similar to the USA, Canadian studies are narrowly focused with four on nitrogen cycling along with one study of changing production after changes in water conditions, a survey of the various benefits of restoration aquaculture, and two studies of the negative impacts of aquaculture on other ecosystem services. Although several U.S. studies do estimate the quantity and value of shellfish that are produced, this is never linked to the concept of provisioning ES. The studies from Japan are also narrowly focused, but all four of the MA categories are covered in the five studies, with only provisioning services appearing twice.

An interesting observation regarding the results of this targeted literature search is that much of the research quantifying ES around aquaculture does not actually estimate an economic value. Studies estimate quantities such as the nitrogen removed from the water by shellfish culture, the changes in species abundance around an aquaculture site, and the percentage of oyster farmers expressing a preference to work in nature, but do not convert these quantities to an economic value. This is the case for 34 of the 41 studies in the U.S. report, seven of eight for Canada, and all five of the Japanese studies. China is the exception, with a total economic value computed in most of the studies. However, it is clear from the studies in which an economic value is computed that the external benefits could be sizable; for instance the value of nitrogen removal in Connecticut, USA, at current aquaculture production levels is estimated to be $8.5 million in Bricker *et al*. (2018). In order for there to be improvement in the policy decisions being made, research into aquaculture and MES will need to calculate and communicate the associated economic values to policy makers.

[8] In Ayvazian *et al*. (2022) the regulating services of bioextraction and denitrification are measured along with the supporting service related to associated macrofaunal species, including fish and crabs.

3.2 *Canadian case studies*

3.2.1 Aquaculture production in Canada

Canada ranked 20th in global aquaculture production in 2017, accounting for 0.2% of global production (191,416 tonnes valued at $1.4B).[9] Canada ranked 4th in terms of global farmed salmon production, accounting for 6% of global salmon production (121,000 tonnes in 2017). Canada's production volume increased by 110% over the 1998–2017 period, falling behind the global growth rate during the last decade (Fig. 3.1).

Canadian aquaculture has grown over time. From 1991 to 2020, total production grew from about 50,000 tonnes to 171,000 tonnes in volume and $234 million to $1.0 billion in value (Fig. 3.2). Aquaculture occurs in all provinces of Canada, with marine and coastal aquaculture occurring on both the Pacific and Atlantic coasts. There are approximately 50 different species of finfish, shellfish, and marine plants farmed and cultivated in Canada, in marine and freshwater environments as well as in land-based ponds or tanks. However, over 90% of the production volume and value of cultured production comes from species primarily grown in marine and coastal environments, including salmon, mussels, oysters, and clams (Fig. 3.3). Almost 60% of total production volumes and 64% of total value was from British Columbia (BC) in 2020. This was followed by New Brunswick (NB; 12% of volume and 13% of value), Prince Edward Island (PEI; 11% of volume and 4% of value), Nova Scotia (NS; 7% of volume and 9% of value), and Newfoundland and Labrador (NL; 6% of volume and 6% of value). By province, the most commonly farmed species are: salmon in BC, NB and NS, oyster and mussels in PEI, and trout in Central and Western Canada. In BC, 94% of the provincial value was from salmon production in 2020.

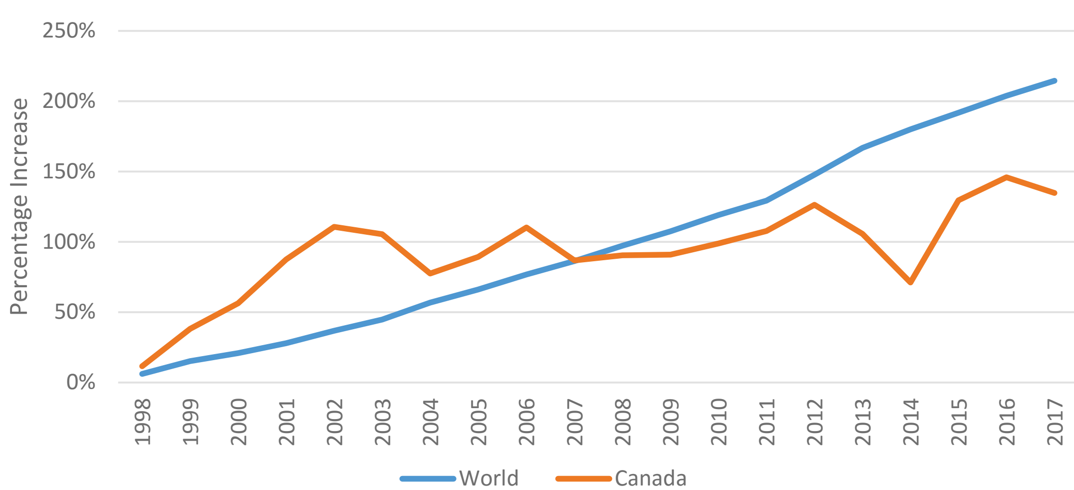

Fig. 3.1 Canada *vs*. Global Aquaculture Relative Growth since 1997 (1998–2017). Source: FAO, Fisheries and aquaculture software. FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: FAO Fisheries and Aquaculture Department [online].

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[9] Fisheries and aquaculture software. FishStatJ - Software for Fishery and Aquaculture Statistical Time Series. In: FAO Fisheries and Aquaculture Department [online].

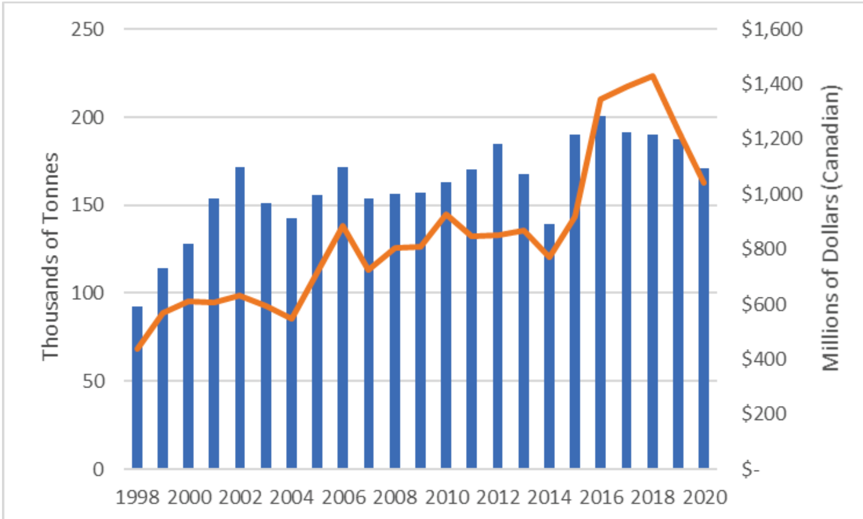

Fig. 3.2 Total Canadian aquaculture production, including marine and freshwater, 1998–2020. Source: Statistics Canada. Table 32-10-0107-01 Aquaculture, production and value. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210010701. Retrieved February 28, 2022.

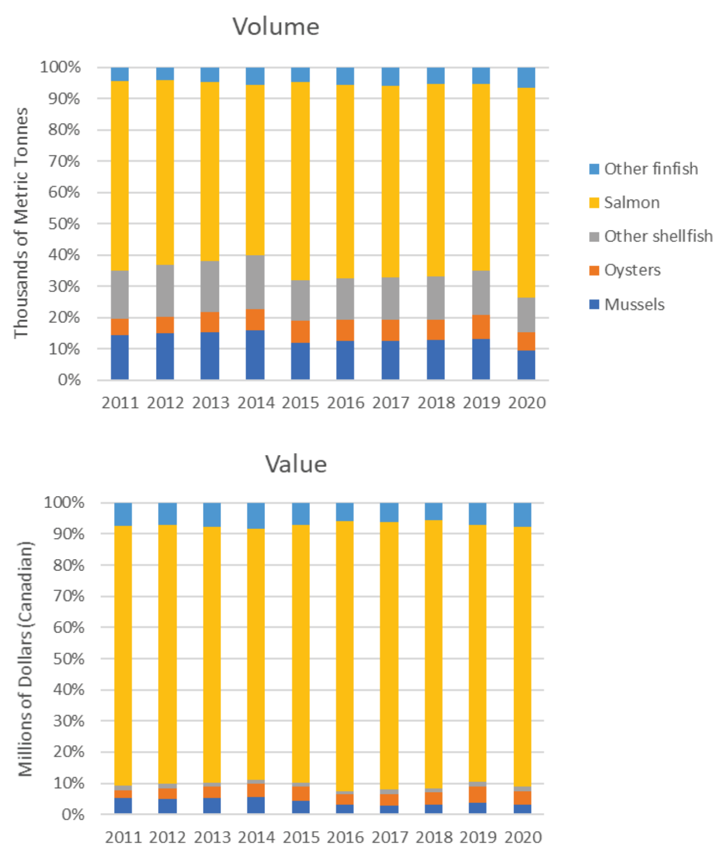

Fig. 3.3 Distribution of Canadian aquaculture production volume and value by species, 2011–2020. Source: Statistics Canada. Table 32-10-0107-01 Aquaculture, production and value. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210010701. Retrieved February 28, 2022.

Canadian aquaculture production is oriented towards finfish, which accounted for 82% of total volume and 92% of value in 2020, a level that has been fairly consistent for several decades. While the vast majority of finfish production, by both volume and value, is Atlantic salmon, 27 different species of finfish are commercially farmed, including several Pacific salmon species, trout, sturgeon, sablefish, and Arctic char.[10] Salmon has accounted for about 90% of all Canadian finfish aquaculture production by volume and value over the past few decades. BC is the top provincial producer of cultured salmon, followed by NB, and smaller amounts from NL and NS. Key salmon producing areas include the Discovery Islands and Campbell River in BC, Bay of Fundy for NB and NS, and the south coast of Newfoundland. Salmon on both coasts primarily uses conventional marine open net-pen or cage systems; however, the federal government is working with the province of BC and Indigenous communities on a plan to transition from open net-pen salmon farming in coastal BC waters by 2025.[11] This includes the phasing out of existing salmon farms in the Discovery Islands by June 30, 2022.[12] Work on the plan is ongoing.

Shellfish is also an important segment of the farmed seafood sector on both coasts, with 20 different species of shellfish cultured, with major species including mussels, oysters, clams, and scallops. Other species such as sea urchins, crayfish, and sea cucumber are commercially produced in small amounts. [13] While shellfish aquaculture accounted for about 18% of the farmed seafood production volume in 2020, it represented only about 9% of value. Mussels and oysters are the two most commonly produced shellfish species. In 2020, mussels accounted for 10% of aquaculture production volume and 3% of value, while oysters accounted for 6% of volume and 4% of value. Depending on the species, shellfish may be grown at intertidal, subtidal, or suspended facilities and depending on the facility a variety of methods can be used, including beach planting, near-bottom bags and cages, and ropes and trays suspended from longlines or rafts.

3.2.2 Literature search structure and results

To identify literature that measures the ES provided by aquaculture, or potentially the services impacted by aquaculture, an iterative literature search was conducted on the Web of Science. Two alternative query structures were used with limited overlap in the results. Both searches used the topic field and limited the results to articles. Articles were reviewed for relevance and relevant articles were then mined for any relevant studies cited within (*i.e.*, backwards reference search). Relevant cited studies were also mined for their citations. The first search was conducted on April 9, 2021 using the search terms:

> TS=("ecosystem service*" AND (canada OR canadian) AND (marine OR coast* OR ocean OR sea) AND (aquacultur* OR maricultur* OR farm* OR cultivat*) AND (economic OR ecolog* OR cultur*) AND (valu* OR assess* OR measur* OR quantif*))

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[10] Canadian Aquaculture Industry Alliance (2018). The State of Farmed Seafood in Canada.

[11] Fisheries and Oceans Canada. Departmental priorities and mandate commitments. Available at: www.dfo-mpo.gc.ca/about-notre-sujet/mandate-mandat-eng.htm

[12] Open-net pen transition plan: initial engagement process. As-was-heard report December 14 to April 13, 2021. Letter from the Parliamentary Secretary.
Available at: www.dfo-mpo.gc.ca/aquaculture/publications/open-net-filets-ouverts-eng.htm

[13] Canadian Aquaculture Industry Alliance (2018) The State of Farmed Seafood in Canada.

The search yielded 32 articles. Upon review, only two were identifed as meeting the inclusion criteria (Wieland *et al*., 2016; Clements and Comeau, 2019). The majority of excluded articles did not include a Canadian context, but rather had Canadian researchers who contributed to studies outside of Canada. A review of the references of the two articles yielded no additional relevant articles.

In an effort to identify additional articles, a revised search was conducted on August 9, 2021, with modifications informed by the first search and suggestions from co-authors in other countries. Restrictors used to define environment (*e.g*., marine), general methods of assessment (*e.g*., economic) and terms for types of measurement (*e.g*., value) were removed and assessed through a review of the abstract. The search expanded the ES term to include some specific services, and expanded the spatial identifiers to include Canadian provinces and key Canadian aquaculture production areas using the following search:

> TS=((“ecosystem service*” OR denitrification OR bioextract* OR bioassimilat* OR “nitrogen extract*” OR “nitrogen remov*” OR sequest*) AND (aquacultur* OR maricultur*) AND (Canada OR Canadian OR “British Columbia” OR “Discovery Island*” OR “Fraser River” OR “Broughton Archipelago” OR Quebec OR “Nova Scotia” OR “New Brunswick” OR “Prince Edward Island” OR “Malpeque Bay” OR Newfoundland OR Labrador OR “Gulf of Saint Lawrence” OR “Gulf of St. Lawrence” OR “Bay of Fundy”))

The search located 14 articles, including two of the articles identified in the April search. Two new articles met the inclusion criteria based on review (Cranford *et al*., 2007; Ridlon *et al*., 2021). Several articles were excluded due to spurious results from the spatial identifiers (*e.g*., author’s Canadian educational institution and locations cited for other reasons). No additional articles were found from reviewing the references of the two new relevant articles.

In addition, the sources referenced in Weitzman (2019) and van der Schatte Olivier *et al*. (2020), the starting points for this study, were mined for relevant articles as were those articles, yielding two articles specific to Canada (Hatcher *et al*., 1994; Klain and Chan, 2012).

3.2.3 Review of studies

While all six of the identified articles considered MES in some way, not all of them were focused on estimating the production or value of the service. For example, two of the three studies in BC examined cultural services, but only one (Klain and Chan, 2012) attempted to quantitatively assess the service (or disservice). In contrast, the three articles addressing denitrification and nitrogen removal conducted quantitative modeling analyses, although only one of the articles attempted to provide a monetary value for the service (Clements and Comeau, 2019). None of the other studies provided monetary estimates of the services mentioned or examined.

Following are brief summaries of the articles selected for inclusion, with key aspects of the studies summarized in Table 3.1. The summaries are grouped into two categories, shellfish nutrient studies and other.

Table 3.1 Key attributes of articles identified in the Canadian studies.

Reference	Reference to ecosystem services (ES)	Link to aquaculture and ES	Aquaculture species referenced	Province*
Clements, and Comeau (2019)	Keyword	Nutrient (N) removal with estimate of mitigation costs	Oysters (*Crassostrea virginica)* Mussels (*Mytilus edulis*)	NB and PEI
Cranford *et al*. (2007)	No	Nitrogen cycling	Mussels (species not specified)	PEI
Hatcher *et al*. (1994)	No	Benthic Nutrient cycling, denitrification	Mussels (*Mytilus edulis* and *M. trossulus*	NS
Klain and Chan (2012)	Keyword, title, throughout	Finfish aquaculture as threat to other cultural services	Salmon	BC
Ridlon *et al*. (2021)	Once in reference to outcomes for restored oyster beds	Hatchery used for restoration	Olympia oyster (*Ostrea lurida*)	BC
Wieland *et al*. (2016)	In abstract, used in general context	A negative impact on other ES; *i.e*., aquaculture reduces access to Indigenous wild shellfish harvest	Shellfish (no species) Finish (no species)	BC

* BC = British Columbia (Pacific coast); NB = New Brunswick (Atlantic coast), NS = Nova Scotia (Atlantic coast), PEI = Prince Edward Island (Atlantic coast).

3.2.4 Shellfish nutrient studies

Clements and Comeau (2019) appears in both searches, and considers a specific ecosystem service (nutrient removal) provided by shellfish aquaculture in two provinces (NB and PEI). The study calculated the nitrogen removal potential (NRP) for four culture methods, oysters (*Crassostrea virginica*) in bottom or suspended culture, and mussels (*Mytilus edulis*) in suspension alone or in combination with oysters. The nitrogen removal rate was based on values found in the literature and totals were calculated based on harvest volumes for 77 bays (NB = 22, PEI = 55), totaling 99 tonnes in NB and 204 tonnes in PEI. For 14 bays, an estimate of the nitrogen loading removed *via* shellfish harvesting was calculated, which varied from 86% for a bay with low loading and dense production to 0.1% for several bays with high loading and limited aquaculture production. The average was less than 10%. While not a focus of the study, the authors provide an estimate of the range in total value of the nitrogen removal service provided by existing shellfish aquaculture sites of CA $0.46–17.82 million, using the range of replacement cost estimates from Rose *et al*. (2015b) (Clements and Comeau, 2019: Table 6)

Cranford *et al*. (2007) examined suspended mussel culture (the species is not specified, but most likely was *Mytilus edulis*) in Tracadie Bay, PEI. The study used a nitrogen budget and an ecosystem model based on extensive field data to estimate the amount of nitrogen contained in the mussels removed during harvest. This was compared to the nitrogen inputs from agriculture. The study found that the mussels played a dominant role in the nitrogen cycling in the Bay, influencing all aspects of the cycle. A substantial fraction of the phytoplankton production in the Bay was dependent on land-derived nutrient inputs, predominantly from agriculture. Despite these inputs into the Bay, mussel production may have been food (*i.e*., phytoplankton) limited and carrying capacity met or exceeded (*i.e*., harvest weight fell despite increased stocking densities). Annual nitrogen removal based on the existing mussel harvest levels was estimated to be 9 tonnes per year, or small in comparison to inputs from agricultural run-off (10% of inputs). The model suggested an increase in the retention of nitrogen within the Bay from freshwater (*e.g*., agriculture) and offshore sources in the presence of mussels, and the potential for severe eutrophication effects in benthic communities. This was supported by a past benthic geochemical survey showing hypoxic and anoxic sediment conditions within the boundaries of the mussel farm or lease. The study concludes that mussels direct approximately 20 times more nitrogen to the water column and sediments in their urine and biodeposits than is removed in the harvest. However, since mussel aquaculture utilizes nutrients already present in the system, mussel culture does not cause enrichment but does determine where the products from eutrophication, as a result of excess nutrient run-off, end up.

Hatcher *et al*. (1994) did not use the term "ecosystem services" [14] but focused on the effect of enhanced sedimentation under mussel culture (*Mytilus edulis* and *M. trossulus*) sites on benthic nutrient cycling in an enclosed bay in NS. The study used sediment traps, bottom cores, and water column measurements (*e.g*., temperature, chlorophyll concentrations) to provide a seasonal analysis of nutrient fluxes (*e.g*., nitrogen, phosphorus), and the impact of suspended mussel culture on those fluxes. The study concludes that long-term burial of carbon and nitrogen was 12 times higher at the mussel site than at the reference site without mussels. The results are not presented in terms of nitrogen removal or carbon sequestration as a result of the culture activities, although there are results that suggest this may occur.

3.2.5 Other studies of ecosystem services

The article by Klain and Chan (2012) was referenced in Weitzman (2019), but did not come up as part of the search processes. The article uses the term "ecosystem services" in the title,[15] and used an interview and mapping protocol to identify a range of CES for an area in BC. A number of valued ES were identified by participants, including tangible and intangible non-monetary benefits, although aquaculture was not described as a benefit. Rather, salmon (finfish) aquaculture was identified as a threat to the ecosystem by the majority of participants. Salmon aquaculture had the highest relative threat index based on the number of participants identifying the threat, their weighting of the threat, and size of the areas identified. The location of this study is a key production area for salmon aquaculture in Canada, and there are currently discussions regarding the future of the salmon aquaculture in terms of production methods and location.[16]

Ridlon *et al*. (2021) mentioned aquaculture from the perspective of hatchery-raised Olympia oysters (*Ostrea lurida*) used for restoration projects on the west coast of the United States and Canada (*i.e*., BC). The study measured expert opinions about whether restoration aquaculture was providing the

[14] Based on the Web of Science this article has been referenced 159 times with only 3 of the articles mentioning ecosystem services, illustrating the difficulty in identifying relevant articles.

[15] According to the Web of Science, the Klain and Chan (2012) article has been referenced 191 times, but when this list was screened using the search term "ecosystem service*" only three articles were identified, demonstrating the difficulty identifying the relevant literature.

[16] https://www.cbc.ca/news/canada/british-columbia/salmon-farms-discovery-islands-closing-1.5845502

desired ES, but did not estimate the level of service provision. An expert survey was used to gather information on 39 oyster restoration projects, one of which was in BC. In addition to collecting details on the project implementation (*e.g*., timing and costs), respondents were asked if increasing ES was an objective of the project. As the paper describes, restored oyster beds may provide a range of ES such as increases in desired animal species, shoreline protection, and water quality. Thirty-two percent of respondents identified ecosystem services as part of the objectives for their project, although success was low (*e.g*., nine projects identified an increase in desired animal species as an objective but only three reported success for this service). Although this study includes restoration aquaculture in the United States, this study did not appear in their literature search and is not double-counted.

Wieland *et al*. (2016) was identified in both searches, although the link between aquaculture and ES is in the form of a negative impact. The primary focus of the study was wild shellfish harvest by Indigenous communities (First Nations) in BC. Both shellfish and finfish aquaculture were identified as activities that reduce access to the wild harvest, limiting the potential benefits to Indigenous shellfish harvesters of increases in wild shellfish populations. The paper focuses on the potential disconnect between a change in the supply of ES (*e.g*., food provisioning and cultural services) and the realization in benefits under four impediments to access (*i.e*., geographic location, technical capacity, markets and user conflicts, and management structures).

3.2.6 Concluding remarks

A limited number of papers were identified that discussed the ES provided by aquaculture in Canada, or the impact of aquaculture on other ES. Of the six articles identified, three were related to shellfish aquaculture in Atlantic Canada and were linked to nutrient removal, cycling or productivity. Of the three articles related to aquaculture in BC, on Canada's Pacific coast, two identified aquaculture as having a negative impact on other ES. A positive impact of aquaculture on ecosystem services was identified only in the case of restoration aquaculture with the native Olympia oyster.

The term "ecosystem service" was used in the literature search to identify relevant papers. However, it is clear that more targeted searches may better capture the literature, due to the absence of articles on other potential ES (or disservices) provided by aquaculture, such as food provisioning, supporting services such as habitat, other regulating services such as carbon sequestration, and cultural services outside of BC. This first review can support expanded efforts to more fully capture the trade-offs in ES as a result of aquaculture in Canada.

3.3 Chinese case studies

3.3.1 Introduction

Marine ecosystems play an extremely important role in food supply, climate regulation, biological regulation and control of pests and diseases, as well as shoreline protection (Costanza *et al*., 1997), providing valuable support for economic and cultural development. Marine aquaculture (hereafter, mariculture) is a significant means by which humans interact with marine ecosystems (Wang, 2010). China is a leading nation for aquaculture production. In 2020, the total output of aquaculture in China was 52.2 million tons, accounting for about 79.8% of the national total output of aquatic products. The output of mariculture was 21.4 million tons, accounting for about 41% of the total, with a year-on-year increase of 3.4% (MARA, 2020). China's mariculture industry has gradually shifted from large-scale and multi-species development to intensive mono-culture and high-quality development mode (Huang and Yuan, 2021). With the footprint of aquaculture expanding and the structure of aquaculture becoming standardized, the Ministry of Ecology and Environment of China and Ministry of Agriculture and Rural Affairs of China put forward suggestions to strengthen the supervision of mariculture to minimize its negative impacts on the local ecosystems. As a result, the net ecological impact of Chinese mariculture is gradually improving.

Generally speaking, the ES of mariculture are the benefits that people can get directly or indirectly from the structure and function of mariculture. Quantifying the value of ES provided by mariculture cannot only add to the academic knowledge base, but may also inform critical policy decisions regarding mariculture siting and marine spatial planning. Therefore, calculating the value of ES associated with mariculture can contribute to the sustainable development of mariculture.

Costanza *et al*. (1997) classified global ES into 17 categories and estimated their value. Based on the classification of ES, some studies estimate their value for categories such as marine, wetland, forest, and river (Brenner *et al*., 2010; Quoc Vo *et al*., 2015; Lamhamedi *et al*., 2021; Vermaat *et al*., 2021). Some studies combine ecosystem service value assessment with socio-economic issues, such as Feng *et al*. (2021), which assessed the value of MES along the Pacific coast of Canada to study the sensitivity of coastal areas to oil spills. Ghermandi *et al*. (2019) discussed the interaction between aquaculture and the tourism, cultural, and provisioning services of mangroves. Mangroves provide valuable coastal protection, carbon sequestration, and other ES, but the economic pressures to replace mangroves with prawn aquaculture threatens the continued provision of these services. Some scholars have studied the impact of land use change, land coverage, and other factors on ecosystem service value or the value of a specific service from different angles (Ghosh and Bhunia, 2021; Makwinja *et al*., 2021; Peng *et al*., 2021; Tolessa *et al*., 2021). In addition, scholars have also studied landscape patterns (Chen *et al*., 2021; Hu *et al*., 2021). The relationship and influence between the presence of certain species and ecosystem service value are explored from the perspectives of temporal and spatial evolution of the ecosystem service value (Lin *et al*., 2021) and species richness (Pathak *et al*., 2021; Wan *et al*., 2021).

Chinese scholars began to classify and evaluate MES in 2000, with more careful coverage beginning in 2003. According to the research results of Costanza *et al*. (1997), combined with the current situation of China's marine ecological environment and resources, the classification and evaluation framework of China's MES value is established from a theoretical level (Xu and Han, 2003; Shi *et al*., 2007). On this basis, empirical studies on the value of MES continue to emerge. A few of them have calculated the value of China's overall MES (Chen and Zhang, 2000; Gengyuan *et al*., 2021). Most of the studies have estimated the value of regional MES, while the value of offshore ES has been estimated in Shandong Province, Zhejiang Province, Jiangsu Province, Hainan Province, Guangdong Province and Guangxi Province (Han *et al*., 2008; Li *et al*., 2011; Wang, 2012; Li and Tan, 2013; Xia *et al*., 2014; Yu *et al*., 2016). We identified only one article related to aquaculture and ES in China that was published in a foreign journal. Zheng *et al*. (2009) estimated the value of food production, oxygen production, climate regulation, waste treatment, and other related services in Sanggou Bay, and established a model based on income cost analysis to determine a sustainable mariculture model.

Because supporting services derive their value from feeding into the other three service categories, it is important to avoid double-counting these intermediate services. This is usually done by omitting supporting services from the computation and evaluating only final goods and services.

Our literature review revealed that there are few studies estimating the value of MES. This scarcity may be related to the relatively recent interest in MES. Based on the search methodology, to be described subsequently, nine relevant papers published from 2007 to 2019 on MES valuation in China were found. The marine areas studied in the literature were in the Yellow Sea, the East China Sea and the South China Sea. The aquaculture varieties include algae, shellfish, shrimp, and fish. The methods and results of marine aquaculture ecosystem services and value evaluation in China are compared in detail.

3.3.2 Literature search

Keywords such as “mariculture ecosystem service”, “aquaculture ecosystem service value evaluation” and “marine ecosystem service value evaluation” were searched for in the China National Knowledge Infrastructure (CNKI) for papers published between January 1, 1979 and December 31, 2020. This search yielded 81 relevant Chinese documents for further review. After applying the inclusion and exclusion criteria discussed in the introduction to section 3, nine relevant studies related to the ecosystem service value of mariculture in China were identified. Some of these studies do not expressly include “aquaculture” in the text, but are from areas known to the authors to have production that is primarily aquaculture. The role that marine ranching plays in China’s aquaculture production is growing, and therefore the literature search also included value estimation for the ES of marine ranching. Searches for relevant articles from the English Literature Library returned only one paper, which estimated the value of ecosystem services in Sanggou Bay (Zhang *et al*., 2007). Since three of the nine Chinese-language studies selected in this report evaluate the ES of mariculture in Sanggou Bay, this English-language study is included in the following analysis.

In terms of the classification of ES, most researchers draw from the classification method of the Millennium Ecosystem Assessment (MA, 2005), where ecosystem services are divided into provisioning, regulating, cultural, and supporting services (Fig. 3.4). The provisioning services include food supply, fishing value, raw material supply, provision of genetic resources, *etc*. Regulating services include climate regulation, gas regulation (air quality regulation), waste treatment, water purification, biological regulation, control of pests and diseases, *etc*. Cultural services include leisure and entertainment, cultural uses, employment income, scientific research value, *etc*. Supporting services include primary productivity, nutrient cycling, species diversity maintenance, provision of habitat services, *etc*. The supporting services in mariculture marine ecosystems are intermediate services, while the other three services are final services. Because support services are not final services, many researchers prefer to avoid double-counting by only computing the value of the other three types of services.

Research on ES associated with aquaculture in China focuses mainly on areas with developed coastal shallow water aquaculture, beach aquaculture, and harbor aquaculture (Table 3.2). Most of China’s mariculture is concentrated in the eastern and southern waters of China, *i.e*., the Yellow Sea, the East China Sea and the South China Sea, with the literature providing a relatively comprehensive coverage of the ecosystem service value in these areas. However, in recent years China’s mariculture industry has developed rapidly, but scholarship has lagged behind in evaluating service provision from the emerging mariculture areas and in updating values for the established mariculture areas for recent years.

Mariculture ecosystem services

The benefits obtained by human beings indirectly or directly from mariculture include provisioning service, regulation service, cultural service and energy support service and its subclassification.

Provisioning Services

Products or services produced by mariculture.

- Food supply
- Raw material supply
- Gene resource supply

Regulation Services

The benefits that people get from the regulation of the ecosystem.

- Climate regulation
- Gas regulation
- Waste disposal
- Biological control
- Interference regulation
- Water purification and regulation
- Biological regulation and control of pests and diseases

Cultural Services

People get non-material benefits from the ecosystem through spiritual feelings and knowledge acquisition.

- Recreation and entertainment
- Cultural uses
- Research value
- Employment

Support Services

Ensure that all other ecosystem services provide the necessary basic functions.

- Nutrient cycling of primary productivity
- Maintenance of species diversity
- Provision of habitat services

Fig. 3.4 Definition and classification structure of mariculture ecosystem services.

There is a diversity of culturing methods employed in these areas. In Sanggou Bay, Shandong Province, a multi-trophic level comprehensive aquaculture approach is employed. By incorporating the culture of algae, kelp, oysters, shellfish, and fish together, the mariculture can approximate the ecological advantages of the natural interplay between species. This allows for more efficient utilization of resources and reduces environmental damages. The dominant form of aquaculture in Zhelin Bay, Guangdong Province, is cage culture, which has the advantages of flexibility and a simple operation that can be tailored to local conditions. In addition to cage culture and sea asparagus culture, Shenzhen Bay, Guangdong Province, has adopted long oyster raft hanging culture.[17] Single-species oyster culture is adopted in the Dapeng'ao area of Guangdong Province, and the mixed culture mode of fish, shrimp, shellfish, and algae is adopted along the coast of Fujian Province.

[17] This is a hanging culture mode of oysters. The shells fixing oyster seedlings are connected in series with ropes and hung on the raft at certain intervals (usually 10 cm). This aquaculture model can use vertical space for mariculture, making full use of mariculture space and aquaculture resources.

Table 3.2 Regional mariculture ecosystem service value assessment in China.

Study	Service functions of the ecosystem	Assessment area	Cultured species
1. Yu *et al*. (2014)	Supply services (breeding production, oxygen production); Regulation services (climate regulation, waste disposal, fixation of C, N and P by oysters); Cultural services (leisure and entertainment, scientific research services)	Dapeng'ao (Shenzhen, Guangdong Province)	Oyster
2. Wang *et al*. (2014)	Supply services (food supply, raw material supply, oxygen generation); Regulation services (climate regulation, waste disposal); Cultural services (scientific research services)	Shen'ao Bay (Guangdong Province)	Cage fish culture, long oyster raft hanging culture and sea asparagus culture
3. Ma *et al*. (2019)	Supply services (breeding value, fishing value, raw material production, genetic resources); Regulation services (climate regulation, O_2 production /CO_2 absorption, water purification regulation, biological control); Cultural services (leisure and entertainment, scientific research services)	Zhelin Bay (Guangdong Province)	Cage culture area, algae proliferation area, shellfish bottom sowing area, artificial reef area, proliferation and release area
4. Zhu *et al*. (2017)	Supply service, regulation service and cultural service	Fujian Province	Fish, shrimp, shellfish, algae, polyculture
5. Cheng *et al*. (2014)	Supply services (food supply, raw materials, genetic resources); Regulation services (climate regulation, air quality regulation, water purification regulation, interference regulation, biological control, disease regulation); Cultural services (tourism, entertainment, scientific research and culture); Support services (primary production, biodiversity, habitat services)	Xiangshan Harbor (Xiangshan County, Ningbo City, Zhejiang Province)	Artificial reefs, large-scale transplantation of seaweed, bottom sowing and proliferation of economic shellfish
6. Zhang *et al*. (2007)	Supply services (food supply, raw material supply); Regulation services (climate regulation services, air quality regulation, water purification regulation, biological regulation and control of pests and diseases); Cultural services (knowledge expansion services, tourism and entertainment services)	Sanggou Bay (Weihai City, Shandong Province)	Three-dimensional mixed culture of algae, shellfish and fish, such as kelp, *Undaria pinnatifida*, scallop, oyster, abalone and marine fish
7. Wang (2010)	Supply services (food production, raw material production, oxygen production, provision of genetic resources); Regulation services (climate regulation, waste disposal, biological control, interference regulation); Cultural services (leisure and entertainment, cultural purposes, scientific research value); Support services (primary production, nutrient cycling, species diversity maintenance)	Sanggou Bay (Weihai City, Shandong Province)	Kelp, *Undaria pinnatifida*, cauliflower (seaweed), scallop, mussel, oyster, abalone, razor clam, clam, sea cucumber, shrimp, various fish

Table 3.2 Continued.

Study	The service functions of ecosystem	Assessment area	Cultured species
8. Shi *et al*. (2008)	Supply services (fishery production); Regulation services (gas regulation, sewage treatment, air purification); Cultural services (coastal tourism, cultural value)	Sanggou Bay (Weihai City, Shandong Province)	Oyster, kelp, clam, scallop
9. Lv (2017)	Direct ecological service value (seaweed carbon fixation value, nutrient regulation, heavy metal adsorption and removal value) indirect ecological service value (avoiding the replacement of land ecological service value, avoiding the waste of fresh water resources, and reducing the use value of chemical fertilizers and pesticides)	China (Yellow Sea, East China Sea, South China Sea)	Seaweed

3.3.2.1 Provisioning services

Among the papers found in our search, there is broad agreement that the provisioning services are the most valuable, accounting for the largest proportion of the total service value. The proportion of food production services to the total service value is above 50% at all sites (Fig. 3.5). The highest proportion was in the oyster culture area of Dapeng’ao in 2012, where the value of aquaculture production in the supply service in that year was RMB 31.58 million, accounting for 91.3% of the total ecological service value. The lowest proportion of food production services in the assessment results was the value of food supply services in Sanggou Bay in 2003, which accounted for 50.5% of the total service value.

The proportion of the total value provided by food supply varies between years for the same mariculture areas. For example, in 2012, the proportion of food supply services in the oyster farming area of Dapeng’ao was over 90%, but in 2013 the proportion of this service dropped to 66.3%. This significant decrease in the service value was due to the excessive scale of oyster farming in 2013, the aging of the sea area, and uncontrolled development. The various measures of the proportion of food production services calculated in the literature is shown in Figure 3.5, although two of the studies do not address the valuation of this service (Lv, 2017; Zhu, 2017) and are therefore not reflected in the figure.

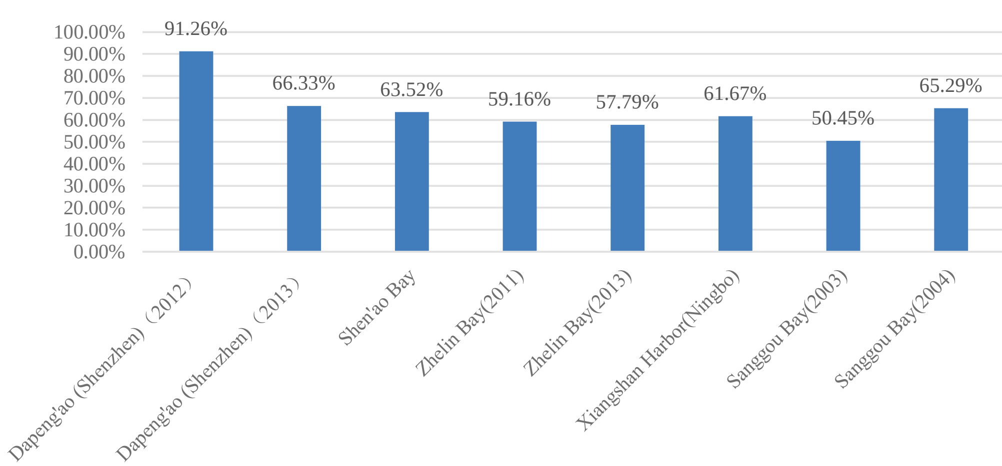

Fig. 3.5 Chinese proportion of food supply service value in total service value.

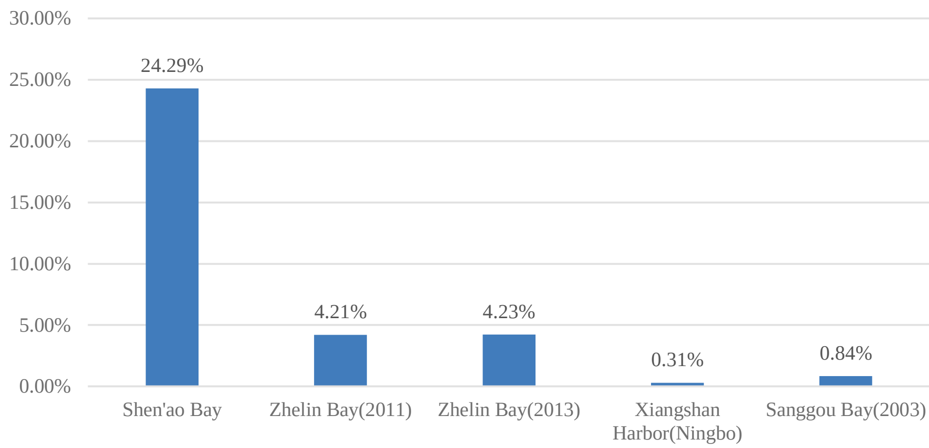

Fig. 3.6 Chinese proportion of raw material supply service value in total service value.

Aquaculture can provide raw non-food materials such as shells. Four of the papers assessed the value of raw material supply services (Fig. 3.6). According to the results, the value of raw material supply services for mariculture was less than 5% for most sites. The exception is Shen'ao Bay, Guangdong Province, where the proportion of total value from raw material value (24.3%) was second only to the value of food supply. The reason for this is that the primary species cultured in Shen'ao Bay are oysters and long bearded greens (*Gracilariopsis lemaneiformis*). These species have a higher raw material utilization value compared to other cultured species such as algae and fish, with oyster shells being used as industrial raw materials for processing and long bearded greens being used to produce agar. This agar production accounts for 70% of the total production value of long bearded greens.

3.3.2.2 Regulatory services

Non-fed aquaculture such as algae, macro-algae, and shellfish provides important regulatory services. The regulating service functions of these species are mainly manifested in climate regulation, air quality regulation, and waste treatment.

The climate regulation function in mariculture works mainly in two ways: first, carbon is fixed and oxygen is released through photosynthesis of algae and macro-algae; second, shellfish feeding on planktonic algae or directly absorbing bicarbonate (HCO_3^-) in seawater form calcium carbonate ($CaCO_3$) shells. The carbon sequestration by algae and shellfish is important for the mitigation of global warming. In the six papers that assessed the value of climate regulation functions (Fig 3.7), the value of carbon sequestration as a proportion of the total service value ranged from a high of 14% to a low of 1.02%. The proportion of carbon sequestration provided by seaweed aquaculture in China in 2014 was 14% of the total service value. This reflects the considerable contribution of seaweed to carbon sequestration, which has been increasing year by year as China's seaweed aquaculture industry continues to develop.

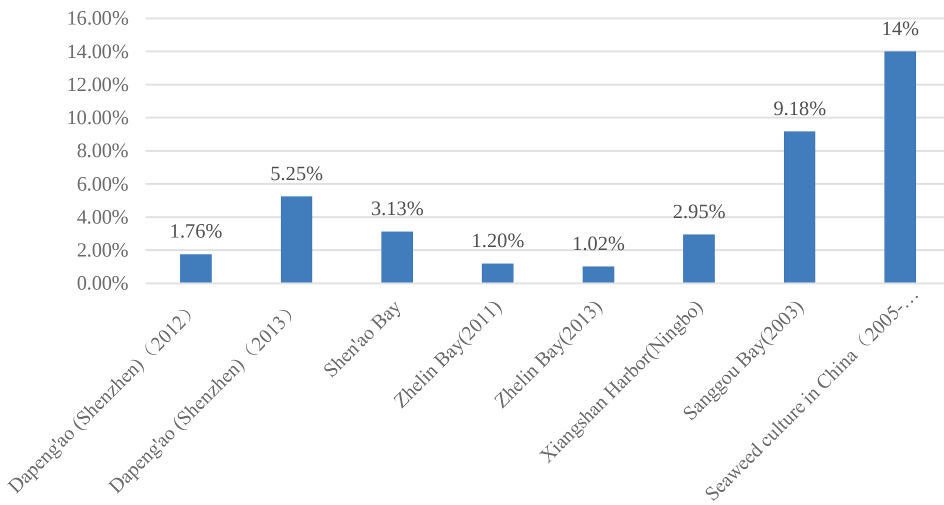

Fig. 3.7 Chinese proportion of climate regulation service value in total service value.

Farmed algae and phytoplankton provide air quality regulation services by fixing carbon and releasing oxygen through photosynthesis, and by absorbing harmful gases such as SO_2 and DMS (dimethyl sulfide of biogenic origin, the main volatile sulfide in the oceans). Two of these papers assessed the value of air quality regulation services of mariculture ecosystems. Zhang *et al*. (2007) calculated the value of oxygen release when calculating the value of air quality regulation services in Sanggou Bay in 2003. The value of air quality regulation services was calculated to be between RMB 37.0–42.0 million according to the afforestation cost method and industrial oxygen production cost method in China, accounting for about 6.1–6.9% of the total service value. Cheng *et al*. (2014) also used the alternative cost method to calculate the value of air quality regulation services in Xiangshan Harbor, Zhejiang Province, at RMB 121.9 million, based on China's afforestation cost method and industrial oxygen production cost, accounting for about 4.5% of the total service value.

The nutrient management function is mainly provided by shellfish and algae culture. Various nutrients such as carbon, phosphorous, and nitrogen are present in the ocean, with wastewater, agricultural runoff, and even finfish aquaculture adding to the release of these nutrients. An excess of these nutrients leads to eutrophication, which can result in an excess of algae or plants and a depletion of dissolved oxygen, which can be dangerous to animals. A total of seven papers assessed the value of nutrient management services of mariculture, with the highest proportion being the value of nutrient management services from seaweed farming in China, accounting for approximately 20% of the total ecosystem service value. The smallest proportion of the assessed results was the value of nutrient management services in Zhelin Bay, Guangdong Province, in 2011 and 2013, at RMB 21.9 million and RMB 25.5 million, respectively, both accounting for 0.04% of the total service value. In contrast, when assessing the service value of nutrient management in Sanggou Bay in 2004, the authors divided the value of nutrient management into the value of sewage treatment and the value of air purification, totaling RMB 113.9 million, and accounting for a relatively high 10.8% of the total service value. Nutrient removal services are provided by different cultured species in each sea area. In the area of Dapeng'ao, Guangdong Province, it is primarily oysters removing nitrogen and phosphorous by incorporating the nutrients into their own soft tissues and shell growth. In Shen'ao Bay, Guangdong Province, nitrogen and phosphorous removal services are mainly provided by phytoplankton, lobelia, and oyster farming. Kelp and other algae culture are also major providers of these nutrient removal services.

3.3.2.3 Cultural services

In studies measuring cultural service values, the focus was on tourism or research services associated with all cultured species in each mariculture region. A total of six papers assessed the value of cultural services in mariculture ecosystems, of which four determined that the value of cultural functions is larger than the regulating functions, namely studies in Sanggou Bay (Wang, 2010; Zhang *et al*., 2007), Xiangshan Port, Zhejiang (Cheng *et al.*, 2014) and Zhelin Bay (Huan *et al.*, 2019), while the cultural functions in the other cases were less than the assessed value of the regulating functions (Fig. 3.8). The cultural service function of Sanggou Bay was more prominent. The value of cultural services (including knowledge expansion services and tourism and recreation services) accounted for 31.4% of the total service value in 2003, and the service value per unit area was RMB 13.3 million/ha, making it the second largest ecological service value in that year after the value of food supply services (Zhang *et al*., 2007). The lowest value of research services in Sanggou Bay was estimated at RMB 9 million from 2003 to 2004, accounting for only 0.7% of the total value of ecosystem services (Wang, 2010). Across studies, the results of the assessment of the value of cultural service functions in the same region in similar years vary considerably, in part because the authors used different classifications of cultural services. For example, Zhang *et al*. (2007) assessed the value of cultural services in Sanggou Bay in 2013 by considering knowledge development services and tourism and recreation services, while Wang (2010) assessed the value of cultural services in Sanggou Bay in 2003–2004 by considering only the value of scientific research services without including the value of recreation. Much of the difference in the assessment results is due to the fact that the value of recreation was not included.

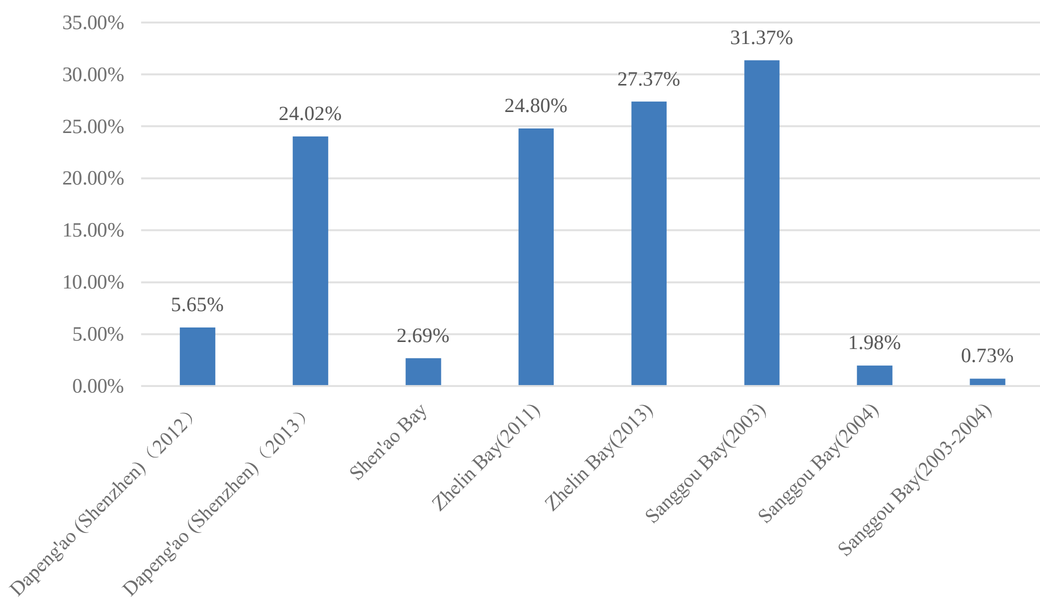

Fig. 3.8 Chinese proportion of cultural service value in total service value.

3.3.2.4 Methods for the valuation of mariculture ecosystem services

A review of the literature reveals that, in terms of the value of MES and valuation methods, Chinese scholars usually use three main types of valuation methods: the direct market approach, the alternative market approach, and the virtual (hypothetical) market approach.

The direct market approach is usually used to calculate the value of provisioning services such as food supply, raw material supply, and oxygen production. This approach uses real market prices to assess the value of services or products provided by marine ecosystems in kind, including the market value approach and the production cost approach. Wang *et al*. (2014) measured the value of food supply services using the unit market price of various seafood products and the annual production of mariculture in Shen'ao Bay.

The alternative market approach is usually used for the assessment of the value of services such as climate regulation and nutrient removal, and cultural services like recreation since these services have no established market value and are difficult to assess. The alternative market approach uses the price of substitutes to approximate the value of non-marketed goods and services. This method includes the alternative cost method, the replacement cost method (avoided cost method), and the travel cost method. Huan *et al*. (2019) assessed the value of oxygen produced by photosynthesis of cultured marine plants when calculating the value of the regulating services in Zhelin Bay. The study used the cost of artificially producing oxygen to estimate the economic value of oxygen from mariculture. Cheng *et al*. (2014) used the travel cost method to assess the value of tourism and recreational services at Xiangshan Harbor.

The hypothetical market approach is usually used to assess the value of services for which economic values are even more difficult to estimate, such as tourism value and cultural value. Some examples include the willingness-to-pay approach and the contingent valuation approach (Cheng *et al*., 2014). The hypothetical market approach can assess the value of services with incomplete or non-existent market values, but the assessment results are prone to bias in different geographical or economic situations. For example, Shi *et al*. (2008) used the willingness-to-pay method in order to measure the cultural value of Sanggou Bay, and calculated the willingness to pay of residents in the area who were willing to live in the estuary or along the coast.

In addition to the three main evaluation methods mentioned above, other evaluation methods are involved for different purposes of the study. Yu *et al*. (2014) used the research cost method to assess the value of research services in the Dapeng'ao area, using the average number of scientific papers, geographic area of the bay, and the average cost of producing marine scientific papers in China for four years from 2010 to 2013 to calculate the average research service value. For the Dapeng'ao oyster culture area, this was estimated to be RMB 715,200/year. For the value of climate regulation services in the mariculture ecosystem, Zhang *et al*. (2007) used the Swedish carbon tax method to assess the carbon sequestration value of shellfish culture species in Sanggou Bay. Wang (2010) surveyed 40 experts in marine ecology and mariculture in Sanggou Bay, who provided scores for the weights of various ES and the impacts of aquaculture on ES in the area. Zhu (2017) established a mariculture service value assessment model to assess the total, average, and marginal values of mariculture services in Fujian Province, separately.

3.3.2.5 Assessment results

The published results include the total value of ES provided by the sea area, and in most cases also include the annual service value per unit of farmed sea area (Fig. 3.9). As the size of the assessed area varies, we focus on the value per unit area of the marine area to perform a comparative analysis. In terms of the assessed value of ES per unit area of farmed marine area per year, the highest was RMB 173,000/ha in Daya Bay, Dapeng'ao, Shenzhen, Guangdong Province, in 2012, and the lowest was RMB 25,600/ha per unit area of farmed marine area in Fujian Province, except for Luoyuan Bay, which was priced at RMB 134,500/ha. The estimated values of ES per unit area of mariculture fluctuated considerably within the same region, *i.e.*, Daya Bay in 2012 and 2013. For example, the value per unit area of culture in Daya Bay was assessed at RMB 173,000/ha in 2012 and RMB 40,700/ha in 2013, with the difference mainly attributable to differences in the production value of oyster culture. Similarly, for Sanggou Bay in Shandong Province, ES per unit area of farmed marine area were valued at RMB 42,400/ha in 2003 and RMB 64,370/ha in 2002, with the difference in values mainly attributable to a change in valuation methodology. The market value approach and the carbon tax approach were used in both papers, but the alternative cost approach and the willingness to pay approach were also used in the assessment of 2004.

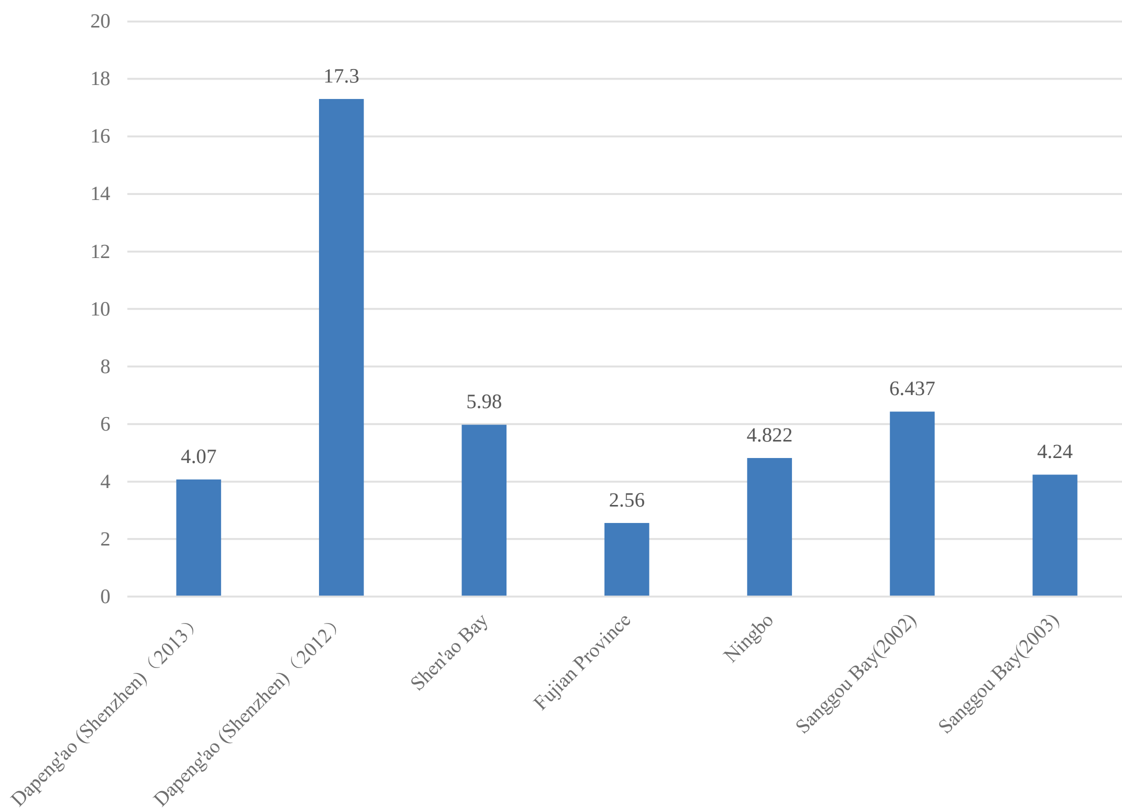

Fig. 3.9 Ecosystem service value per unit area in the study area (RMB 10 thousand /ha).

Finally, most of the literature assesses the total value as well as the individual functional values, and in the case of Shen'ao Bay and Fujian Province, an assessment and comparison of the service values of different cultured species was added. In the case of Zhelin Bay, a comparison of the service value of different farming patterns was also done. Inconsistent assessment units, inconsistent functional classification, and inconsistent corresponding value assessment results were also identified in the literature review.

3.3.2.6 Conclusions of the assessment

Research into the value of ES and mariculture by Chinese scholars has focused on the main mariculture production areas. Although the actual conditions of ecosystems and assessment methods vary from region to region, in general, mariculture has contributed to an increase in the value of MES and to a more efficient development of mariculture.

Synthesizing the findings of Chinese scholarship, firstly, among the three main service categories of mariculture ecosystems, the value of provisioning services (food and raw materials) represents the majority of the total service value. In addition to the provisioning services, the cultured organisms are also able to improve oxygen production, promote oxygen circulation, provide certain genetic resources for species diversity, and enrich the species abundance and diversity in the ecosystem. Secondly, the culture of shellfish, algae, and other species can play a meaningful role in carbon sequestration and oxygen release, providing valuable climate regulation services. Fish, shrimp, shellfish, and algae have an absorption and decomposition effect on the pollutants discharged into seawater, which can maintain the environmental stability of the ecosystem. Thirdly, as the local society and economy grows, the cultural service value of mariculture is also on the rise year by year. In addition to the strong ecological service value of bays such as Zhelin Bay and Xiangshan Harbor, their cultural service values related to tourism services and scientific research services are also an important part of the total ecosystem service value. An addendum to this section presents a bibliometric analysis that further explores patterns of the Chinese ES literature (see section 3 Annex).

3.3.3 Concluding remarks

3.3.3.1 Summary of findings

Research on the value of ecosystem services and mariculture started late in the domestic academic community. Although compared to other countries, there is a relatively large amount of published literature on the valuation of ES and mariculture in China, the absolute number of studies (nine) on the topic is not large. However, the research is of great significance in promoting the development of high quality mariculture and the valuation of the climate regulation benefits of mariculture. The main conclusions from the quantitative and qualitative analyses in the nine examined papers are as follows: (1) Most of the research was focused on the dominant mariculture regions and species. The breadth of the research we found ranged from simple research inquiries about the variety and regional location selection of mariculture to more in-depth research on mariculture technology and the evaluation of the ecosystem service value and carbon sink value of mariculture. (2) Research has only involved four coastal provinces, leaving large geographical gaps in knowledge. In recent years, the mariculture industry in China has developed at a relatively rapid pace, and the research has not kept up with this expansion in terms of new sites and changes in culture techniques. (3) The value assessment was divided into three “final services” categories: provisioning, regulating, and cultural services, of which the value of food production included in the provisioning category provides the majority of the total value. Five studies measured the climate regulation function, which represents at most 9% of total service value, at minimum 1% and on average about 3%. The estimated value of the cultural service function was the greatest for Sanggou Bay in 2003 at 31.4%. The cultural service value exceeded the regulating service value in four studies, but the classification criteria for the cultural service function were not uniform. (4) The economic value was primarily assessed by one of three methods, namely the direct market method, alternative market method, and virtual (hypothetical) market method. Other evaluation methods were infrequently employed. (5) Seven of the papers standardized values by hectare of cultured space, with the highest being RMB 173,000/ha for Dapeng'ao in Shenzhen in 2012 and the lowest being RMB 25,600/ha for Fujian Province, while the value of sea area in the other papers ranged from RMB 40,700/ha to RMB 64,400/ha. The difference in assessment results was mainly due to the different assessment methods. (6) The research was focused on provisioning services, which represents the largest share of ecosystem services, the role of shellfish and algae in carbon sequestration, and the gradual increase in the value of mariculture cultural services. In general, mariculture appears to provide valuable marine ecosystem services.

3.3.3.2 Suggestions for future research

Although mariculture has notable ecological benefits, there are also problems such as ecological threats caused by excessive expansion of the scale of farming, the ecological imbalance created by single-species mono-culture, and the squeezing of development space by other marine industries. In order to further promote the responsible development of mariculture, it is important to incorporate its economic benefits into the concept of sustainable development. The continuous improvement of research on the valuation of ES of mariculture will help to achieve both economic and ecological benefits of mariculture. There are several topics ripe for future research to improve the state of knowledge regarding mariculture and ES.

Firstly, it would be useful to develop a dynamic analysis of the value generated by ecosystem services and mariculture. Current research on MES tends to be static in nature, focusing on the value at a particular location and a particular time. Although this approach produces valuable knowledge, it cannot generate predictions for the value of ES in the future, with changing climate and ocean conditions. In future research, more attention should be paid to changes in ecosystem service values before and after mariculture, and to changes in ES due to changes in the climate and ocean conditions. Furthermore, we should better integrate human activities (*e.g.*, increasing wastewater discharge) and changes in ecosystem service values to achieve a more complete and thorough assessment of the value of MES.

Secondly, a comprehensive assessment of the value of multiple services of mariculture ecosystems should be carried out. Many scholars currently focus on the core services of a particular area, but neglect to assess the value of multiple services, resulting in a conservative estimate. For example, macro-algae culture not only produces oxygen, but also takes up harmful gases, so it is important not to focus only on the value of oxygen supply services while ignoring the value of harmful gas uptake services of cultured species.

Thirdly, the consistency of service function classification and value assessment methods should be improved. It is clear from the literature review that different quantitative results can result from differences in the service function classifications and assessment methods. The differences in the classification of cultural service functions in the literature lead to large differences in the value assessment results. Clarifying the differences in assessment results between different research methods applied to different types of ecological service functions, cultured species, and culture methods will help to standardize the valuation of ES and make the assessment results more comparable and practical.

Therefore, research on the adaptability of ecosystem value assessment methods to various types of service functions needs to be further improved in future studies.

Finally, the literature would benefit from a consistent standard unit of measurement for ecosystem service measurement. In the nine studies discussed here, the differences in units for the value assessment and the lack of uniformity in the assessment content led to difficulties in comparing the results, and the data available for comparative analysis were limited. In this report, we chose to compare ecosystem service values by category as a percentage of the total value, and to compare ecosystem service value per unit area. The ecosystem service value per unit area was calculated based on the information in each paper, and some of the studies did not state the footprint of aquaculture in the study area and thus could not be included in the comparison. Being able to compare differences in the value of ecosystem services associated with differences in farming conditions, environments, or practices would promote high quality development of mariculture. Therefore, it is recommended that the units for assessing ecosystem service values and the content of research be harmonized for research on the valuation of ecosystem services in mariculture, thus increasing the applicability of the findings for business and policy decisions.

3.4 Japanese case studies

3.4.1 Introduction

The total combined production of capture and aquaculture of seafood (fish, crustaceans, molluscs, *etc*.) in Japan reached 4.17 million metric tons in 2020, with aquaculture accounting for about 23.2% of that total (approximately 1 million metric tons) (Ministry of Agriculture, Forest and Fishery, 2020). Aquaculture production reached a peak of 1.34 million metric tons in 1994, and declined slightly thereafter with the exception of Yellowtails (*Seriola quinqueradiata*) and a few others maintaining fairly constant levels of production (Fisheries Agency of Japan, 2020). Figure 3.10 shows the recent downward trend of fisheries and aquaculture.

Japanese aquaculture production ranks 11th in the world, yet comprises only 1% of global aquaculture production. Numerous species are cultured, as illustrated in Figure 3.11. Approximately 30% of the production is Nori seaweed (*Pyropia yezoensis*), 16% oysters (*Crassostrea gigas*), 15% scallops (*Mizuhopecten yessoensis*), 14% Yellowtails, 6% Red Seabream (*Pagrus major*), with the remaining species representing 5% or less of total production each. The impact of aquaculture in Japan and its associated ecosystem services are important to understand, particularly as it compares to other member countries in the North Pacific region. In the following we perform a literature search to summarize the body of knowledge related to ES and aquaculture in Japan.

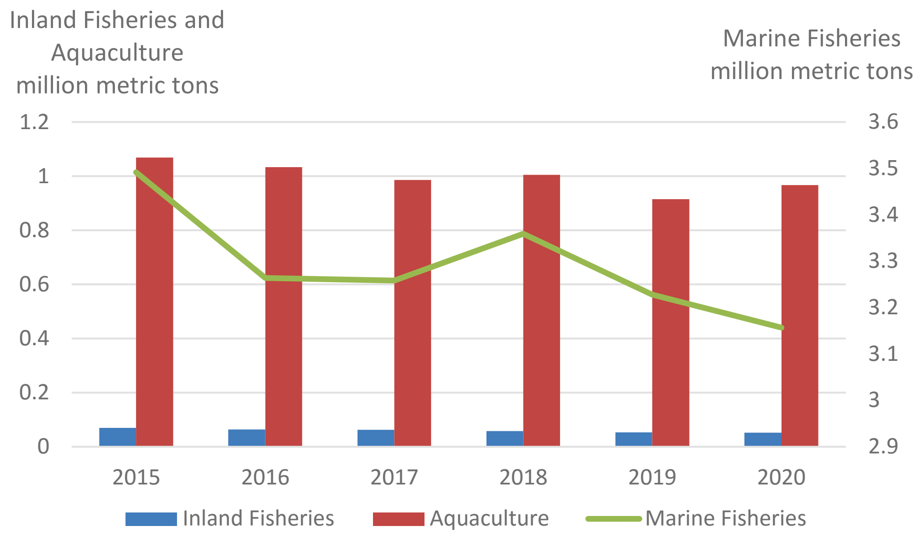

Fig. 3.10 Production of fisheries and aquaculture in Japan (Ministry of Agriculture, Forest and Fishery, 2020).

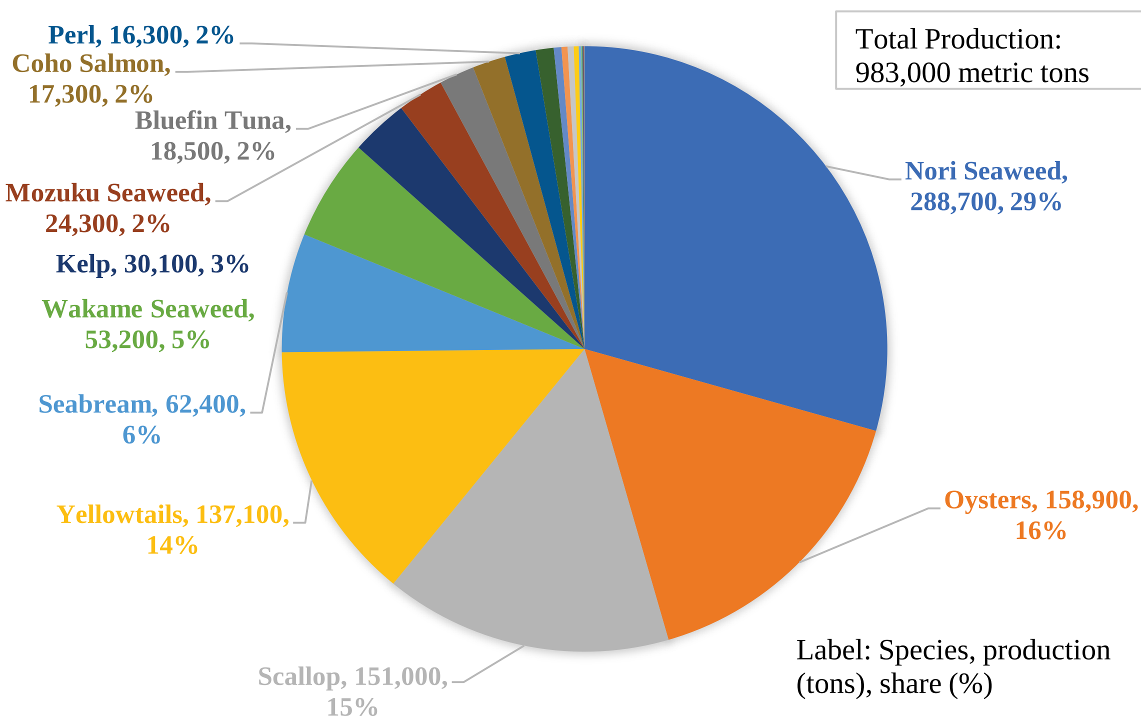

Fig. 3.11 Share of aquaculture production by species in Japan (Ministry of Agriculture, Forest and Fishery, 2020).

The Japanese government has historically used the term “multifunctional services” of ecosystems (multifunctionality) as a synonym for ecosystem services. This term has been used in the agricultural field in Japan since the 1990s (Kunii, 2016). Since the 2000s ES terminology has also been popular, and Japanese researchers have used both ES and multifunctionality verbiage, depending upon needs and occasions (Kunii, 2016). This is partly because the Japanese government launched the “multifunction payment grant” in 2014 (Ministry of Agriculture, Forestry and Fisheries, MAFF) to maintain/support ecosystem services, and “multifunctionality” is included in the name of the grant/subsidy (MAFF, multifunction payment grant).[18] This grant was given to farmers through local governments and 48,652 million yen (439.6 million USD in June 28, 2021) was granted in total in 2021 fiscal year (MAFF, “Budget of multifunction payment grant”).[19] Accordingly, there is a possibility that studies related to ES in Japan may not include the term “ecosystem services,” but instead, include multifunctionality for the purpose of grant application. Hence, we considered multifunctionality or related words as a search word in this case study.

Similarly to the other PICES member countries’ case studies, we used a common set of search terms, but also included “multifunctionality” as a country-specific search word. In addition, we employed backward- and forward-referencing to make up for any shortcomings of the above search method. The following sections detail the specific literature search methods used, the results, and a discussion.

3.4.2 Literature search methodology

The literature search was conducted using Web of Science (WoS), which covers literature from 1900 through the present. We conducted queries over the “topic” field, which looks for matches in the title, abstract, author keywords, and keywords. The basic search terms used are the following and generally follow the ones used by the other member countries.

> (“marine” or “coast*” or “ocean”) and (“aquacultur*” or “maricultur*” or “sea farm*” or “ocean farm*”) and “ecosystem service*” and (“economic” or “ecological” or “cultur*”) and (“valu*” or “assess*” or “measur*”) and (“Japan*")

We also separately searched the basic keywords by the following 4 layered topics:

1. Marine ecosystem services (MES) in Japan

   (“marine” or “coast*” or “ocean”) and “ecosystem service*” and (“Japan*”)

2. Aquacultural MES in Japan

   (“marine” or “coast*” or “ocean”) and (“aquacultur*” or “maricultur*” or “sea farm*” or “ocean farm*”) and “ecosystem service*” and (“Japan*”)

3. Economic, ecological or cultural MES in Japan

   (“marine” or “coast*” or “ocean”) and “ecosystem service*” and (“economic” or “ecological” or “cultur*”) and (“valu*” or “assess*” or “measur*”) and (“Japan*”)

[18] www.maff.go.jp/j/nousin/kanri/tamen_siharai.html, Accessed on June 28, 2018
[19] www.maff.go.jp/j/nousin/kanri/attach/pdf/tamen_siharai-69.pdf, Accessed on June 28, 2021

3.1 Economic MES in Japan

("marine" or "coast*" or "ocean") and "ecosystem service*" and ("economic") and ("valu*" or "assess*" or "measur*") and ("Japan*")

3.2 Ecological MES in Japan

("marine" or "coast*" or "ocean") and "ecosystem service*" and ("ecological") and ("valu*" or "assess*" or "measur*") and ("Japan*")

3.3 Cultural MES in Japan

("marine" or "coast*" or "ocean") and "ecosystem service*" and ("cultur*") and ("valu*" or "assess*" or "measur*") and ("Japan*")

4. Country-specific keyword (multifunctional services)

("marine" or "coast*" or "ocean") and ("multifunctional*") and ("Japan*").

3.4.2.1 Manual searches

Using the literature found by the basic keyword searching, we identified additional articles related to aquaculture ecosystem services in the reference lists of these initial results. In addition, we further searched literature using forward reference, searching literature that cited the obtained literature by the basic search in WoS.

3.4.2.2 Country-specific keyword search

As noted above, multifunction may be used synonymously instead of ES in Japan. Accordingly, "multifunctional*" is substituted with "ecosystem service" as a country-specific keyword and some search words were omitted to capture more of the relevant literature. The following search query was used:

("marine" or "coast*" or "ocean") and ("multifunctional*") and ("Japan*").

3.4.3 Results

As a result of WoS and manual searching, we found three articles related to aquaculture ES in Japan. The WoS search query with the basic search words found three articles related to aquaculture ES, with one excluded due to the study site being in the United States. The other two articles are related to aquaculture and ecosystem services (Nos. 1 and 2 in Table 3.3). With the reference list search, we found three additional articles related to ecosystem services (Nos. 3, 4 and 5 in Table 3.3). With forward reference, we found no additional studies related to quantifying marine aquaculture ecosystem services. The country-specific search in WoS found nine articles. However, four articles were not related to ES; three were related to agriculture or freshwater (pond, paddy field); and one was about MES but related to fisheries management rather than aquaculture. In conclusion, the country-specific query found no additional studies related to aquaculture-based ES.

Thus, in total, our search procedure returned five relevant articles with details in Table 3.3 (and depicted in Figure 3.12). Chakraboty and Gasparatos (2019) used historical research and focus-group interviews to understand the variety of ecosystem services in Oita, Japan. The targeted community depends on coastal ecosystem services and has developed resource management practices over generations, which are informed by a rich body of traditional and local knowledge. They found 14 ES that were related to the well-being of the local community. While the community receives livelihood from the ecosystems, their characteristic food culture and food-sharing practices give them a sort of pride and cohesion for the local community. They also found that several key provisioning and cultural ES have degraded over time, which leads to habitat change/loss and overexploitation. The role of aquaculture in producing ES received limited attention in this study, although it is noted that the provisioning service is important for the community and that it provides employment for 30 people. Instead, the discussion of impacts on ecosystem services of prawn mariculture was focused on the trade-offs associated with the lost natural ES due to habitat change/loss.

In the next study, Smith *et al*. (2018) investigated the interactions between long-line oyster (*Crassostrea gigas*) aquaculture on *Zostera marina* seagrass in Akkeshi-ko estuary, Hokkaido. Using stratified random sampling, they found that *Zostera marina* seagrass is not affected by oyster aquaculture with respect to the morphology, density, or biomass of the seagrass. However, the composition and related abundances of species in the surface ecosystem (epibiont communities) differed in seagrasses near aquaculture. The result suggests that long-line oyster aquaculture may be sustainable with careful management and monitoring.

Table 3.3 Japanese search results.

Author	Method	Target	General summary	Type of ecosystem service
1. Chakraborty and Gasparatos (2019)	1. Historical document review 2. Focus group discussion	Prawn	Newly started prawn mariculture created trade-off of ES (*i.e.*, habitat loss and change, and monetary benefit)	Cultural ecosystem services
2. Smith *et al.* (2018)	Sampling sea grass (stratified random sampling) and (mobile epifauna study)	Oyster and sea grasses	Surveyed seagrass of oyster farm site and one far from the site, and found no bad effect of oyster farming while they also found some change in epibiont community.	Supporting ecosystem services
3. Liu *et al.* (2012)	Genetic diversity analysis using AMOVA	Kelp	Found intensive artificial selection affected the population genetic structure of kelps (*S. japonica*)	Regulatory ecosystem services
4. Gao *et al.* (2013)	Morphological comparison between kelps with and without thallus excision	Kelp	Earlier thallus excision in January and February makes kelp grow faster than conventional kelp.	Provisioning services
5. Sato *et al.* (2016)	Morphological comparison kelps across locations	Kelp	Morphological features vary across locations.	Provisioning services

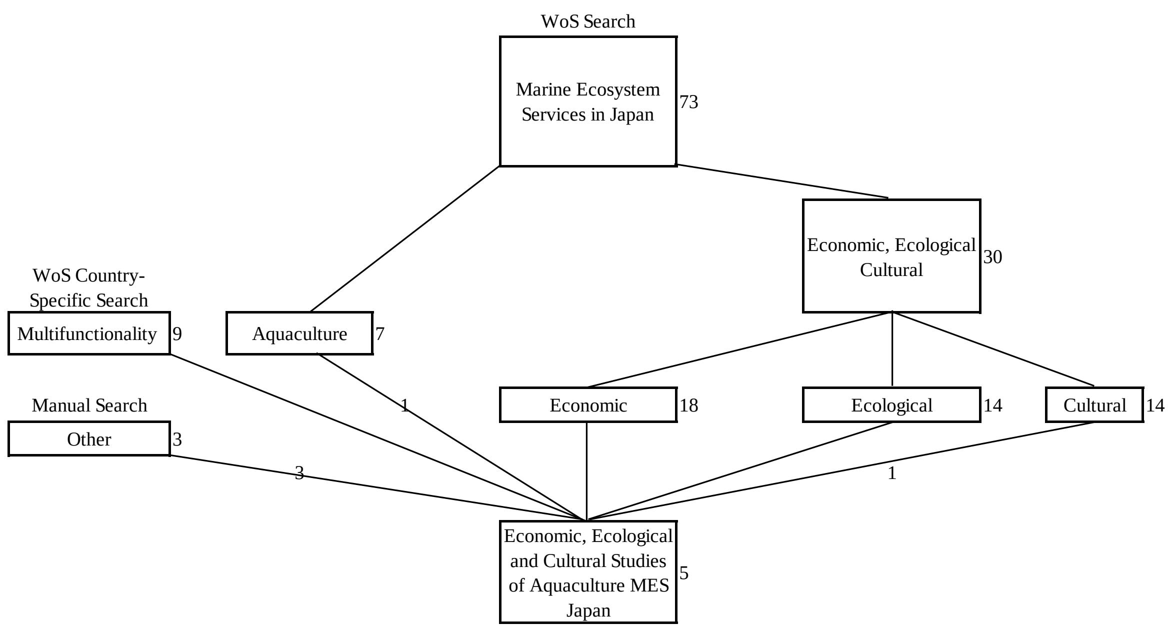

Fig. 3.12 Structure of literature search results. WoS = Web of Science.

Liu *et al*. (2012) studied differences in genes of wild and farmed kelps (*Saccharina japonica*) in different countries, including Japan. They tested genetic structure using simple sequence repeat markers and found that the genetic diversity in wild kelps in the Russian Far East is higher than the wild kelps in Hokkaido, Japan. They also found the Japanese wild kelps have higher genetic diversities than farmed ones from China. They suggested cultivation of kelps reduces the genetic diversity in ecosystem.

Gao *et al*. (2013) and Sato *et al.* (2016) examined the morphological features of kelp (*Undaria pinnatifida*) in Japan. Gao *et al*. compared the conventional kelp with kelp having thallus excision and found kelp with early thallus excision in January and February showed significantly larger compensatory abilities, resulting in increased kelp production. Sato *et al*. also compared the morphologic characteristics of kelp across locations in Japan, and found significant differences between locations, which contributes to breeding programs.

3.4.4 Discussion

There is no comprehensive study that investigated the effects or economic evaluation of aquaculture on one entire ecosystem service in Japan. One study investigated 14 ecosystem services, and looked at ecosystem management, but not at the effect of management on ecosystems (Chakraborty and Gasparatos, 2019). Another study focused on the effects of oyster farming on the seagrass in the same farming site (Smith *et al*., 2018). The other studies were not related to the effects of aquaculture on an ecosystem, but to the biological, chemical or environmental science of certain species (Liu *et al*., 2012; Gao *et al*., 2013; Sato *et al*., 2016). Hence, very few studies exist on the evaluation of ES in Japan.

Considering that 30 studies exist in economic, ecological, and cultural studies of ES in Japan, most of them are related to capture fisheries, but literature related to aquaculture ecosystem services in Japan is underdeveloped compared with other fields such as agriculture, land use, forestry, and fisheries.

3.5 U.S. case studies

3.5.1 Aquaculture production in the U.S.

In recent decades, U.S. aquaculture has lagged behind the rest of the world, with the U.S. production of 680 million pounds (3.08×10^8 kg) ranking 17th worldwide (NMFS, 2021). Opposition to aquaculture from coastal communities and the fishing industry, and the complex web of regulations originating from several state and federal agencies, are likely major causes for the relative scarcity of marine aquaculture in the U.S. (Knapp and Rubino, 2016). However, the federal government is encouraging increases to aquaculture production as evidenced by the NOAA Fisheries Priorities and Annual Guidance (2019) and Executive Order 13921, Promoting American Seafood Competitiveness and Economic Growth (2020). One of the solutions to the relatively low U.S. aquaculture production levels proposed in Knapp and Rubino (2016) is demonstrating the benefits of aquaculture, something which further research on ecosystem services could accomplish.

The Fisheries of the United States report (NMFS, 2021) provides data through 2018 on the state of aquaculture in the United States. It indicates that for 2018 the majority of U.S. aquaculture is freshwater, with marine aquaculture representing just 14.3% of aquaculture by weight and 37.4% by value. Although the volume of marine aquaculture production in the U.S. has remained relatively stable within the range of 85–100 million pounds (3.85×10^7 kg to 4.53×10^7 kg) between 2013 and 2018, the value of production for U.S. marine aquaculture has been increasing since 2014 (see Figure 3.13). The major marine species cultured in the U.S. are Atlantic Salmon, oysters, clams, mussels, and shrimp. No marine finfish species aside from salmon are included in the species-level data. The data by species are summarized in Figures 3.14 and 3.15 and generally show stability in the relative importance of these species to U.S. producers. There is a slightly increasing trend in the relative production of oysters and a decreasing trend in the production of salmon. The Gulf of Mexico was responsible for the majority of U.S. aquaculture production by volume (see Table 3.4). However, by value the Gulf of Mexico was less productive than the Pacific region (west coast of U.S.) and Atlantic region (east coast of U.S.) This is due to lower prices received for cultured seafood from the Gulf. The report also highlights the growing significance of seaweed farming, with production increasing 132% from 2017 to 2018.

In the United States, salmon farming is predominantly Atlantic Salmon in net-pens. There had been Atlantic Salmon aquaculture in Pacific waters; however, accidental releases led Washington state to ban the production of non-native species in 2018. There is also growing interest in on-shore salmon aquaculture in both coastal states and in-land. Net-pen tuna “ranching” is underway for both Yellowfin and Pacific Bluefin tuna, with efforts to develop hatchery capability in the works. Oyster farming is done using both on-bottom and off-bottom techniques, while clam farming is exclusively on-bottom. Both clam and oyster farming are in shallow waters, typically bays. Seaweed farming typically employs long-lines seeded using zoospores obtained from harvesting wild sorus tissue.

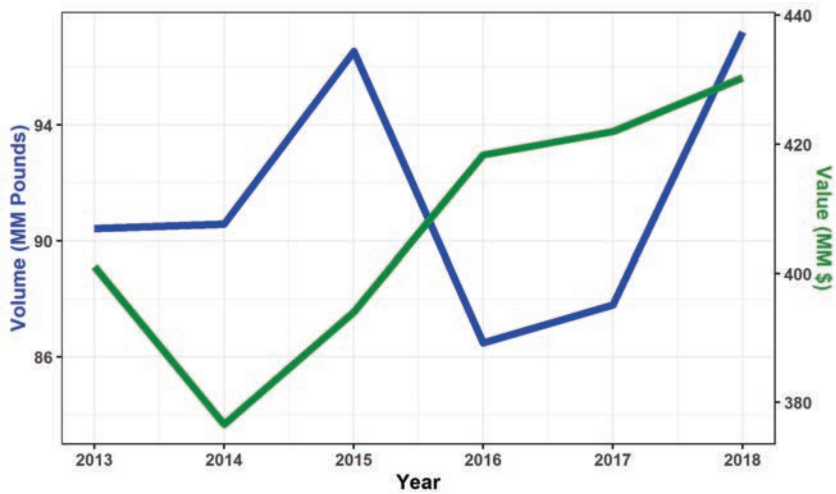

Fig. 3.13 U.S. total aquaculture production by volume and value.

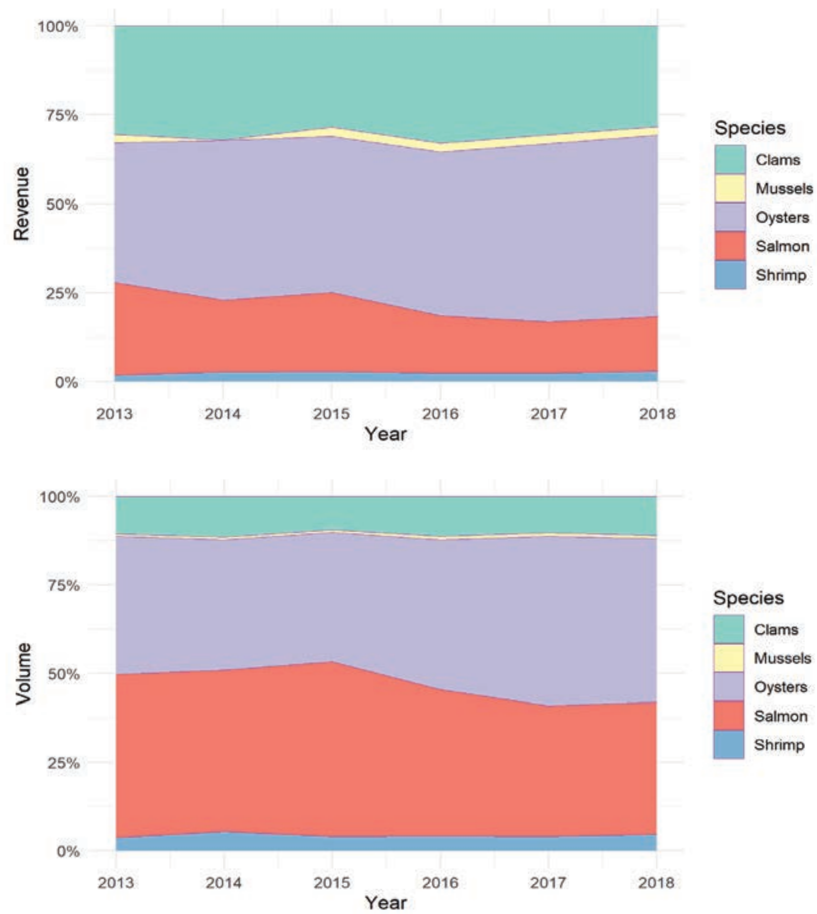

Fig. 3.14 U.S. aquaculture proportion of revenue and volume for major species groups.

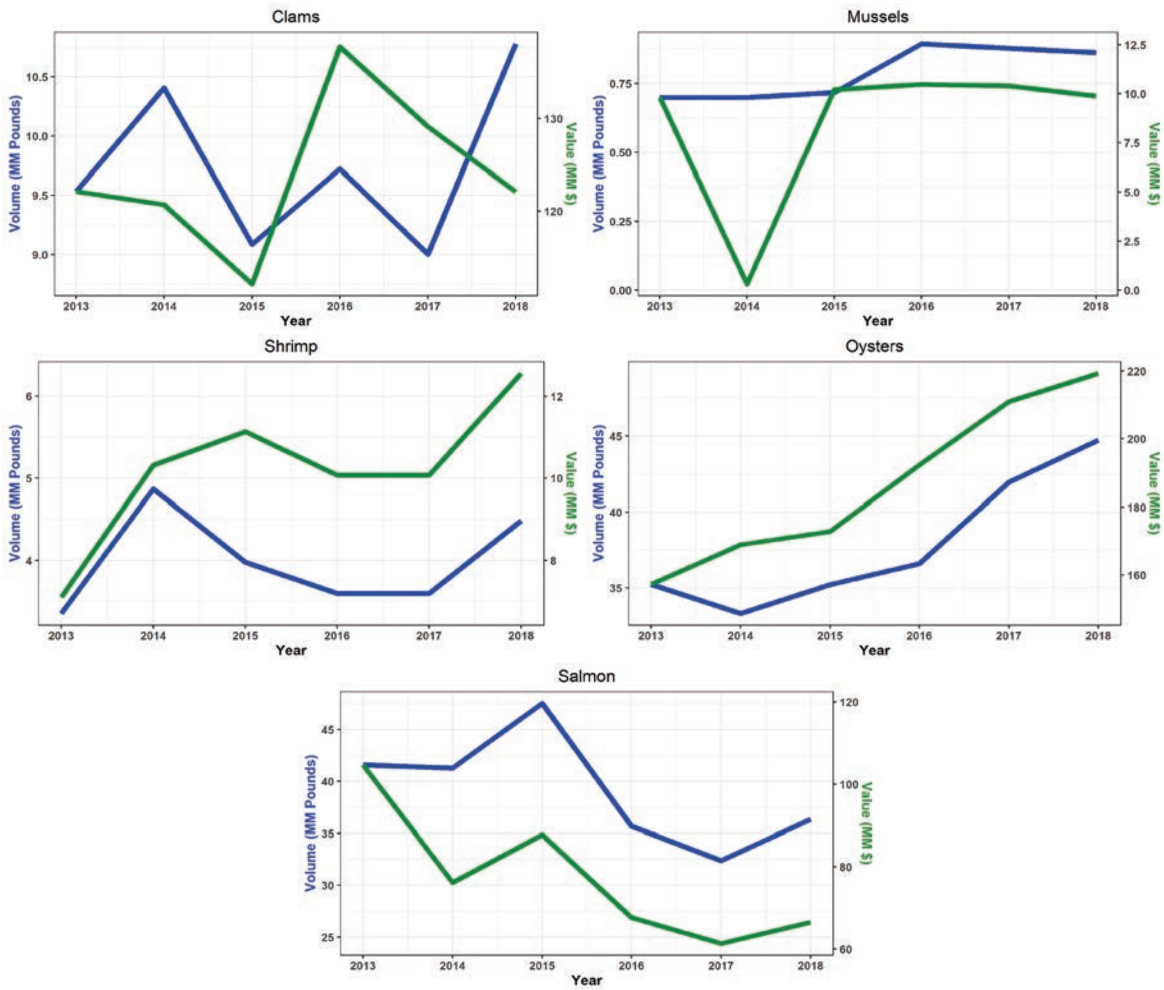

Fig. 3.15 U.S. aquaculture production volume and value by major species group.

Table 3.4 Percentages of marine aquaculture production by U.S. region (2018).

Region	Volume (%)	Value (%)
Pacific region	21	36
Atlantic region	28	41
Gulf of Mexico	51	23

3.5.2 Literature search methodology

The literature search began on Web of Science with a query for studies containing “aquaculture” or “mariculture”, “ecosystem services”, a reference to “ecological”, “economic”, or “cultural” to further focus on ecosystem services, and some reference to the United States or one of the coastal states. This search returned 21 studies, of which only five met the criteria for inclusion in the report. These five studies were then mined for any relevant studies cited within, and these cited studies were then mined for their citations, and so on. Expanding our search outwards in this way led to an additional 11 studies that met the criteria for inclusion in the report. With this total of 16 studies, we modified the search terms with the goal of returning all 16 studies in the literature search. The process was largely successful, with the final query returning 13 of the 16 studies.[20] The final query included the additional specific search terms "bioassimilation", "bioextraction", "denitrification", "nitrogen extraction", and "nitrogen removal" in addition to the generic "ecosystem services." This query was repeated several months later, including studies published through the end of 2021, producing an additional eight studies meeting the criteria for inclusion. This final search returned 98 studies, of which 21 met the criteria for inclusion in the report. The iterative reference searches of these studies produced an additional 20 studies, bringing the total to 41.

The results revealed a lack of diversity in the types of aquaculture and MES studies being performed in the U.S. There were 38 studies of bivalves, four studies of kelp, and none of finfish. Some studies included multiple species, but the totals by species were: six studies of Pacific oyster (*Crassostrea gigas*), 24 studies of Eastern oyster (*Crassostrea virginica)*, as well as one study that did not specify the species but was likely to be *C. virginica* based on the study site, six studies of hard clam (*Mercenaria mercenaria*), two studies of geoduck clam (*Panopea generosa*), one study of Manila clam (*Venerupis philippinarum*), three studies of sugar kelp (*Saccharina latissima*), and one study of the red algae species *Gracilaria tikvahiae* Mclachlan. The types of ES studied were somewhat limited, with 21 of the studies pertaining to the regulating/supporting service of nutrient removal, 19 related to the supporting services of animal/plant interactions, and two related to cultural services. Eutrophication mitigation in the form of nitrogen regulation was the subject of all the nutrient removal papers, although seven also estimated the removal of carbon and three also included phosphorous removal. Of these studies, 11 measured the direct removal of nutrients into the living organism (bioextraction) and nine measured the impact of aquaculture on the microbial processes of denitrification and dissimilatory nitrate reduction to ammonium (DNRA). Cultural services were explored in two closely related studies, in which surveys of oyster farmers and hatchery workers revealed non-monetary benefits such as a connection with family or community identity and working in nature.

There are two branches of the literature in the search results that could have been included; however, these studies did not adequately quantify or value the ES related to aquaculture. The first branch consists of studies on Integrated Multi-Trophic Aquaculture, the practice of pairing extractive species culture such as bivalves or kelp with intensive aquaculture such as finfish or shrimp. The extractive species may filter the water or remove some of the excess nitrogen associated with the feed for and feces from the primary cultured species. This research in the U.S., however, has focused on feasibility and profitability rather than the ecosystem effects. The second branch relates to the practice of "conservation aquaculture," in which aquaculture techniques are used to achieve conservation goals for threatened species of marine life. For instance, U.S. Pacific estuaries where the native Olympia oysters (*Ostrea lurida)* have historically been abundant but are now scarce (or even absent) are being restored by the placement of hatchery-raised specimens. Although such species may be important for their role in the ecosystem or may have particular cultural significance to nearby communities, these values have not been quantified in any study to date.

[20] One study that could not be recovered does not refer to aquaculture or mariculture, but simply "cultured oysters." Expanding the query to include "culture*" did return that paper, but at the expense of adding hundreds of irrelevant papers. The other two studies do not include location details in the searchable fields.

3.5.3 Results

3.5.3.1 Bioextraction

Bioextraction (or bioassimilation) is defined in Rose *et al*. (2015a, page 2) as "the cultivation and harvest of shellfish and/or seaweed for the purpose of nutrient removal." Because nitrogen is the nutrient primarily responsible for the harmful effects of eutrophication (Howarth and Marino, 2006), it is included in all such studies as the primary nutrient of interest. Carbon and phosphorous removal are also measured in some studies, but monetary values for either of these services are rarely computed. This is surprising in light of the numerous estimates of the social cost of carbon, such as the estimate of $31 per ton of carbon dioxide for the U.S. computed in Nordhaus (2017). Because the nutrients are contained in the tissue of the harvested product, it is relatively straightforward to measure. The shellfish or seaweed can be harvested, dried, and run through a chemical analyzer to determine the total weight of nutrients. This direct measure of nutrients per individual can be readily scaled up to the level of a single farm or an entire ecosystem to estimate both the currently realized bioextraction and the maximum potential extraction under expanded aquaculture.

An alternative to directly measuring the nutrient extraction is the computer simulation known as Farm Aquaculture Resource Management (FARM) which takes as inputs data on the conditions of the water and currents, and data on the farm including species, harvest size, seeding density, and mortality rate (Ferreira *et al*., 2007). As with direct measurement, it is straightforward to estimate nutrient removal at the farm scale and potential removal in the case of expanded aquaculture. Converting the nutrient removal to an economic value only requires a "dollars per kg" value that can be based on economic studies, replacement cost methods, or cap-and-trade permit values. Nevertheless, few studies actually compute a dollar value for the nutrient removal. A summary of the U.S. studies of bioextraction is presented in Table 3.5.

Table 3.5 Summary of U.S. bioextraction studies.

Study	Species	State	Method	N removal (kg ha^{-1} yr^{-1})
Bivalves				
Higgins *et al* (2011)	*Crassostrea virginica*	VA	Direct	331
Reitsma *et al*. (2017)	*C. virginica*	MA	Direct	11–327*
Bricker *et al*. (2018)	*C. virginica*	CT	Simulation	309
Bricker et al. (2020)	*C. virginica*	NH	Simulation	177
Parker and Bricker (2020)	*C. virginica*	MD	Simulation	69
Parker and Bricker (2020)	*C. virginica*	MD	Simulation	128
Parker and Bricker (2020)	*C. virginica*	MD	Simulation	200
Parker and Bricker (2020)	*C. virginica*	MD	Simulation	217
Parker and Bricker (2020)	*C. virginica*	MD	Simulation	761
Parker and Bricker (2020)	*C. virginica*	MD	Simulation	902
Parker and Bricker (2020)	*C. virginica*	MD	Simulation	1129
Saurel *et al*. (2014)	*Venerupis philippinarum*	WA	Simulation	1317
Cubillo *et al*. (2018)	*Panopea generosa*	WA	Simulation	573

Table 3.5 Continued.

Study	Species	State	Method	N removal (kg ha^{-1} yr^{-1})
Kelp				
Kim *et al*. (2014)	*Gracilaria tikvahiae*	NY	Direct	28
Kim *et al* (2014)	*G. tikvahiae*	NY	Direct	94
Kim *et al* (2015)	*Saccharina latissima*	NY	Direct	180
Kim *et al* (2015)	*S. latissima*	NY	Direct	67
Kim *et al* (2015)	*S. latissima*	NY	Direct	38
Augyte *et al*. (2017)	*S. latissima*	ME	Direct	89
Grebe *et al*. (2021)	*S. latissima*	ME	Direct	19–26
Grebe *et al*. (2021)	*S. latissima*	ME	Direct	74 –176

* Calculated from reported grams per oyster and reported stocking densities from other studies. VA = Virginia, MA = Massachusetts, CT = Connecticut,, NH = New Hampshire, MD = Maryland, WA = Washington, NY = New York, ME = Maine

3.5.3.2 Shellfish

Eastern oyster (*Crassostrea virginica*)

In Higgins *et al*. (2011), the nitrogen, carbon, and phosphorous content of *C. virginica* cultured in Chesapeake Bay, Virginia, is measured directly. They estimated that the farmed oysters would remove 331 kg N per ha, 47 kg P per ha, and 9,567 kg C per ha for each seed-to-harvest cycle (typically 12–24 months), but did not compute an economic value. The differences in nitrogen content were compared across seasons, and for on-bottom *versus* off-bottom culture in Reitsma *et al*. (2017) for Cape Cod, Massachusetts. Overall, the nitrogen content was measured at approximately 0.12 to 0.49 g per oyster, with more potential for nitrogen assimilation in the fall and for on-bottom methods. Converting this to kg N per ha per year is an uncertain exercise since the stocking density is not included in the article. Looking to the stocking densities reported in similar sites, Bricker *et al*. (2018) reported a stocking density in nearby Connecticut of 62 oysters per m^2 with 55% mortality (28 surviving oysters per m^2) and Bricker *et al*. (2020) reported a stocking density in nearby New Hampshire of 100–200 oysters per m^2. Assuming a standard three-year grow out, and using 28 and 200 as the bounds for the stocking density along with the min and max reported nitrogen content per oyster, the calculated range for nitrogen removal is 11 to 327 kg N per ha per year.

The FARM and EcoWin computer models were used in Bricker *et al*. (2018) to estimate nitrogen removal for Long Island Sound, Connecticut, with an estimated 125 kg N per acre per year (~309 kg N per ha per year). Using the avoided cost method for various control technologies and levels of abatement requirements, they estimated a value of $32, $37, and $98 per kg N annually. In another estimate based on computer simulations, Bricker *et al*. (2020) estimated nitrogen removal in Great Bay Piscataqua River Estuary, New Hampshire, to be 0.072 metric tons per acre per year (177 kg N per ha per year). Based on Trowbridge *et al*. (2010), they used a replacement cost ranging from $150 to $172 per kg N annually. Another computer model estimation for Chesapeake Bay, Maryland, was performed in Parker and Bricker (2020). They reported a very large range of possible nitrogen removal values, between 28 and 457 kg per acre per year (69 to 1,129 kg per ha per year). Furthermore, they reported an extremely wide range of replacement costs. The study is unclear as to what replacement values are used to compute the potential value of nitrogen removal, but the array of values in their Table 2 has a low of $2.20 and a high of $1,034 per kg N. Although they do not present a comparable value, Ayvazian *et al*. (2022) report that, at the observed sites, cultured oysters had significantly more tissue (and thus a greater rate of bioextraction).

The amount of nitrogen removal observed for *C. virginica* ranges from 69 to 1,129 kg per ha annually although 150 to 350 is where most of the observations lie. The economic valuation based on replacement costs covers an even wider range in the few studies that include it. This variation highlights one shortcoming of that method, with one study using $32–98 per kg (Bricker *et al*., 2018), another using $150–172 (Bricker *et al*., 2020), and a third using $2.20–1,034 (Parker and Bricker, 2020).

Hard clam (*Mercenaria mercenaria*)

Reitsma *et al*. (2017) measured the nitrogen removal of the hard clam using direct measurements. The observed range of nitrogen per clam was 0.11 to 0.26 g compared to 0.12 to 0.49 g for the Eastern Oyster.

Manila clam (*Venerupis philippinarum*)

Saurel *et al*. (2014) estimated the nitrogen removal of farmed Manila clams in North Puget Sound, Washington, with the FARM model. They estimated a farm-scale nitrogen removal rate of 3,423 kg N per year for a 2.6 ha site, applying the Meybeck *et al*. (1990) valuation of $12.40 per kg N to compute an economic value of $42,445 per year. Compared to the results for Eastern oysters, this is a rather large rate of nitrogen removal, at 1,316.5 kg N per ha per year.

Geoduck clam (*Panopea generosa*)

The nutrient removal potential for farmed Pacific geoduck clams in South Puget Sound, Washington, was estimated using the FARM and Net Energy Balance models in Cubillo *et al*. (2018). They reported the removal of 149 kg N per year on a farm of 0.26 ha, which converts to 573 kg N per ha per year. This is larger than the average for oysters, but given the large size of geoducks and the tendency for tissue to contain more nitrogen than shells[21] this is not surprising. They also estimated the carbon sequestration to be 2,534 kg C per year (9,746 kg C per ha per year). Using the $12.40 per kg N valuation of Lindahl *et al*. (2005)[22], they computed the economic value of the ecosystem service, noting that this was on the low end of the replacement cost method values used in other studies.

3.5.3.3 Kelp

Kim *et al*. (2014) directly measured the nutrient removal of the kelp species *Gracilaria tikvahiae* Mclachlan in the waters off New York and Connecticut. At the Long Island Sound (LIS) site, they estimated a removal of 28 kg N per ha and 300 kg C per ha, and at the Bronx River Estuary (BRE) site they estimated a removal of 94 kg N per ha and 727 kg C per ha. Using cap-and-trade market values to derive the economic value, they estimated ecosystem service values of $311 (LIS) and $940 per ha (BRE) for N, and $5.51 (LIS) and $13.32 per ha (BRE) for C. They followed up on this study in Kim *et*

[21] See Reitsma *et al*. (2017).
[22] Note that this is a second distinct source of a $12.40 per kg N valuation.

al. (2015) to estimate the nutrient removal from sugar kelp (*Saccharina latissima*), which could be cultured in conjunction with the *G. tikvahiae* Mclachlan, to provide year-round nutrient removal. Additionally, they reported separate values for Western Long Island Sound (WLIS) and Central Long Island Sound (CLIS). They estimated nitrogen removal of 180 (BRE), 67 (WLIS), and 38 (CLIS) kg per ha, and a carbon removal of 1350 (BRE), 1800 (WLIS) and 1100 (CLIS) kg per ha. Again, using cap-and-trade permit values they valued the nitrogen removal at $1600 (BRE), $760 (WLIS) and $430 (CLIS) per ha, and carbon sequestration valued at $30−300 (BRE), $40−400 (WLIS), and $24−240 (CLIS) per ha. Augyte *et al*. (2017) directly measured the nitrogen and carbon removal of a unique form of sugar kelp (forma *angustissima*) grown at farms in Maine, finding site-average removal of 88.7 kg N per ha and 1666.7 kg C per ha. Grebe *et al*. (2021) also measured the tissue levels of nitrogen in *S. latissima* farmed in Maine, estimating that a hectare cultivated for 6 to 7 months could remove 19.2 to 176.0 kg N. Across these studies there is a wide range of nitrogen removal observed, from 19.2 to 180 kg N per ha.

3.5.3.4 Nitrogen cycling

In addition to directly removing nutrients through their metabolic processes, shellfish are also believed to indirectly influence nutrient levels by altering the natural nitrogen cycle. In particular, research has focused on the impact of shellfish on the microbial processes of denitrification and dissimilatory nitrate reduction to ammonium (DNRA). It is not actually the nitrogen itself which causes eutrophication but the nitrate (NO_3^-). Denitrification converts the bio-available nitrate into non-available dinitrogen gas (N_2), while DNRA converts it to the yet bio-available ammonium (NH_4^+). Shellfish aquaculture is thought to influence these processes through the laying of crushed shell (cultch) as a substrate, and through the feces and pseudofeces they excrete which provide nutrients to microbes. Microbial communities in the guts of shellfish and on their shells may also contribute (Ray *et al*., 2019). These processes are more challenging to measure than bioextraction, requiring the measurement of gas fluxes underwater. These processes are typically measured in μmol N m^{-2} h^{-1}, making it difficult to compare with bioextraction or compute an economic value. In fact, none of these studies have attempted to assign an economic value to the nitrogen removal measured therein.

Eastern oyster (*Crassostrea virginica*)

The effect of off-bottom oyster aquaculture on denitrification in Chesapeake Bay, Virginia, is measured in Higgins *et al*. (2013). They used two different scientifically accepted methods, ^{15}N tracer and multi-isotope imaging spectrometry (MIMS), to measure the sediment N_2 production. They measured N_2 production of 0.63 to 1.56 mmol N m^{-2} per day, which worked out to 0.49 to 12.60 kg N per year. This overlaps the observed production at a reference site of 2.27 to 16.72 kg N per year, and thus the researchers concluded that the aquaculture cannot be credited with enhancing denitrification. The researchers noted that bioextraction is a much more reliable and readily measured nutrient removal mechanism. An oyster farm in Chesapeake Bay, Maryland, was analyzed in Testa *et al*. (2015) using sediment core intubations. They reported denitrification rates of 9−115 μmol N m^{-2} h^{-1}, but noted that the "sediment denitrification did not change in response to the introduction of the aquaculture operation." (page 215). Humphries *et al*. (2016) used a novel *in situ* methodology to measure the gas fluxes at oyster beds in Ninigret Pond, Rhode Island. This study compared both restored wild oyster reefs and oyster aquaculture with reference sites having bare sediment and cultch. Wild reefs were found to enhance denitrification more (581.9 N_2–N m^{-2} h^{-1}) than aquaculture (346.0)[23], but the difference was not statistically significant. Both the wild and cultured oyster sites were significantly more effective at enhancing denitrification than the reference sites of cultch (36.4) and bare sediment (24.4).

Lunstrum *et al*. (2017) used sediment cores to estimate denitrification and DNRA from Chesapeake Bay, Virginia. The measured rates of denitrification are comparatively low for the literature, with oyster sites having significant seasonal variation, ranging from <1 to 19.2 µmol N m^{-2} h^{-1}. DNRA rates were higher, with oyster sites averaging 25.4 µmol N m^{-2} h^{-1}. The denitrification rates were higher than bare sites both under oysters and nearby, whereas DNRA is only enhanced directly under oysters. Smyth *et al*. (2018) analyzed the nitrogen cycling effects of both oysters and clams (presented in the next subsection) in Smith Island Bay, Virginia, using core incubations. For oysters, there was significant seasonal variation in the effects. The results were presented in a figure from which numerical values can only be visually estimated, but the spring, summer, and fall measures of denitrification are approximately 4, 16, and 1 µmol m^{-2} hr^{-1}, respectively, while rates of DNRA are approximately 0.5, 0, and 0.5 µmol m^{-2} hr^{-1}, respectively. They concluded that bivalve aquaculture can be a net source or sink of N in the ecosystem, depending on local conditions and species. In Ray and Fulweiler (2020), the researchers estimated the nutrient fluxes from wild oyster reefs and a farm in Narragansett Bay, Rhode Island. The study did not directly state the species of oyster in the body, but the context strongly suggests it was *C. virginica*. Estimating the fluxes over the seasons, they measured denitrification rates of 48.8 µmol N_2–N m^{-2} h^{-1} in the spring, −44.8 µmol N_2–N m^{-2} h^{-1} in the fall, and −2.7 µmol N_2–N m^{-2} h^{-1} in the summer. The net effect annually was approximately zero, but the effects on the ecosystem of the seasonal variation in alternatively removing or adding nitrogen merit consideration. Ayvazian *et al*. (2020) provided an interesting new take on the shellfish nitrogen cycling research by additionally considering the impact of macrofauna. With study sites including wild oyster reefs and bare sediment at Green Hill Pond, Rhode Island, and oyster farms at nearby Ninigret Pond, they used *in situ* flux measurement techniques along with traps and nets to measure macrofauna abundance. They did not clearly report rates of denitrification or DNRA but stated that they did not observe stimulated rates of denitrification relative to bare sediment. Regarding the pathway of oysters on nitrogen cycling through macrofaunal abundance, they reported that areas with more carnivores saw lower ammonium release, possibly due to oysters defensively closing their shells. There was no notable effect through this pathway on denitrification.

These studies suggest that the impact of Eastern oyster aquaculture on the nitrogen cycle vary significantly by location and across season, and whether it is a net source or sink of bio-available nitrogen is dependent on these factors.

Hard clam (*Mercenaria mercenaria*)

Murphy *et al*. (2016) took sediment core and porewater samples from 10 sites in a shallow tributary to Chesapeake Bay, Virginia. Clam beds showed DNRA rates greater than the control by an average of 151.3 µmol m^{-2} d^{-1}. Seasonal measures of denitrification rates varied, with results indicating enhanced denitrification rates for July and November but in May both clam and control sediments were similar. However, the sediment around the clams was found to be a source of nutrients to the water column and may, in fact, promote eutrophication because of the release of ammonium. To further explore these results, Murphy *et al*. (2018) explored the denitrification and DNRA enhancement of clam aquaculture

[23] It appears that N_2–N is another scientifically accepted way of denoting “denitrification.”

across different species and ecosystems. The American *M. mercenaria* grown in Chesapeake Bay are compared to *Ruditapes philipinarum* cultured in Italy, with sediment core analyses. The biomass of clams was used as an independent variable in a regression to explain denitrification and DNRA. With the exception of one site, no significant effects were identified. This suggests that the clams themselves were not responsible for the observed changes in the nitrogen cycle. The rates of denitrification and DNRA for *M. mercenaria* reported in Smyth *et al*. (2018) are only displayed in figures, but are approximately 5–6 μmol N m^{-2} hr^{-1} and 0.3–2.1 μmol N m^{-2} d^{-1}, respectively.

3.5.3.5 Effects on other species (supporting services)

The presence of shellfish aquaculture may not affect just water quality, but also other species directly by changing the structure of available habitat/refugia and indirectly as a result of their filter feeding. Oysters, which live on the surface (epifaunal) or on floating gear, can add structure that other creatures prefer to bare sediment. Similarly, the off-bottom oyster aquaculture methods also create structure that may be used by other species. Clams, which live below the surface (infaunal), do not create such added habitat. However, the anti-predation nets typically placed over cultured clams do provide some structure and protection for smaller marine organisms. The final consideration is that the addition of cultured bivalves could lead to competition for resources that might impact other benthic species. The studies examining aquaculture's impact on other species focused predominantly on animals, with 12 studies exclusively focusing on animals, while only five studies exclusively studied submerged aquatic vegetation, and two studies included interactions with both.

The impact of oyster culture on animal species can be measured in several ways, including traps, lift nets, divers, and video analysis. An additional complication arises with the selection of the baseline. Some studies are interested in how animal assemblages differ between oyster aquaculture and wild oyster reefs, others compare aquaculture to natural structures such as rocky reefs or submerged aquatic vegetation, and yet others compare aquaculture to non-vegetated seabed. For valuing the ES related to aquaculture, the proper comparison would be to the *status quo* at the site, but all of the reference points provide useful information. There are several ways to quantify the species assemblages: total abundance is simply the observed number of organisms, species richness is the count of distinct species, whereas species diversity is an abundance weighted measure of the count of species, and finally species evenness is a measure of the equity of abundance. Here, we organize the results by cultured species.

The Pacific oyster (*Crassostrea gigas*) was introduced to the U.S. Pacific coast for aquaculture purposes, as well as to replace some of the ES lost due to the dwindling populations of the native Olympia oysters (*Ostrea lurida*) (Shatkin *et al*., 1997). As a non-native species, it is important to understand how the ecosystem responds to its presence. Looking at the impact of cultured Pacific oyster, Muething *et al*. (2020) used a combination of underwater video, traps, predation tethering units, and eelgrass surveys to understand the interactions between oyster aquaculture, fish, and the federally protected eelgrass (results discussed in the aquatic vegetation section) in Washington state. Most of the observed fish species used the long-line aquaculture and eelgrass habitats similarly with minimal edge effects, but the on-bottom aquaculture was used less. They observed species-specific effects, noting that the larger meso-predators like Pacific staghorn sculpins were more often seen in the aquaculture habitats than in eelgrass habitats. The interactions of cultured Pacific oysters and native Olympia oysters with juvenile Dungeness crab (*Metacarcinus magister*) are studied in Dumbauld *et al*. (2021). For two estuaries of Willapa Bay, Washington, crab densities were comparable around aquaculture sites and both remnant and restored native oyster beds. These densities were greater than those observed for eelgrass or bare sediment, and therefore, they concluded that the supporting ecosystem service provided by oyster aquaculture should be considered in managerial decisions. These results suggest that the culture of Pacific oyster is providing valuable habitat/refugia to native species, although with harvest and other disturbances more work should be done to ensure this is not a population sink.

On the Atlantic coast, bivalve aquaculture is primarily the native species of Eastern oyster (*Crassostrea virginica*) and hard clam (*Mercenaria mercenaria*). This obviates concerns about invasive species, so much of the research has been directed towards evaluating how well the cultured oysters can substitute for the lost abundance of wild oysters. The habitat value provided by modified rack-and-bag oyster culture is compared to submerged aquatic vegetation (*Zostera marina*) and non-vegetated seabed in Rhode Island by Dealteris *et al*. (2004). A mesh net was used to sample organisms at least 5 mm in size, and measures of species abundance, richness, and diversity were calculated. The results show that shellfish aquaculture gear had habitat value significantly greater than non-vegetated seabed and similar, if not greater, value than submerged aquatic vegetation. A similar study in Virginia sampled species at least 2 mm in size, and found that annelids (worms) are the most abundant taxonomic group by far, followed by mollusks and crustaceans (O'Beirn *et al*., 2004). The oyster density showed no impact on the count of distinct species, but greater abundance was associated with higher densities. They conjectured that these associated organisms may not successfully mature and reproduce, and thus the aquaculture gear may be an ecological sink. Without further research it is unclear if the increased abundance actually produces environmental benefits.

Traps were used to compare the presence and age structure of fish around Rhode Island oyster cages and natural reefs in Tallman and Forrester (2007). They furthermore tagged the fish to measure growth and disappearance rates. Cunners (*Tautogolabrus adspersus*) preferred natural reefs to oyster cages, while scup (*Stenotomus chrysops*) and tautogs (*Tautoga onitis*) were the opposite. Black seabass (*Centropristis striata*) showed no difference across the two habitats. Recapture analysis indicated that scups had not only a lower disappearance rate at oyster cages but also a slower growth rate. This growth rate/mortality tradeoff was significantly overshadowed by the three times greater abundance at oyster cages, suggesting it was still a net positive for scups. Both macro-faunal and infaunal assemblages around modified rack and bag gear in Delaware were compared by Erbland and Ozbay (2008). They used basket-traps to compare the macro-faunal assemblages between the aquaculture gear and a wild reef, and used sediment cores to compare the infaunal assemblages under the aquaculture gear and a point 10 m away from the gear. Greater total abundance and species richness were observed around the oyster cages but greater species evenness was found on the wild reef. Species diversity was similar between the two. Conversely, infaunal species were less abundant under the oyster gear.

Marenghi *et al*. (2010) compared the species assemblages around floating aquaculture gear and created reef in Delaware. The oyster cages were associated with a significantly greater total abundance and species richness, while the species evenness was higher on the reef. Species diversity was not significantly different across the two habitats. They suggest that an additional ecosystem service could be provided by oyster aquaculture if it is strategically sited to "provide connectivity in an otherwise fragmented habitat". Ayvazian *et al*. (2020) compared the collections from box traps, seine nets, minnow traps, and shrimp traps around wild oyster reefs, off-bottom aquaculture sites, and bare sediment in Rhode Island. The results indicate that the density, biomass, species richness, and diversity of species were all greater at the oyster sites than bare sediment, with the off-bottom aquaculture site performing similarly to the wild oyster reefs. Trap sampling was used to estimate the abundance of juvenile fish and invertebrates around Connecticut oyster cages in Mercaldo-Allen *et al.* (2020). The juvenile finfish assemblages were generally similar between aquaculture gear and a rock reef, while on-bottom oyster culture had greater numbers of scup and black sea bass. Across the three habitat types, the invertebrate communities were more variable but crabs were more highly abundant around both on-bottom and floating oyster aquaculture.

In the lone study concerning provision of habitat by hard clams, Powers *et al*. (2007) tested if macroalgal growth on anti-predation nets also functions as habitat for other species. The seagrass beds and the macroalgal growth on clam nets were similar in terms of biomass and significantly greater than on the sandflats. Likewise, the community structure of mobile invertebrates and juvenile fishes was relatively similar between the seagrass and macroalgal growth on clam nets, with significantly more in these habitats than the sandflats.

Less research has been done on the interaction between bivalve aquaculture and submerged aquatic vegetation, although this is an important component of local ecologies. More has been written about the interaction of bivalves and seagrass/kelp in general (see Ferriss *et al*., 2019),[24] but the additional structure and human presence implied by aquaculture must be considered in addition to the presence of the organisms. The most common species for such studies in the U.S. is the Pacific oyster. An experiment to measure the impact of Pacific oyster mariculture on eelgrass (*Z. marina*) in Oregon revealed significant reductions in the abundance of eelgrass around aquaculture, using both stake and rack gear (Everett *et al*., 1995). A similar finding comes from Wisehart *et al*. (2007) which expands on the interaction between Pacific oysters and eelgrass by testing the impact of oyster culture on seed production and seedling germination. Both seed production and seedling germination were much lower around long-line oyster culture, while the on-bottom culture saw high rates of seed production and seedling germination.

A negative impact of on-bottom Pacific oyster culture on eelgrass was also observed by Wagner *et al*. (2012). These experimental treatments sought to understand not just the effect of oyster culture on eelgrass, but also the pathway. To get at the pathway of impact they varied the density of oysters and tested the effect of empty shell, nutrients, and their combination. For their study site, nutrients had no impact on eelgrass growth. However, the presence of live adults and empty shells decreased eelgrass density in excess of their physical footprint. There was a non-linear density-dependent relationship, with a threshold of about 22% oyster coverage beyond which there were exponential declines in eelgrass shoot density. Interestingly, they reported that 20% was the average oyster cover for local aquaculture, suggesting that eelgrass and oyster culture can co-exist. Muething *et al*. (2020) also estimated the interaction between eelgrass and Pacific oyster aquaculture, showing that the density of eelgrass declined within the aquaculture habitats, but less so for the long-line (off-bottom) habitat. These findings of negative impacts of oyster culture on eelgrass are consistent with meta-analysis results for oysters on the U.S. West Coast in Ferris *et al*. (2019). It should be noted that the concept of ES is rarely mentioned with these findings of aquaculture negatively impacting eelgrass.

The impact of the geoduck clam culture on eelgrass in Washington state was estimated through an experimental design by Ruesink and Rowell (2012). The clams had no impact on the recovery of the eelgrass and did not reduce density in the winter. However, the density in the summer was 30% lower at

[24] Although the title of the paper indicates the topic is bivalve aquaculture interactions with eelgrass, and the authors state that “Most studies included in our analysis related to cultured shellfish”, our search of the U.S. studies listed among the included papers found the terms “culture” and “farm” to be entirely absent. In fact, many of the studies appear to have placed bivalves on-bottom without protective netting; the antithesis of bivalve culture. The reference to “cultured shellfish” may be indicative of the species, and not the production method.

the clam sites. The largest effect was the result of harvesting, which led to a 70% reduction in density. The hypothesis that anti-predation nets on hard clam culture provides anchoring structure for seaweed was tested in Powers *et al*. (2007). The seagrass beds and the macroalgal growth on clam nets were similar in terms of biomass and significantly greater than sandflats, indicating that the nets are highly effective at providing structure for seaweed to grow, which is an ecosystem service on its own. The effect of the disturbance caused by depuration of Eastern oysters in Connecticut was measured by Vaudrey *et al*. (2009), with the results indicating that there are no significant effects on eelgrass from the short-term presence of depuration gear.

While the studies of Pacific oysters on eelgrass generally agree on a negative impact on eelgrass, the results regarding long-line aquaculture are conflicting. Specifically, long-line aquaculture is found to be relatively better for eelgrass in Muething *et al*. (2020) and relatively worse for eelgrass in Wisehart *et al*. (2007). In contrast to the negative interactions observed between Pacific oysters and eelgrass, Eastern oysters and geoduck clams seem to have little to no negative effects on eelgrass. Furthermore, hard clam aquaculture appears to support growth of macroalgae. The diversity of results highlights the importance of further work to clarify the relationship between submerged aquatic vegetation and aquaculture.

3.5.3.6 Cultural services

The cultural services provided by aquaculture are more challenging to identify, and particularly challenging to quantify. Perhaps because aquaculture usually inhibits recreational use of the waters (a commonly studied cultural ES) and is perceived as damaging the natural beauty of the seascape, its cultural services have received scant research.

We only located two studies on the topic for the U.S., both of which surveyed oyster growers to reveal some of the non-monetary benefits they obtain in their work (Michaelis *et al.*, 2020, 2021). The first of these, Michaelis *et al*. (2020) focuses on the role of ES in oyster growers' decision to enter the industry with a series of interviews of Maryland oyster farmers. Less than a quarter of those interviewed cited the provisioning, regulating, and supporting ES of oyster aquaculture in their decision, but over 80% mentioned some form of CES. These services referenced by the growers were quite varied, including connection to communal history, connection to family history, enjoyment of working amidst the beauty of the ocean, and job satisfaction.

The second study (Michaelis *et al.*, 2021) is a follow-up intended to identify a comprehensive list of CES related to shellfish aquaculture. The researchers used an ethnographic approach to interview not just oyster growers, but wild oyster fishers and oyster aquaculture industry support (*e.g*., hatchery employees) in three regions with multiple states in each region: New England (Rhode Island and Massachusetts), Chesapeake Bay (Virginia and Maryland), and Gulf of Mexico (Mississippi, Alabama, and Florida). The CES were categorized into contributions to identities, experiences, and capabilities according to the framework introduced by Fish *et al*. (2016). They identified 46 distinct benefits associated with working with shellfish, including six regulating and supporting services, eight provisioning services, and 32 cultural services divided into 10 identities, 17 experiences, and five capabilities. The interview format allowed them to identify links between different services in the eyes of the interviewees, and they found that every benefit was connected to at least one other. These connections highlight the complexity of the ES associated with aquaculture. By interviewing wild oyster fishers as well, they were able to identify how the CES associated with aquaculture differed from the wild fishery. In general, the two produced very similar benefits to the practitioners, but aquaculture provides less sense of adventure while providing a greater sense of pride at their accomplishment in producing a quality product. In addition to the distinct differences, a number of services were viewed as being better in aquaculture by some and better in the wild fishery by others, indicating that individual perception and interpretation play an important role in evaluating such benefits. These cultural benefits, largely accruing to the industry participants, are often overlooked in spite of representing a real anthropocentric value.

3.5.4 Concluding remarks

There are a number of significant gaps in the literature relating aquaculture and ES in the United States. The absence of finfish and shrimp are particularly notable, with these representing approximately 37.4% and 4.6% of U.S. aquaculture by weight in the year 2018 (NMFS, 2021). There are significant geographical gaps in research on MES provided by aquaculture in the U.S., as illustrated in Figure 3.16. There has been comparatively little research in Pacific waters, with only six studies from Washington and one from Oregon compared to 32 for the Atlantic. Alaska, California, and Hawai‘i are completely absent from the literature. It would be worthwhile to replicate the existing types of studies for these states. Research in Pacific waters has focused on the interaction of shellfish aquaculture with eelgrass and animals, while research in Atlantic waters has focused on nutrient removal. An additional possibility would be an analysis of the CES associated with the restoration of native fish pond (*loko i‘a*) aquaculture practices in Hawai‘i . Even more notable, although the Gulf of Mexico accounts for 51% of U.S. aquaculture production by volume (NMFS, 2021), the only study to consider Gulf states was the survey to analyze CES from aquaculture (Michaelis *et al*., 2021). It is also surprising that there have been no U.S. studies on the impact of kelp aquaculture on the diversity and biomass of other species given that kelp is known to be an important habitat (Radulovich *et al*., 2015). There are papers estimating the value of shoreline protection provided by wild oyster beds (Scyphers *et al*., 2011) and wild kelp (Morris *et al*., 2020). However, this branch of research has not extended to include estimates for aquaculture sites. The closest we could find were two studies that used the observed characteristics of U.S. mussel and kelp aquaculture sites in Saco Bay, Maine, as inputs to their theoretical model (Zhu *et al*., 2020, 2021).

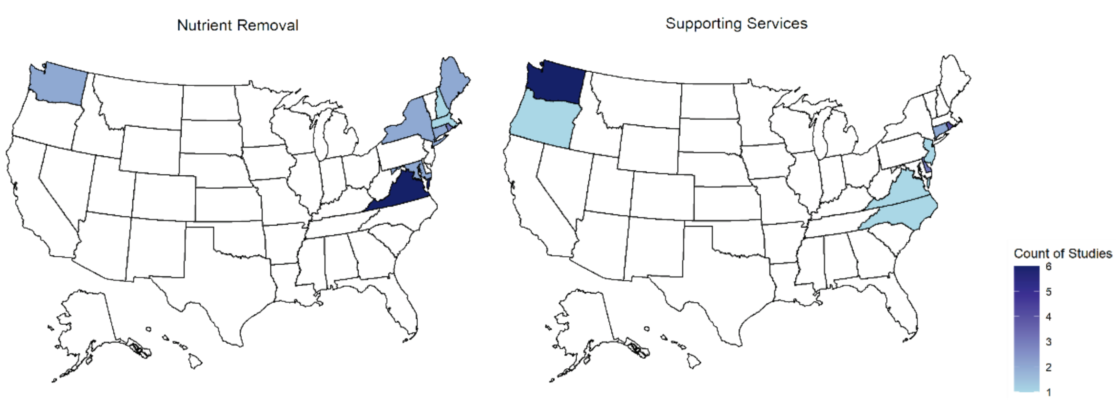

Fig. 3.16 Number of nutrient removal and support services studies by state.

The fact that the literature is largely centered on the regulating service of nutrient removal likely stems from two major factors. First, the fact that bioextraction and denitrification enhancement can be measured directly *via* scientifically established methodologies means that one can more readily produce publishable research. Second, the opportunity for aquaculture operators to receive payments from cap-and-trade programs (Cornwell *et al*., 2016) has likely resulted in greater financial incentives for this type of research. Given the interest in climate change and the importance of carbon sequestration, it is surprising to see that few studies report the carbon sequestration of shellfish and kelp, with even fewer assigning a dollar value to it in spite of the significant economic literature estimating the social cost of carbon (see the review and meta-analysis in Wang *et al*. (2019)). The relative dearth of research into aquaculture ecosystem services other than nitrogen removal is a rather surprising gap in the literature.

Another notable trend in the studies of aquaculture using the "ecosystem service" terminology is to only report *positive* contributions to ES. The oft-cited concern of the negative aesthetic impact of aquaculture would represent a loss of CES. However, such research is not recovered in a literature search requiring the "ecosystem service" term. Finfish farming is also associated with negative externalities, such as increasing nitrogen levels due to biological waste and excess food, disease transmission from cultured to wild fish, and escaped farm fish competing for resources or altering the genetic pool of local populations (*e.g*., Hindar and Fleming, 2007). Each of these negative externalities could be mapped to ES lost as a result of aquaculture. Not only have these negative externalities not been considered in the U.S. aquaculture ES literature, our literature search using terms regarding externalities or damages related to U.S. aquaculture returned no results.

It is also worth noting that the "ecosystem services" terminology has not permeated the relevant literature. Among the papers estimating bioextraction, three did not use the ecosystem services term anywhere in the paper, and likewise, four denitrification enhancement papers did not use the term, including papers written in 2020 and 2021. Although this created some additional challenge in finding these relevant papers in our literature search, they were found only because similar papers did include the ecosystem services terminology. There could be other types of relevant studies for which none include the terminology and are thus absent from this report. The ES framework seeks to tie together numerous disciplines, but it has not yet become ubiquitous across relevant disciplines.

3.6 Overall conclusions and gap analysis

Overall, the reviews found the existing literature regarding ecosystem services and marine aquaculture to be small and narrowly focused within the PICES member countries of Canada, China, Japan, and the United States. With respect to the categories of ES described in the Millennium Ecosystem Assessment, much of the research has focused on the regulating ES of nitrogen cycling and carbon sequestration provided by culture of macro-algae and shellfish, as well as the supporting services related to the impact of aquaculture on species in their vicinity. Cultural services have received some attention in each country, but it is the category with the least developed knowledge base. Meanwhile, provisioning services have been the subject of little academic research (with most of that in China). As far as the cultured species in the body of research, the non-fed aquaculture groups of shellfish and macro-algae have been the dominant choice. The literature survey procedures employed by each country uncovered only five studies for Japan, six in Canada, nine studies for China, and 41 in the United States. As a reminder, the restrictive nature of the literature search means that the difference in quantity of studies may not be due to a difference in the accumulated knowledge, but rather due to other details, such as differences in terminology or a tendency for relevant research to be in the form of government reports rather than peer-reviewed articles.

The relatively unexplored nature of this topic is not particular to PICES, but is a worldwide phenomenon. For example, a report on the effects of aquaculture in North Atlantic nations by Mikkelsen *et al*. (2021, page 614) indicates that "Non-market valuation data on the impacts of aquaculture on aesthetic view, environmental quality and other ecosystem services are for our case countries mostly lacking…" Although they are referring to data, rather than to research *per se*, the data on ES provided by aquaculture are a preliminary requirement for research. What data exist are usually collected directly by researchers for a narrow geographical scope, but these studies are informative as to the variables that can and should be collected, and the methods to collect them.

The literature survey revealed a number of issues in the existing research on the value of ecosystem services provided by marine aquaculture. Firstly, the valuation of ES is both infrequent and of questionable accuracy. Assigning an economic value to the ES being measured was not common outside of China. None of the Japanese studies computed an economic value, one of the six Canadian studies did, and only seven of the 41 studies in the U.S. report computed an economic value. Computing the economic value will be an important step in guiding effective aquaculture policy. Furthermore, even where it is calculated, the methodologies are likely to produce inaccurate measures of the ecosystem service values, as discussed in the introduction to section 3 and illustrated in the Chinese and U.S. case studies. Another issue which appears in the literature is inconsistency in ecosystem service classifications, particularly for cultural services where some studies consider tourism and recreation values, other studies consider employment incomes or the non-monetary value of aquaculture employment, and others consider the research value. Each of these are components of cultural services, but no study that we located considered all of them.

Another source of inconsistency is the measurement methodology, with this issue spanning all types of services and cultured species. Nitrogen uptake by shellfish is estimated using both live specimen and computer simulation techniques. Denitrification is measured both *in situ* and in controlled laboratory experiments, with further variation in measurement techniques employed for each of these two categories. Assessing impacts on other animal species is also accomplished through a variety of techniques, including capture in traps/nets or live monitoring by video or divers. The diversity of survey techniques are also likely to produce methodological variation. It is not reasonable to expect that all studies use a single methodology, especially as new and improved methods may be developed, but it is important to acknowledge and understand any possible biases introduced by the different measurement techniques.

An additional issue that was apparent from the literature survey was the usage, or lack thereof, of the term "ecosystem services" when paired with marine aquaculture. The term has been used almost exclusively to refer to the positive benefits generated by aquaculture, and does not typically appear in studies examining negative spillovers from aquaculture even if these spillovers may take the form of lost ecosystem services.[25] Furthermore, many of the included studies did not include the term "ecosystem services" at all, instead referring directly to the service such as carbon sequestration or bioextraction. Using the term "ecosystem services" more holistically, incorporating both the positive

[25] The exception was one Japanese study (Chakraborty and Gasparatos, 2019) which examined the ecosystem services in Oita, Japan, more broadly. Within this broader context, they note the reduction in ecosystem services surrounding prawn mariculture sites.

and negative effects of aquaculture on the ecosystem, would lead to improvements in management and regulation decisions by better accounting for the net effects. At present, management decisions are based mostly on the potential damages (*e.g*., Environmental Impact Assessments). The potential benefits are beginning to be incorporated after-the-fact; for instance, there is some movement towards incorporating shellfish farms into nitrogen permit trading in the U.S. in order to provide compensation for the positive ES (Rose *et al*., 2014; Racine *et al*., 2021). A greater push is also being made to incorporate possible benefits in the initial siting and permitting decisions as part of a paradigm known as "restorative aquaculture" in which aquaculture generates positive environmental outcomes (Theuerkauf *et al*., 2019). It will be important to more consistently utilize the ES terminology in the research and to consider the positive and negative effects as part of the whole environmental impact of aquaculture.

Yet another important issue observed in the literature is determining the proper baseline for comparison in the valuation of ES. The ideal would be a before-and-after comparison of the site, but for existing sites this is not possible. Therefore, it is common to select a reference site nearby. However, even this is not always a simple decision. For instance, in the analysis of the change in population densities around net-pen fish farms, the meta-analysis of Barrett *et al*. (2019) reports differences that vary by orders of magnitude, depending on whether the reference habitat is a nearby natural reef or open featureless water. While different circumstances will call for different baselines for the calculation, these decisions should be clearly explained.

Research on aquaculture-related ecosystem services in PICES member countries has covered an array of species and ES, but with very unequal coverage. There is significant disparity between the countries in this report in the volume of published research, and even within countries, geographic gaps are identified. Likewise, by ecosystem service category there are large differences in the depth and breadth of the literature. Cultural ecosystem services are scarcely considered, while the regulating service of eutrophication mitigation is by far the most frequently estimated. The prevalence of studies estimating bioextraction of nitrogen and denitrification enhancement is likely the result of two unrelated factors: it is a readily measured and quantifiable ecosystem service, and regulatory requirements to reduce nitrogen levels have led to more demand and funding for this type of research. Another common topic is the impact of aquaculture sites on the abundance and diversity of other species in their vicinity.

That being said, there are a number of gaps in the literature that stand out. While the impact of shellfish aquaculture on other species is measured in a number of studies in different locations, we identified no studies on the impact of macro-algae culture on other animals. Studies of the habitat and refugia provided by wild macro-algae are common, but more information is needed about the role that cultured macro-algae can play in supporting other species. With cultured macro-algae, the periodic harvest is a significant difference that is likely to alter the habitat/refugia value, and could in fact, turn it into a population sink. Another important ecosystem service that may be provided by near-shore aquaculture is shoreline protection. There is significant evidence that mangrove forests, wild oyster reefs, and kelp forests can protect the shoreline from strong waves, but the role that cultured oysters and kelp (with the accompanying infrastructure) has not been measured. It is also important to note that these studies of ES and marine aquaculture are tied to one time and place. Understanding the dynamic evolution of these services with changes in the sea and climate conditions, and with changes in aquaculture density, will be important in the coming decades. Developing models that can effectively predict ecosystem services from aquaculture under these changing conditions should be a priority for research.

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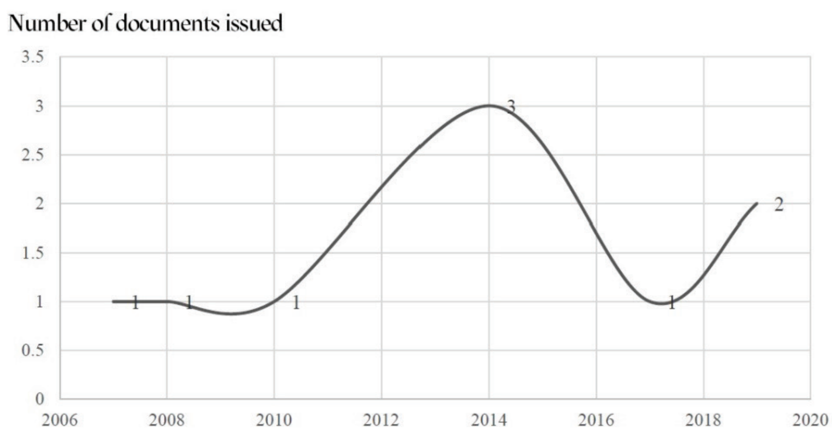
Annex

Detailed bibliometric analysis of Chinese literature

CiteSpace is a Java-based software for visual analysis of literature surveys developed by Professor Chen Chaomei of the Dalian University of Technology. It can generate a map of scientific knowledge, collect documents in a certain discipline, and provide knowledge structure analysis services. It shows the structure, medium centrality, dissemination, future development trends, and cutting-edge hotspots of knowledge. CiteSpace software is used for visual analysis of clustering, keyword co-occurrence and timeline, and the research progress in this field is analyzed in detail. In recent years, the number of documents issued by CiteSpace software has also been rising, providing technical support for researchers in various fields.

Overall characteristics of the study

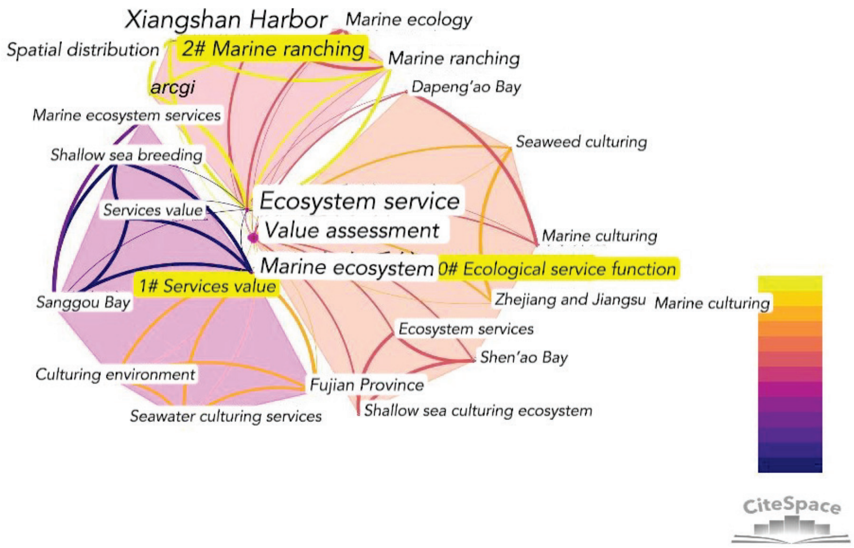
There has been relatively little research regarding the economic value of ecosystem services associated with mariculture (Annex Fig. A1). It is helpful to summarize the research progress in this field, find the research hotspots and cutting-edge issues, and provide guidance and suggestions for future research.



Annex Fig. A1 Chinese mariculture ecosystem services papers by year.

Research frontier and hotspot analysis

Through the visual analysis of documents by CiteSpace, the clustering map of nine studies is drawn (Annex Fig. A2). According to the clustering analysis, three clusters can be obtained: ecological service function, service value, and marine ranching (the clustering number in the figure does not represent the sequence number of clustering, but represents the number of keywords included in the cluster. The smaller the number, the more keywords included in the cluster). It shows the characteristics of knowledge structure in the field of mariculture ecosystem. The clustering data in the keyword map have a modularity Q = 0.4028 > 0.3, mean silhouette = 0.828 > 0.5, which indicate that the results and structure of the map are reliable.

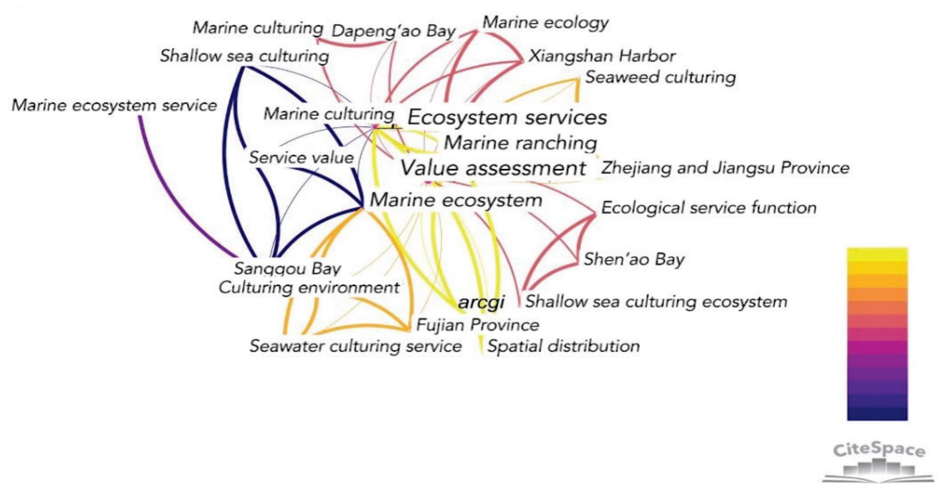


Annex Fig. A2 Keyword clustering analysis view.

Cluster #0: *Ecological service function*. This cluster mainly identifies and estimates the value of ecosystem service functions of mariculture. The nine documents focus on the ecosystem services of aquaculture marine areas, classify and study the ecosystem services and functions of aquaculture marine areas, and carry out the analysis and value evaluation of marine ecosystem services from three aspects: provisioning services, regulating services, and cultural services according to the classification method of the Millennium Ecosystem Assessment: Zhang *et al*. (2007), Honghua Shi *et al*. (2008) and Wang (2010) assessed the value of Sanggou Bay's service functions such as provision, regulation, and culture; scholars have evaluated the aquaculture ecosystem service value of other aquaculture marine areas in China, such as Dapeng'ao, Xiangshan Harbor, Shen'ao Bay, Zhelin Bay, and Fujian Province (Cheng *et al*., 2014; Wang *et al*., 2014; Yu *et al.*, 2014; Zhu, 2017; Huan *et al*., 2019). Lv (2017) estimated the direct ecological value and indirect ecological value of seaweed culture in China.

Cluster #1: *Service value*. This cluster mainly evaluates the ecosystem service value of mariculture. Nine documents have evaluated the ecosystem service value of aquaculture marine areas, taking China's typical mariculture bays as the object to evaluate the ecosystem service value of mariculture: Sanggou Bay (Zhang *et al*., 2007; Shi *et al*., 2008; Wang, 2010), Xiangshan Bay (Cheng *et al*., 2014), Shenzhen Bay (Wang *et al*., 2014), Dapeng'ao (Yu *et al*., 2014), and Zhelin Bay (Huan *et al*., 2019). Zhu (2017) assessed the service value of mariculture in Fujian Province by taking the province as the boundary, and Lv (2017) assessed the ecological service value of mariculture in China as the object from the whole.

Cluster #2: *Marine ranching*. This cluster studies the ecological service value and carbon sink value of marine ranches. Marine ranches are similar to terrestrial ones, except they are stocked by captured wild organisms. It is a method to raise fish, shrimp, shellfish, algae and other crops in a certain place through artificial reefs, proliferation and release in a certain marine area, so as to realize the ecological and economic value of mariculture. The literature mainly focuses on the ecosystem service value before and after the establishment of marine ranching (Cheng *et al*., 2014; Huan *et al*., 2019).



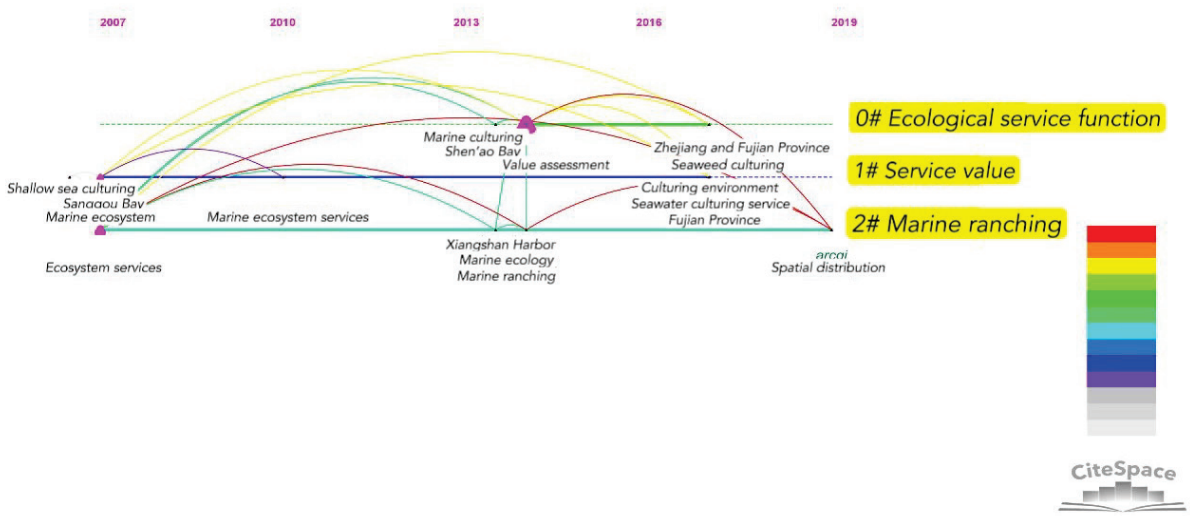
Annex Fig. A3 Keyword co-occurrence analysis view.

The keyword co-occurrence diagram identifies keywords which appear together in studies by connecting lines, with the font size of the node indicating the frequency of the keywords (Annex Fig. A3). Due to the limited number of studies included in this analysis, the node size is not obvious, and only the node "value assessment" is slightly larger. As seen in Annex Figure A3, most of the connecting nodes in the figure focus on the three keywords of "value assessment", "ecosystem services", and "marine ecosystem", indicating that the accuracy of our literature search scope is confirmed by keyword cluster analysis. In addition, in the divergent nodes, there are also keywords such as location name, algae culture, culture environment, geographic information system, marine ecology, spatial distribution and so on, which shows that the research of the mariculture ecosystem also needs the assistance of geography and ecology to make the research results more convincing.

Annex Table A1 shows the top five keywords of intermediary centrality, in which the year is the time when the keyword first appeared in the selected articles. Intermediary centrality measures the degree to which the keyword is used and focused on by scholars. The higher the intermediary centrality, the higher the degree to which the keyword is studied. According to the data, the intermediary centrality of "value assessment" is as high as 0.96, which shows that all the nine articles we found meet the requirements of the case study on the value service evaluation of mariculture ecosystem in China. In addition, the intermediary centrality indices for "ecosystem services" and "marine ecosystem" are high, which mainly involves the classification of ecosystem services and the value assessment of marine ecosystem services.

Annex Table A1 Top 5 betweenness centrality keywords.

Rank	Frequency	Intermediary centrality	Year	Keyword
1	6	0.96	2014	Value assessment
2	6	0.59	2007	Ecosystem services
3	3	0.20	2007	Marine ecosystem
4	3	0.19	2007	Sanggou Bay
5	2	0.01	2014	Ocean ranch



Annex Fig. A4 Keyword timeline view.

The keyword clustering is divided according to the timeline, and the timeline map of CiteSpace 2007–2019 is drawn to analyze the characteristics of research hotspots over time. Annex Figure A4 shows the map, including the three clustering analysis maps, which can be summarized as follows:

(1) The relevant research on mariculture ecosystem services in China began in 2007. The initial research content began with shallow water aquaculture, and studied the ecosystem service value of aquaculture in China's typical mariculture areas such as Sanggou Bay and the coast of Fujian Province. These initial studies also have a certain correlation with subsequent mariculture-related research, and lay a foundation for the follow-up research.

(2) From 2007 to 2013, there were two relevant studies on Sanggou Bay related to ecosystem services and mariculture. Compared with the previously published articles, the research content was deeper. On the basis of value assessment, the research touched on the impact on ecosystem services of different aquaculture modes, such as multi-trophic culture, kelp culture, shellfish culture, and so on.

(3) 2014 featured the most studies on the topic of value assessment. The research contents included the value assessment of ecosystem services in three different mariculture areas: Shangang, Dapeng'ao and Shen'ao Bay. The structure of the paper written by the author is also to evaluate the classification of mariculture ecosystem services.

(4) After 2014, research on mariculture ecosystem services gradually extended to new geographical areas.

To sum up, in the field of mariculture and ecosystem service value, the research shows the characteristics of "from shallow to deep". Starting from mariculture, scholars gradually dig into the service classification of mariculture, and then estimate the ecosystem service value of mariculture, including the service value of breeding areas and breeding varieties. In recent years, with the increasing ecological pressure of mariculture, the relevant research on the ecological value and development potential of the mariculture ecosystem has gradually increased.

4 Perceptions and Use of Marine Ecosystem Service Values in Decision-Making in Three PICES Member Countries: Canada, China, and the United States of America

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4.1 Ecosystem services and decision making

As expanded on in earlier sections of this report, the term ecosystem services (ES) broadly refers to the direct or indirect benefits humans derive from ecosystems (Costanza *et al*., 1997; Daily 1997; MA, 2005). Ehrlich and Ehrlich (1981) have been credited with the initial use of the term “ecosystem services” (Braat and de Groot, 2012), using the concept to make an economic case for the importance of biodiversity to society. Research on ES and ecosystem service values (ESV) emerged from the scientific literature on the use of natural resources and human populations as part of ecosystems, but the terminology had limited use until the 1990s (Vihervaara *et al*., 2010). Daily (1997) and Costanza *et al*. (1997) helped to crystalize the concepts to bring attention to the contribution of biodiversity and ecosystems to human well-being, in effect raising awareness and augmenting biological arguments for protection (Laurans *et al*., 2013). In the intervening decades, the idea that ES have economic value has been recognized worldwide, and provides an important tool in global efforts to combat issues at the forefront of conservation, including biodiversity decline and climate change (*Nature*, 2021).

The value of ecosystem services are indicators of the benefits provided by ecosystems to human beneficiaries, and may be economic or sociocultural; concepts and methods of measuring ESV was discussed in more detail in section 2. The measurement of ESV is viewed as important in the development of policy and management that slows the degradation of ES (NRC, 2005; TEEB, 2011). Moreover, ESV are central to payment for ecosystem services (PES) programs (Bulte *et al*., 2008; Jack *et al*., 2008; Farley and Costanza, 2010) and the United Nations-led System of Environmental-Economic Accounting (SEEA), a framework that integrates economic and environmental data to provide a comprehensive view of the relationships between the economy and environment (United Nations, 2014; La Notte and Rhodes, 2020). Other frameworks that benefit significantly from information on ESV include coupled socio-ecological systems (SES) (Liu *et al*., 2007), Integrated Ecosystem Assessments (IEA) (Levin *et al*., 2009), and trade-off analyses (Johnston *et al*., 2018).

Despite the steady increase in research on ES and their values, the use of ESV in policy and management has been, arguably, inconsistent. Though a fair number of examples of the use of ESV in decision-making exist (see Johnston *et al*. (2018); Marttunen *et al*. (2021)), to fully represent the benefits of ES to society, their values should be considered as core components of decision-making—something that has not always been clear in the literature (Laurans *et al*., 2013). For the countries represented in this Working Group report, ESV do not appear to be utilized in a core or systematic manner in marine ecosystem management. Therefore, as part of the WG 41 agenda, three member countries—Canada, China, and the United States—implemented similar surveys to better understand the perceptions, uses, and potential constraints on the use of marine ESV in their respective country's decision-making.

The next three subsections include a brief description by each of the participating countries on linkages between ESV and current management, details on the design and implementation of their country-specific survey, and a summary of country-level results. While each country implemented an online survey as the general methodological approach and covered many of the same topics, the differences in the survey design and implementation employed by each country warrants separate descriptions. Copies of the survey materials are included as Annexes to this section. The section concludes by highlighting similarities and differences in the country-level results. The project was not intended to be a comparative study across countries, although the results suggest some interesting parallels and differences concerning ESV awareness and use, and elucidate unique opportunities and challenges for each country in incorporating ESV in marine management and decision-making.

4.2 Canada's marine ESV survey

4.2.1 ESV in marine management and decision making

The work of Fisheries and Oceans Canada (also known as the Department of Fisheries and Oceans, DFO) to manage Canadian marine resources is authorized by various legislation, primarily the *Fisheries Act* (1985) and the *Oceans Act* (1996) with additional authority provided by the *Species at Risk Act* (SARA) (2002). While ecosystems are mentioned in this legislation, ES are not.

A number of DFO internal guidance documents use the concept of ES. While most DFO guidance documents for economic analysis reference the concept of final ES and their associated values, in all cases the use of ESV is not mandatory. For example, in the National Framework for Canada's Network of Marine Protected Areas (Government of Canada, 2011), the second Network Goal is "To support the conservation and management of Canada's living marine resources and their habitats, and the socio-economic values and ecosystem services they provide" (page 6). While the DFO economic guidance documents to support the Marine Protected Area (MPA) network design does not reference ESV (Fisheries and Oceans Canada, 2017), final ES are referenced in the guidance document for cost–benefit analysis to support the regulatory process to designate individual MPAs (Fisheries and Oceans Canada, 2016). Other internal economic guidance documents also reference final ES and their values, specifically those related to the development of cost–benefit analysis for regulatory purposes under the SARA (2002) and risk assessments and regulatory cost–benefit analysis to support the Aquatic Invasive Species Regulations (2015).

Statistics Canada, the national statistical agency, publishes frameworks, reports, and accounts that include ES and ESV in support of ecosystem accounting. This was largely initiated with the publication of a compendium of interdisciplinary research focused on understanding the value of ES, including marine and coastal ES (Statistics Canada, 2013). While much of the information over the intervening years focused on terrestrial and freshwater ecosystems and ES, the most recent version of the series includes information on ocean and coastal ecosystems assets, including extent, condition, and pressures (Statistics Canada, 2022a). This was a key outcome of a collaboration between Statistics Canada and DFO to develop pilot "Ocean Accounts." Beginning with the ocean and coastal ecosystem extent account (Statistics Canada, 2022b), additional accounts, including ES accounts, will be released which can include valuation information.

4.2.2 Survey design and implementation

Canada's Marine Ecosystem Services Valuation (MESV) survey was developed to better understand current awareness, use and views of ESV within DFO, and identify those ESV of the most value to the work of DFO. The project supports DFO's Ocean Accounts initiative and will be used to guide priority setting for research to support programs in Aquatic Ecosystems and Fisheries and Harbour Management. The survey was designed based on a template provided by NMFS (see section 4.4 for details) and informed by the survey implemented in China (see section 4.3 for details). The survey template was modified to reflect a Canadian context and then refined based on interviews with four potential participants.

The MESV survey was administered between October 21 and December 24, 2021. An initial email was sent to each participant inviting them to participate with the information provided on the purpose of the survey and providing a link to a short video with background on ES and economic valuation of those services (see Annex A for a transcript of the video). The invitation to participate was sent out in three batches; the survey window for each group of invitees was three weeks. All invitees were contacted twice more, once after week one and again one week before the end of the three-week access period. All survey materials were made available in English and French.

The survey consisted of 22 questions and was composed of 4 main parts (see Annex A for a copy of the survey). The first focused on understanding the familiarity and use of ES and ESV among DFO staff. It included questions asking respondents to indicate their level of knowledge of ES and ESV on a 4-point scale, as well as to specify if and how ES and ESV had been used in a professional setting, within or outside of DFO.

The second part was the main component of the survey, consisting of questions focused on understanding the utility of specific coastal and ocean ESV for regulation, policy, management, and decision-making. The list of marine ES included provisioning, regulating, supporting, and cultural services, with individual ES descriptions based on published sources but modified based on feedback from DFO staff. Respondents provided their individual perceptions on the utility or importance of marine ESV, first for the work of the Department as a whole and then in their current role. The 4-point scale ranged from: "Very important", "Moderately important", "Only a little important", to "Not at all important"; an "Unsure" option was also provided.

The third part (item 13) focused on understanding respondents' perceptions of ESV and factors that could limit their usefulness. A 5-point Likert scale was used, with respondents asked to provide their level of agreement with statements from "Strongly agree" to "Strongly disagree"; an "Unsure" option was also provided. The wording of this section was not changed from the survey template and aligns closely to the language used in the U.S. survey.

The last part collected work-based demographic information on respondents such as DFO region, sector, program linkages, type of position and other factors.

4.2.3 Sampling and response

The target audience for the survey included DFO staff involved in making recommendations to which ESV may be relevant. This was determined to include staff working in programs related to aquatic ecosystems science, fisheries and oceans management, policy development and economics at the levels of Assistant Deputy Minister and equivalent to that of analyst. Participants were identified in all DFO regions. The mailing list was assembled from several sources including program-specific contact lists (*e.g.*, MPA practitioners), individuals recommended by directors and managers, and personal knowledge of the survey development team. The final list consisted of 336 individuals, 6 of which had left the department before the survey was distributed, for a sample size of 330.

A total of 81 surveys were completed for a 24.5% response rate. The number of initiated and incomplete surveys could not be tracked. Respondents completed the survey in an average of 32 minutes.

4.2.4 Results

4.2.4.1 Respondent characteristics

All DFO regions were represented in the responses, with 25% of respondents from the Pacific region (British Columbia), 44% from Atlantic regions (Newfoundland and Labrador, Maritimes, and Gulf), 31% from national headquarters (Ottawa), and 9% from other regions (Ontario and Prairies, Quebec, and Arctic). Of the sectors identified to participate in the survey, Aquatic Ecosystems was the most heavily represented, accounting for 45% of survey respondents; this sector included those working in the areas of Marine Planning and Conservation and Species at Risk. Strategic Policy (which includes departmental economists) and Ecosystems and Ocean Science accounted for 25% and 18% of respondents, respectively. Fisheries and Harbour Management and regional groups with cross-cutting responsibilities accounted for 9% and 5% of respondents, respectively. Finally, the survey received no responses from staff within the Canadian Coast Guard.

Respondents were asked to identify the area in which the majority of their work fell and their position classification or level (Fig. 4.1). Respondents were relatively evenly distributed across fields of work. With the exception of Research, which accounts for only 6% of respondents, Policy/Program Development, Management Support, Policy or Science Advising, and Economic Analysis or Advising accounted for 30%, 28%, 20% and 16% of respondents, respectively. In terms of the classification or level of position held, respondents appeared to be representatively spread between analysis and management. Senior and intermediate level analysts and researchers were the most represented categories, accounting for 31% and 30% of respondents, respectively. These were followed by managers, directors, and senior management above director, which accounted for 19%, 13%, and 7% of respondents, respectively.

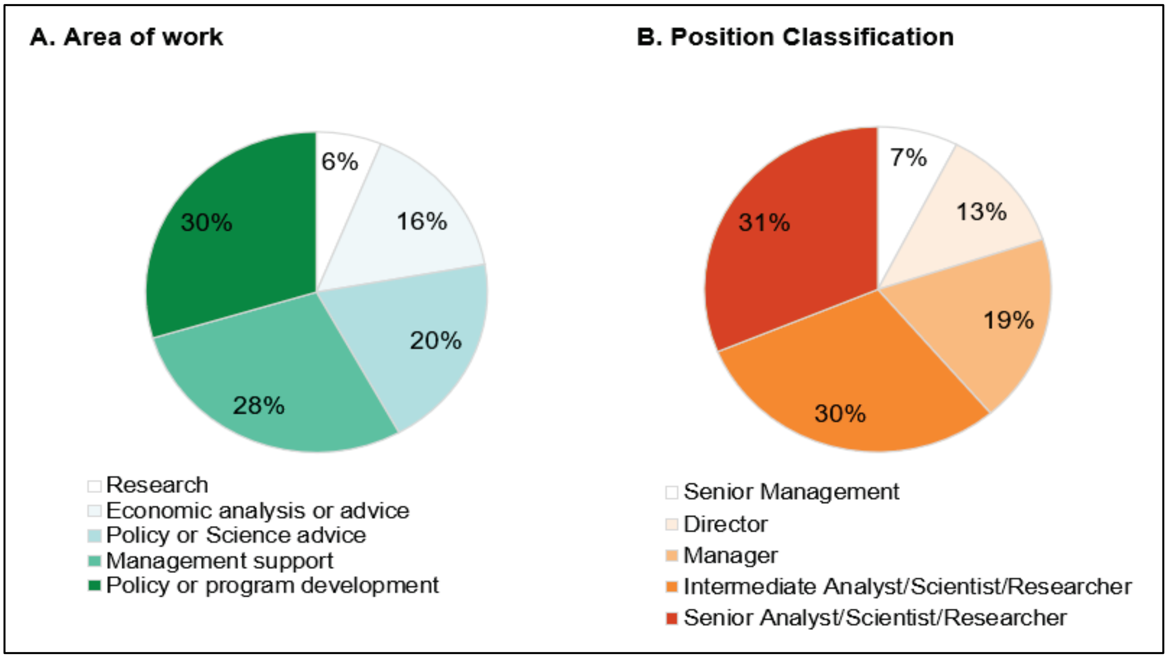


Fig. 4.1 Canada: Respondents by (A) area of work and (B) position classification or level.

Respondents had a high level of work experience and were well educated (Fig. 4.2). The majority of respondents had less than 6 years of experience working in the field of marine resources; however, they had an average of slightly more than 11 years of work experience (median = 10 years) in marine resources. Respondents' time at DFO was an average of slightly more than 4 years (median = 3 years). Regarding education, 79% of respondents reported having at least a master's degree.

Respondents were asked to identify the policies and programs that their work influences, with multiple responses allowed (Fig. 4.3). The majority of respondents reported being involved in work under Fisheries, Species at Risk, Marine Spatial Planning, or Marine Conservation Targets (*i.e.*, MPAs and MPA networks). A total of 6 respondents reported being involved in work which affects all policy or program areas, with these respondents typically in senior management roles. The green bars in Figure 4.3 identify program areas that regularly involve regulatory analysis, which requires regulatory impact analysis, including cost–benefit analysis; ESV may be particularly relevant in the regulatory context. The purple bars represent policy and program areas where regulatory analysis is not present or infrequent. There were more responses within the non-regulatory policy or program areas, although this may be due to more non-regulatory options being provided and respondents being allowed to select all applicable categories. It is also important to note that while the regulatory and non-regulatory categorization was assigned for summary purposes, both regulatory and non-regulatory activities may take place within many of the policy and program areas.

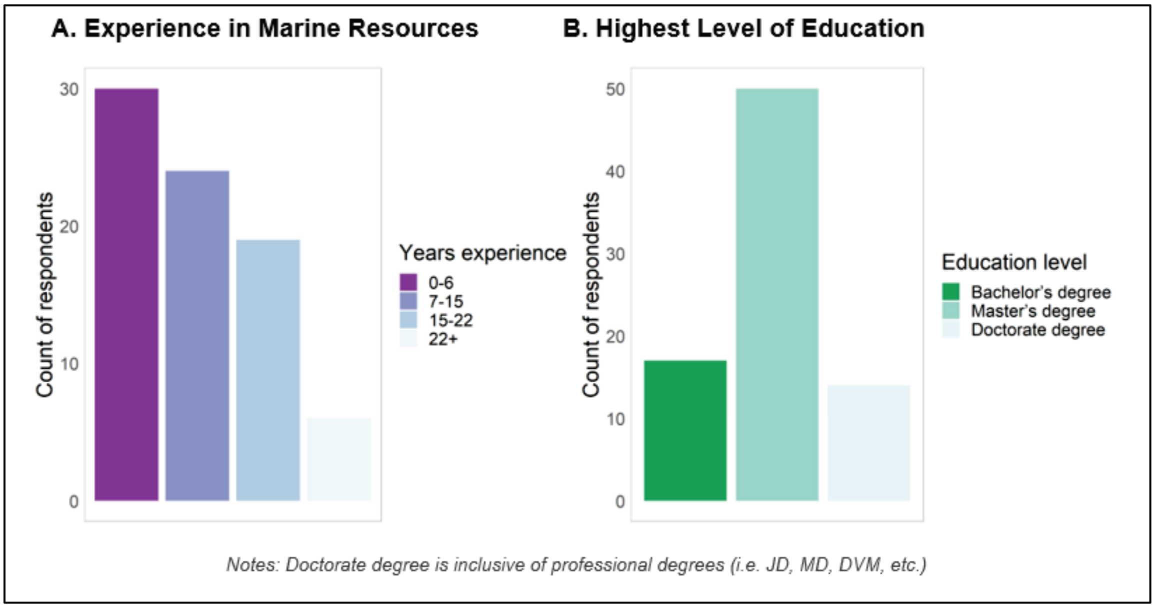


Fig. 4.2 Canadian respondent experience in (A) a marine resources agency and (B) education level.

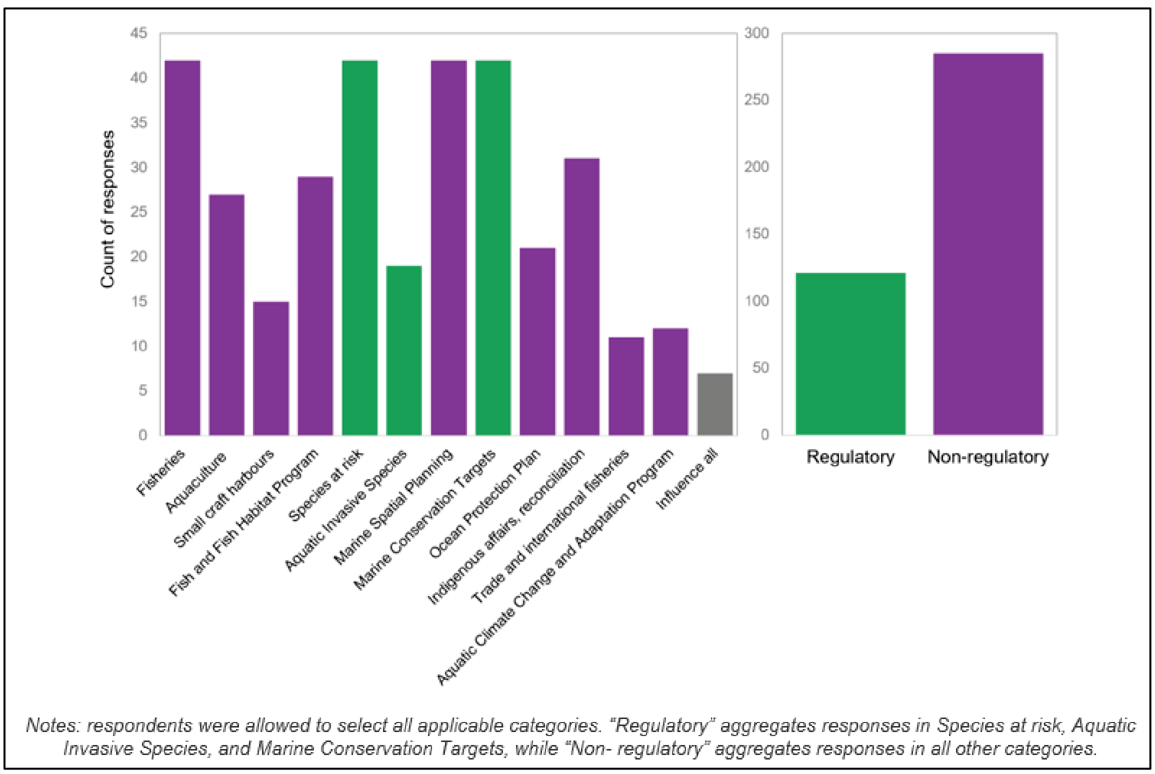


Fig. 4.3 Canada: Policies or programs which respondents' work influences.

4.2.4.2 Familiarity and experience with ESV

Figure 4.4 summarizes respondents' familiarity with the concept of ES and the economic valuation of ecosystem services. The majority of respondents reported having a good prior knowledge of the concept of ES, with 71% of respondents reporting a high or moderate familiarity and 29% reporting having only a little familiarity or none at all. In contrast, respondent understanding of the economic valuation of ecosystem services was lower. While the majority of respondents still reported having some familiarity with ESV, the proportion of respondents reporting that they were "very familiar" with this concept dropped by 19 percentage points, from 27% of respondents to only 8%. Most respondents reported either having little (41%) or moderate (47%) familiarity with ESV.

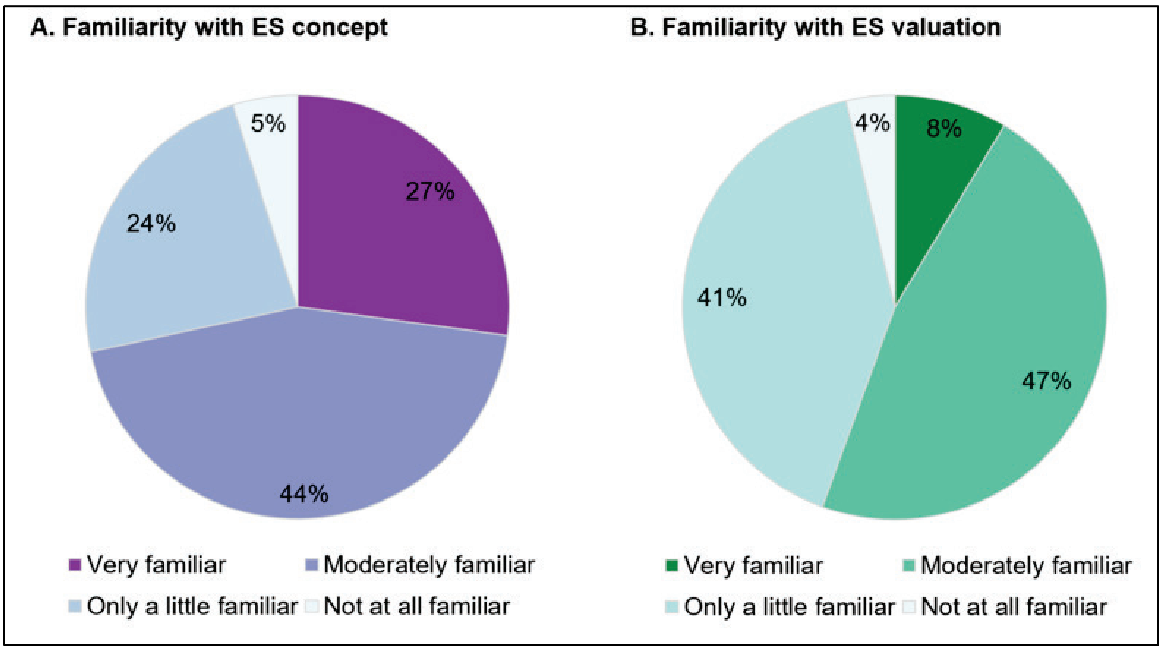


Fig. 4.4 Canada: Respondents' familiarity with (A) the concept of ecosystem services (ES) and (B) ES valuation.

Regarding professional experience with ESV, 72 respondents indicated they had experience with ESV. Figure 4.5(A) summarizes the type of professional experience these respondents had, with multiple responses allowed. Most respondents with some professional experience with ESV have discussed or been consulted on the use of ESV (35 respondents), or learned about ESV in a work context but have not themselves applied ESV within an analysis (26 respondents). Only a few respondents reported having applied ESV within their work or research, with 19 respondents reporting having applied ESV in their work at DFO, 11 having applied in work outside of DFO, and 11 having investigated or conducted research on ESV within or outside DFO.

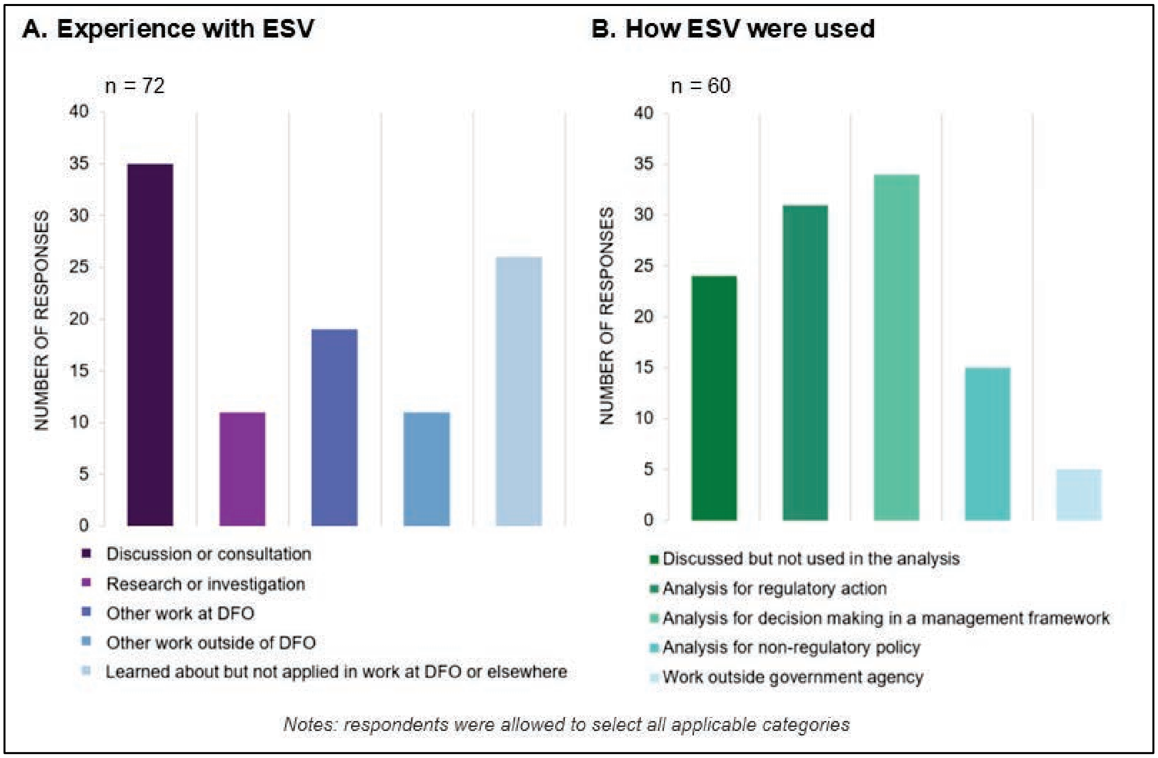


Fig. 4.5 Canada: Respondent experience with (A) ESV and (B) use of ESV in a professional context.

For the 60 unique respondents who indicated some type of use of ESV, Figure 4.5(B) summarizes how ESV have been used within a work context. ESV have most commonly been used within analyses for decision-making under a management framework, such as Integrated Fisheries Management, Ecosystem Based Management, Marine Spatial Planning, Management Strategy Evaluation, SARA recovery planning, or Aquatic Invasive Species (AIS) risk assessment (34 respondents). ESV have also commonly been applied within analyses supporting proposed regulatory action or changes to regulation, such as an MPA designation, SARA listing or AIS listing (31 respondents), or for the development of non-regulatory policy such as a strategic policy or operational guide (24 respondents). Many respondents also reported having discussed ESV in their work at DFO without actually implementing them in an analysis (15 respondents). Finally, a few respondents reported having no professional experience with ESV within DFO, but noted they had applied ESV in a research or other professional context outside the organization (5 respondents).

4.2.4.3 Importance of specific ESV to work

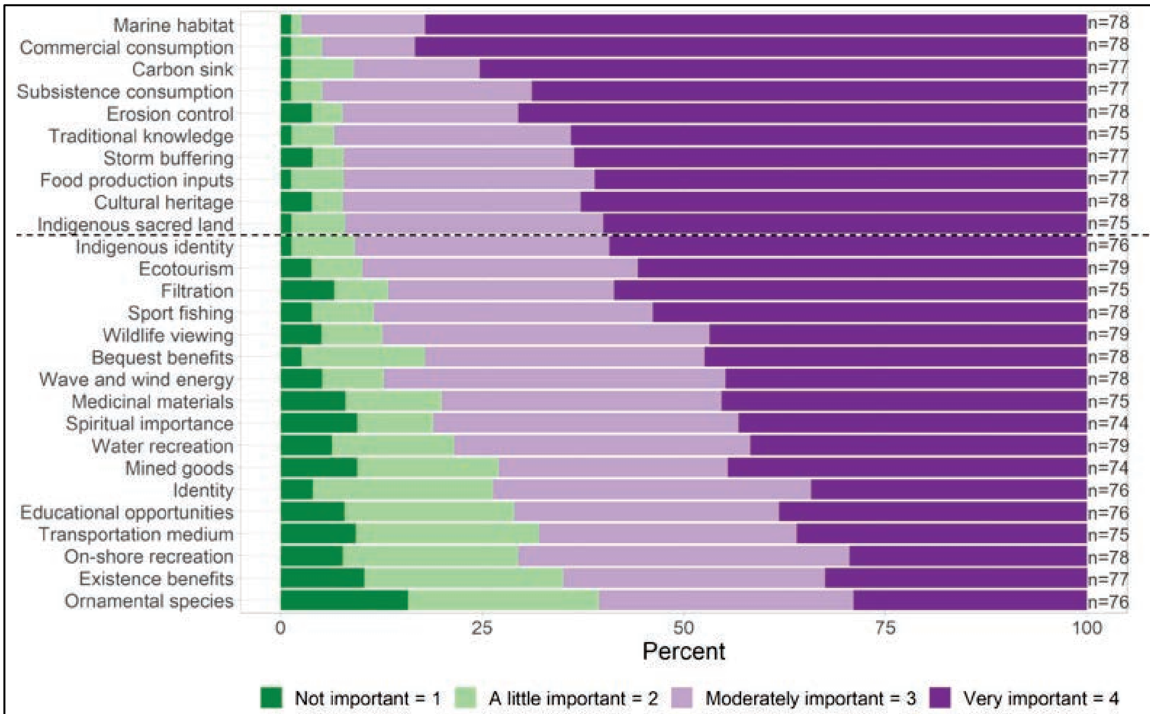
The survey included two slightly different questions to identify respondents' perceptions of the usefulness of economic values for different types of ES. First, they were asked to identify the importance to DFO decision-makers in general, and second, to their ability in their current role to provide useful information to DFO decision-makers. Usefulness was rated on a 4-point scale from "Very important" to "Not at All Important", with an "Unsure" option provided.

Table 4.1 includes the complete list of ES included in the survey questionnaire, as well as the short descriptor used in the figures. For both questions, the order of the list of 27 ES that was presented was identical. For ease of presentation within each question, the list of provisioning and regulating ES was presented in one table and cultural ES in a different table.

Table 4.1 List and description of marine ecosystem services (MES) included in the Canadian survey.

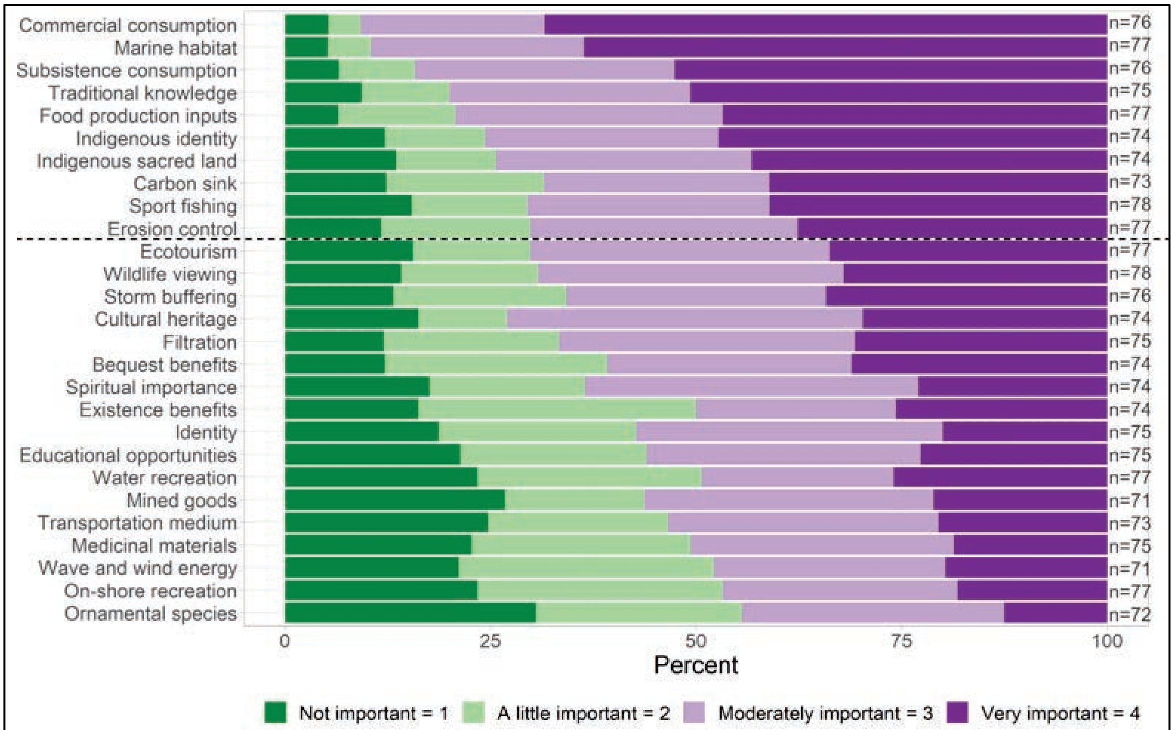
	Short descriptor	Long description in survey
Provisioning	Commercial consumption	Fish, other animals, and plants harvested for human consumption via commercial fishing or aquaculture
	Subsistence consumption	Fish, other animals, and plants harvested for human consumption via hunting and subsistence/artisanal fishing
	Food production inputs	Fish, other animals, and plants used as inputs in human food production process (*e.g.*, food ingredients, bait, feed used in aquaculture/agriculture)
	Mined goods	Minerals, rare earth elements, petroleum/oil, natural gas, and other valuable materials that can be mined, dredged, or harvested
	Medicinal materials	Materials needed for, or potentially useful for, medicine or pharmaceuticals
	Wave and wind energy	Wave and wind energy that can be harnessed
	Ornamental species	Fish, other animals, and plants harvested for ornamental use (*e.g.*, aquariums)
	Transportation medium	Medium for transportation of goods and people
Regulating	Carbon sink	Carbon sequestration
	Filtration	Filtration and remediation
	Erosion control	Shoreline protection and erosion control
	Storm buffering	Storm buffering for areas other than shore
	Marine habitat	Habitat for marine and coastal plants and animals
Cultural	Water recreation	Water recreation (*e.g.*, scuba diving, swimming, surfing, kayaking)
	Sport fishing	Sport fishing opportunities
	Wildlife viewing	Wildlife and scenic viewing opportunities (*e.g.*, bird watching, whale watching)
	On-shore recreation	Onshore/coastal recreation activities (*e.g.*, tide pooling, sunbathing)
	Ecotourism	Ecotourism
	Cultural heritage	Cultural heritage
	Spiritual importance	Spiritual, or religious importance
	Identity	Sense of place / identity
	Educational opportunities	Educational opportunities
	Traditional knowledge	Traditional ecological knowledge / indigenous knowledge
	Indigenous sacred land	Spiritual significance/Sacred landscape for Indigenous peoples
	Indigenous identity	Sense of place/identity for Indigenous peoples
	Existence benefits	Existence benefits (knowing that something exists even if it is never visited /used)
	Bequest benefits	Bequest benefits (knowing that something will be available for future generations)

The rank of the perceived importance of the ES within each of the questions was based on the average score, with “Very important” scored as 4,”Moderately important” scored as 3, “Only a little important” scored as 2, and “Not at all important” scored as 1. “Unsure” or missing responses were not included in the calculation of average response. The distribution of responses is shown in ranked order of perceived importance of ES valuation information for DFO management decisions in general (Fig. 4.6), and in respondents’ ability to provide information to decision makers (Fig. 4.7). When compared to DFO management decisions in general (Fig. 4.6), respondents appear to score the potential utility of ES valuation information lower for their individual work (Fig. 4.7). For the majority of ES, the difference in responses to the two questions is found to be statistically different using both a Mann-Whitney U test, and a Chi-squared test (see Annex A3 for test results).



Notes: See Table 1 for a full description of each MES. The top 10 scored MES are indicated by the dashed line. “Unsure” and missing entries were removed from the percentage distribution resulting in varying n values for each marine ecosystem service (MES); MES are ranked according to the total score, where Likert responses are scored as indicated in the legend. The top 10 MES are found to be scored significantly higher than the next 10 MES under a chi-squared test with alpha<1%.

Fig. 4.6 Canada: Distribution of responses, indicating level of importance of ecosystem service valuation (ESV) for DFO management decisions in general.



Notes: See Table 1 for a full description of each MES. The top 10 scored MES are indicated by the dashed line. "Unsure" and missing entries were removed from the percentage distribution resulting in varying n values for each marine ecosystem service (MES); MES are ranked according to the average score where Likert responses are scored as indicated in the legend. The top 10 MES are found to be scored significantly higher than the next 10 MES under a chi-squared test alpha<1%.

Fig. 4.7 Canada: Distribution of responses, indicating perceived importance of ESV information for respondents' work at DFO.

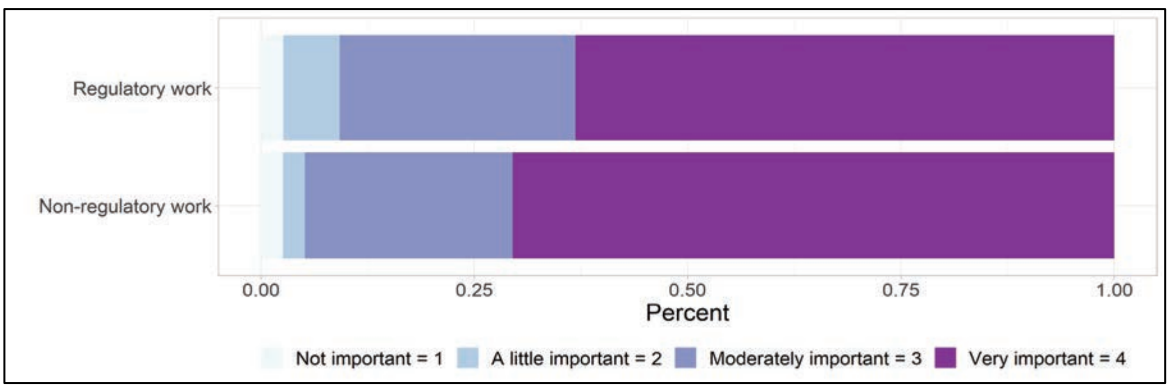


Fig. 4.8 Canada: Respondents' perceived utility of ESV information for regulatory and non-regulatory work.

To understand the specific activities that would benefit from information on ESV, the survey asked respondents to score the potential value of ESV information for regulatory work and non-regulatory work on a 4-point scale from "Very important" to "Not important". Regulatory work was specified to include activities such as Treasury Board submissions, Memoranda to Cabinet, budget proposals, and regulatory analyses (triage statement or Regulatory Impact Analysis Statement). Non-regulatory work was specified to include non-regulatory management, policy products, and research-related products such as those related to Integrated Fisheries Management Plans, aquaculture, habitat activities, recovery strategies, risk assessments, Marine Spatial Planning, Indigenous fisheries programs, infrastructure, Science activities, and policy development. Overall, respondents appeared to perceive ESV information of similar value to regulatory and non-regulatory work (Fig. 4.8). The majority of respondents believed ESV information would be very valuable to both regulatory and non-regulatory activities.

4.2.4.4 Opinions related to ESV

The final part of the survey was opinion questions which asked respondents to indicate their level of agreement with each of ten statements that relate to various issues that could influence use of ESV. A 5-point scale was used for level of agreement ranging from “Strongly agree” to “Neutral” to “Strongly disagree”; additionally respondents could indicate they were “Unsure” of their level of agreement.

Table 4.2 presents the distribution of responses. The statements with the largest level of uncertainty, included statements 3 (“too expensive”), 8 (“time and resource constraints”) and 4 (“best case-by-case”) with 19%, 15% and 14%, respectively, of respondents indicating they were “Unsure.” A majority of respondents agreed (strongly or moderately) with statements 2 (“appropriate”), 9 (“good to evaluate trade-offs”), 5 (“include to greatest extent”) and 8 (“time and resource constraints”) at 84%, 83%, 77% and 61%, respectively. Statement 4 (“best case-by-case”) had only 50% in agreement. A majority of respondents disagreed (strongly or moderately) with statements 7 (“ESV unnecessary”), 10 (“unethical”) and 3 (“too expensive”) at 77%, 69% and 61%, respectively. Two statements related to science, statements 1 (“science too uncertain”) and 6 (“do not know enough about ecosystems”) had more disagreement than agreement, with 50% and 49% disagreeing, respectively.

In general, respondents were not ethically opposed to the use of economic values for ES (statement 10), and were of the opinion that ESV could be appropriate and useful and should be included in decision-making (statements 2, 7, 9, 5) despite potential costs (statement 3). However, there was more uncertainty with regard to the science behind the estimation of ES and ESV (statements 6, 1) and whether ESV should be considered on a case-by-case basis (statement 4), despite general agreement that time and resource constraints would limit systematic use (statement 8).

Table 4.2 Canada: Distribution of opinions related to statements regarding ecosystem service valuation (ESV).

	Statement	Strongly agree (%)	Moderately agree (%)	Neutral (%)	Moderately disagree (%)	Strongly disagree (%)	Unsure/ no opinion (%)
1	The **science** underlying the economic valuation of marine ecosystem services is **too uncertain** to use ecosystem service values in management.	6	14	20	41	9	11
2	Using ecosystem service values is an **appropriate** way to include human use in decision-making.*	28	56	2	5	5	4
3	Estimating the value of ecosystem services is **too expensive** to make the undertaking worthwhile for management.	1	4	16	30	31	19
4	Including ecosystem service values is **best** done on a **case-by-case** basis.	14	36	17	14	6	14
5	Ecosystem service values should be **include**d **to** the **greatest extent** possible when making decisions about the marine environment.	35	42	12	5	4	2
6	We currently **do not know enough about** physical/biological/ecological relationships within **ecosystems** to be able to estimate most ecosystem service values.	14	15	12	37	12	10
7	Current practices are good enough for sound marine management so **ecosystem service values are unnecessary**.	1	1	14	33	44	6
8	**Time and resource constraints** are a large impediment to systematically using ecosystem service values in management.	19	42	15	9	1	15
9	Using ecosystem service values is a **good** way to **evaluate trade-offs** associated with alternative management scenarios.	41	42	7	2	4	4
10	It is **unethical** to put an economic value on ecosystem services.	2	2	15	17	52	11

* Note that this statement differs from that used in the U.S. version of the survey, which used the term "human preferences."

4.2.5 Concluding remarks

While the survey only had a response rate of 25%, the 81 respondents were distributed across a range groups and DFO regions, with the work of respondents influencing most aspects of the work of the Department where ESV may support decision-making; the absence of respondents from the Canadian Coast Guard is a notable exception. While respondents reported more familiarity with the concept of ecosystem services than with the economic valuation of ecosystem services, a majority (55%) reported they were "very" or "moderately" familiar with ESV, suggesting a good knowledge base within the relevant population. While 89% (72) of respondents had experience with ESV and 74% (60) had used them in some context, only 25% had used them in their work at DFO, suggesting potential constraints or a lack of opportunity for ESV implementation within the Department.

Respondents perceived economic valuation information for a wide range of ES to be important to both the work of the Department and their own work; however, the potential importance for all ESV were perceived to be higher to general management than to their individual work. The ESV receiving the top scores for potential utility covered all service categories (*i.e*., provisioning, regulating and supporting, and cultural). While the specific ordering of ES differs between general and individual uses, the top provisioning services include products for consumption (commercial or subsistence) or food production, the top regulating or supporting services include marine habitat, carbon sequestration, and shoreline or coastal buffering, and the top cultural services include wildlife viewing, sport fishing, and indigenous cultural services.

With regard to factors that could influence the use of ESV, in general, respondents were not ethically opposed to the use of economic values for ES. They believed that ESV could be appropriate and useful and should be included in decision-making despite potential costs, even with the uncertainty regarding the science behind the estimation of ES and ESV.

The reach of the survey within DFO was constrained by technical and policy considerations, and the representativeness of the respondents cannot be tested. However, the results of this survey are useful and will inform a number of ongoing projects within DFO, such as the identification of priority ES where additional information on ESV may be most helpful, and longer-term planning for projects to address scientific uncertainties and resource constraints.

4.3 China's marine ESV survey

4.3.1 ESV in marine management and decision making

The Communist Party of China and the Chinese government are striving to build a marine ecological civilization and have formulated some marine environmental policies. Since 1982, China has taken marine management actions such as marine environmental protection, sea area use management, island protection, marine fishery resources management, and comprehensive coastal zone management to curb the deterioration of the marine environment. In 2001, China issued the Outline of the 10th Five-Year Plan for National Economic and Social Development, which called for strengthening the use and management of sea areas. In 2003, the State Council issued the Outline of the National Plan for Development of Ocean Economy, which put forward the key tasks of protecting the marine ecological environment. In 2004, the State Environmental Protection Administration and the National Bureau of

Statistics jointly launched a research project named China's Green National Economy Accounting to account for nature's contribution to the economy. In 2005, general secretary Xi Jinping put forward the idea of "Clear waters and green mountains are as good as mountains of gold and silver", and pointed out that "protecting the ecological environment is to protect productivity, improving the ecological environment is to develop productive forces", and profoundly expounded that good ecological environment contains infinite economic value. In 2006, the Outline of the 10th Five-Year Plan for National Economic and Social Development emphasized realizing integrated marine management and promoting marine economic development. In 2007, the Ministry of Finance and the State Oceanic Administration issued the Notice on Strengthening the Collection and Management of sea area use fees to improve the efficiency of sea area resource allocation. In 2008, the State Council issued the Outline of the National Plan for Marine Industry Development, which put forward specific requirements for the objectives and tasks of marine ecological environment protection. In 2012, the report of the 18th National Congress of the Communist Party of China clarified the establishment of an ecological compensation mechanism. In 2015, the State Council issued the Notice on the Pilot Scheme for Preparing the Natural Resource Balance Sheet, requesting strengthening the statistical investigation and monitoring of natural resources. In the same year, the Central Committee of the Communist Party of China and the State Council issued the Opinions on Accelerating the Construction of Ecological Civilization, which called for in-depth and sustained promotion of the construction of the ecological civilization. In 2019, the State Oceanic Administration revised the Regulations on the Management of Environmental Impact Assessment of Marine Engineering to strengthen the management of environmental impact assessment of marine engineering construction projects. In 2021, the State Council approved the Marine Economy Development Plan during the 14th Five-Year Plan Period, to coordinate and promote the protection and development of marine resources. In 2022, the Marine Ecological Environment Protection Plan during the 14th Five-Year Plan Period was issued to further promote and strengthen marine ecological environment protection. These marine environmental policies may need to incorporate ESV in the decision process.

To better understand decision-makers' understanding of ESV, what value estimates are actually used in the decision-making process, the management areas in which they are used, and the limits to the effective use of ESV in coastal and marine management in China, a nationwide survey was conducted. The survey was used to determine if different ESV are used in different application areas and to identify reasons why economic values may not be considered in the decision-making process.

4.3.2 Survey design and implementation

A detailed analysis of the results of China's ESV survey was published by Li and Wang (2022). This subsection summarizes the main results from the article and reproduces key figures as provided by the first author. For a discussion of the results and suggestions on how to make better use of ESV in policy, please consult Li and Wang (2022).

A questionnaire consisting of five main parts was designed to canvas coastal and marine environmental decision-makers. Annex B provides an English translation of the survey instrument. The first part provides background, including a definition and explanation of marine ecosystem services and the economic valuation of MES, as well as the objectives and potential value of the survey.

The second part examined respondents' perceptions of MES, including provisioning, regulating, cultural and supporting services defined by the Millennium Ecosystem Assessment (MA, 2005), as well as the use values (direct and indirect use) and nonuse values of MES.

The third and fourth parts documented respondents' actual utilization of use and nonuse values in coastal and marine management. The preliminary question in these two sections focused on the extent to which respondents had applied the use and nonuse values of MES. Respondents who indicated they had previously applied use values or nonuse values were asked to choose the management areas in which the values were applied. An additional set of questions was designed to investigate factors that limit the application of use and nonuse values in policy decisions.

The fifth part collected general sociodemographic information and respondents' role and experience in coastal and marine management.

4.3.3 Sampling and response

A preliminary survey was conducted from early October to December 2019 that informed the final survey design. The formal survey was implemented online between July and September 2020. The 227 respondents came from a highly diverse set of organizations with responsibility for coastal and marine management in China, including national management agencies (*e.g.*, Ministry of Ecology and Environment of China, Ministry of Natural Resources of China, and Maritime Safety Administration of China), national research institutes, provincial or local management agencies, and provincial or local research institutes.

4.3.4 Results

4.3.4.1 Respondent characteristics

Respondents were located in 11 coastal provinces (Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Hainan) in the mainland of China and in Beijing (Fig. 4.9 (1)). Fourteen percent of respondents identified their primary role in coastal and marine management decision-making as a top manager, 22% as a middle manager, 26% as a first-line manager, and 38% as a researcher who played a role in decision-making (Fig. 4.9 (2)). Respondents were asked to identify all the management contexts in which they worked. Thirty-seven percent of respondents indicated they worked on marine ecological restoration, 31% on marine ecological conservation and supervision, 26% on marine environmental impact assessment, 16% on marine development strategies, policies and regulations, 15% on marine resource investigation, registration and supervision, 10% on land-use planning and control, and 7% on marine disaster forecasting and monitoring (Fig. 4.9 (3)). The majority of respondents (73%) had more than 10 years of experience in coastal and marine management decision-making (Fig. 4.9 (4)). Additionally, approximately 70% of respondents reported they had a master's degree or above (Fig. 4.9 (5)).

4.3.4.2 Knowledge and use of ESV

Figure 4.10 summarizes the average scores associated with decision-makers' cognition of ecosystem services and their values. A scale which ranged from 1 to 5 ("Don't know", "Only heard of it", "Know it a little", "Know it a lot" and "Know it very well", respectively) was used to indicate awareness of provisioning, regulating, cultural and supporting services (MA, 2005).

Provisioning services were the most widely known service by respondents, followed by cultural services and regulating services, with supporting services the least known. A clear difference was observed between use and nonuse values. Respondents expressed the highest cognitive level with direct use values, with the highest level of awareness for direct use values, followed by indirect use values. Nonuse values had the lowest average score.

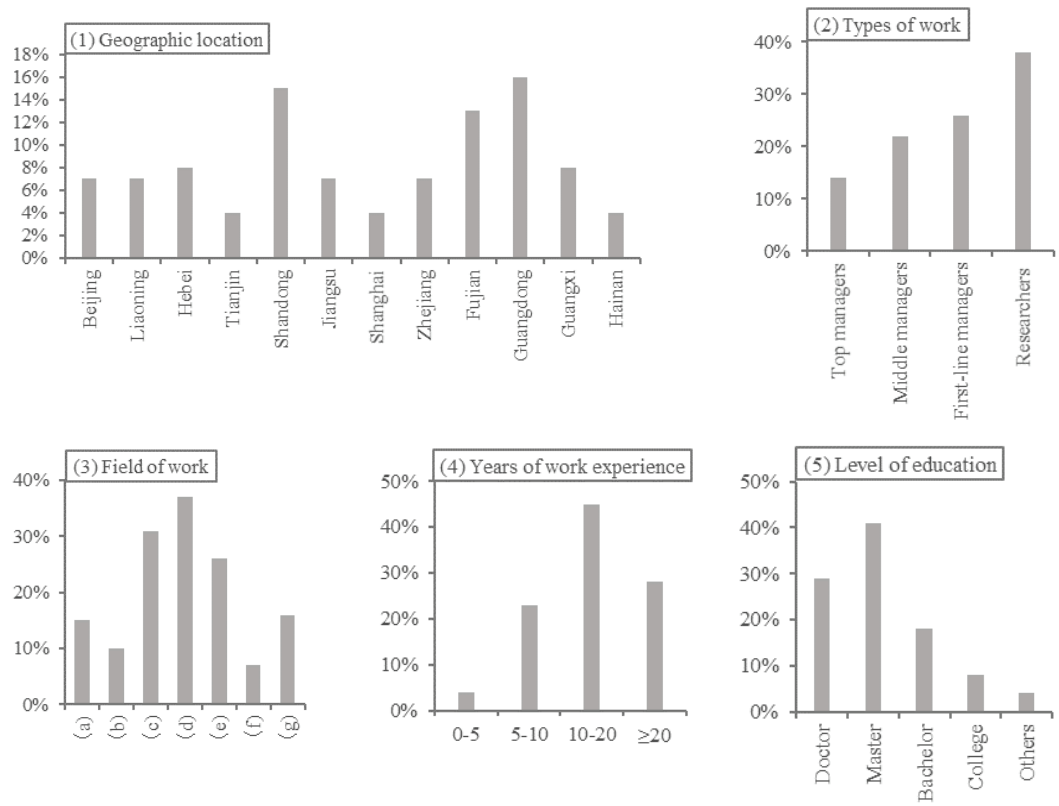


Fig. 4.9 China: Geographic location (1) of the respondents and their characteristics (2–5). (3) Field of work: (a) marine resource investigation, registration and supervision, (b) land-use planning and control, (c) marine ecological conservation and supervision, (d) marine ecological restoration, (e) marine environmental impact assessment (f), marine disaster forecasting and monitoring, (g) marine development strategies, policies and regulations. Source: Li and Wang (2022: p. 5).

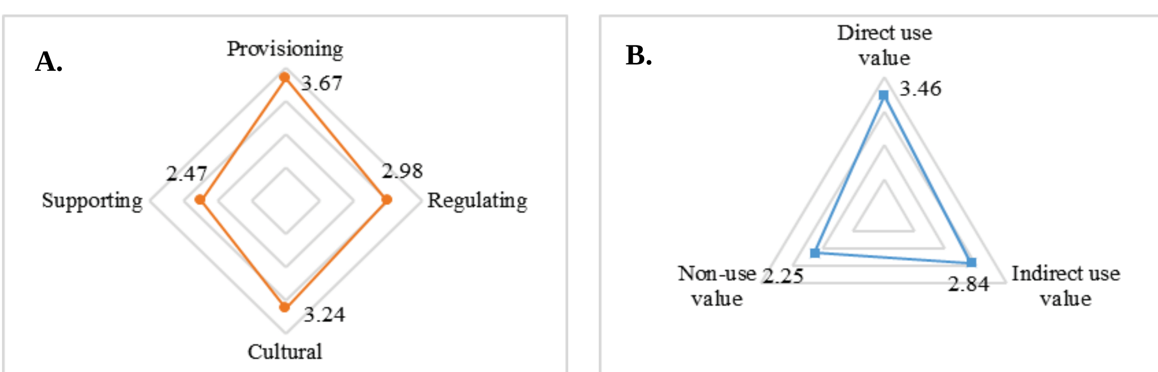


Fig. 4.10 China: Average score of respondents' cognition of coastal and marine ecosystem services by (A) classification and (B) values by type. Source: Li and Wang (2022: p. 5).

Respondents were asked to identify all sources of information for ES and ESV, which included academic lectures (132 respondents), school classes (94 respondents) and professional books (75 respondents). The majority of respondents indicated they thought the use of ecosystem services economic valuation was necessary in coastal and marine decision-making (66% "Very necessary" and 26% "Moderately necessary").

4.3.4.3 Application of ESV

With regard to the application of ESV information in coastal and marine management decision-making process in China, there were differences between use and non-use values (Fig. 4.11). Frequent application of ESV information was 20.70% for direct use values, 17.18% for indirect use values, and 11.90% for non-use values. A substantial share of respondents indicated they had never applied direct use values (38.33%), indirect use values (47.58%) or non-use values (61.20%). Comments from respondents indicated that direct use values are easy to evaluate and utilize in policy-making, and the valuation methods and techniques are mature.

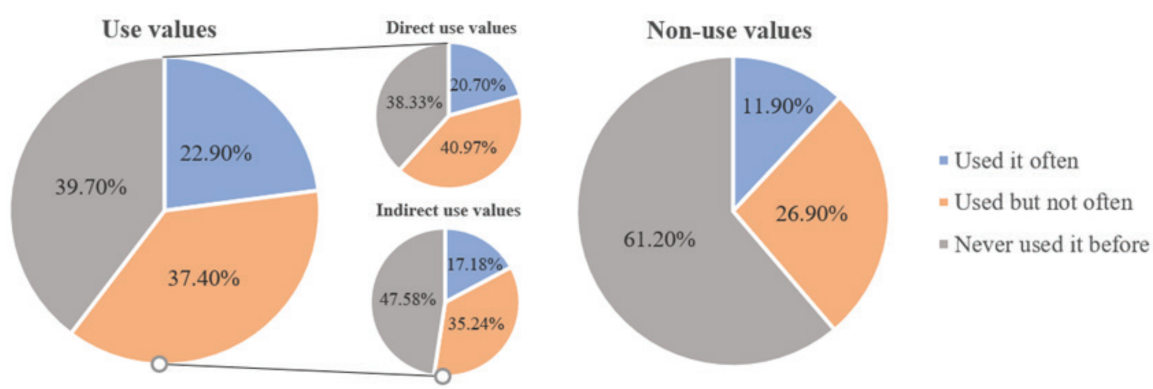


Fig. 4.11 China: Share of respondents who applied direct or indirect use values and nonuse values of coastal and marine ecosystem services in China. Source: Li and Wang (2022: p. 6).

4.3.4.4 How ESV is used

As shown in Figure 4.12, regardless of the management area, the application level of nonuse value information is relatively lower than that of use value information. In addition, both use and nonuse ESV were most frequently applied in an "informative" way than in either a "technical" or "decisive" way. Applications in an "informative" way included use in public education on marine ecological protection (A1), where 36.6% of respondents had applied use values and 20.7% had applied nonuse values. Use and nonuse ESV information was also frequently applied in a "technical" way, while application of use and nonuse value information in a "decisive" way was generally lower than in other applications, although application in environmental impact assessment (EIA) of sea-related engineering construction projects was higher than for several management areas where the application was "technical".

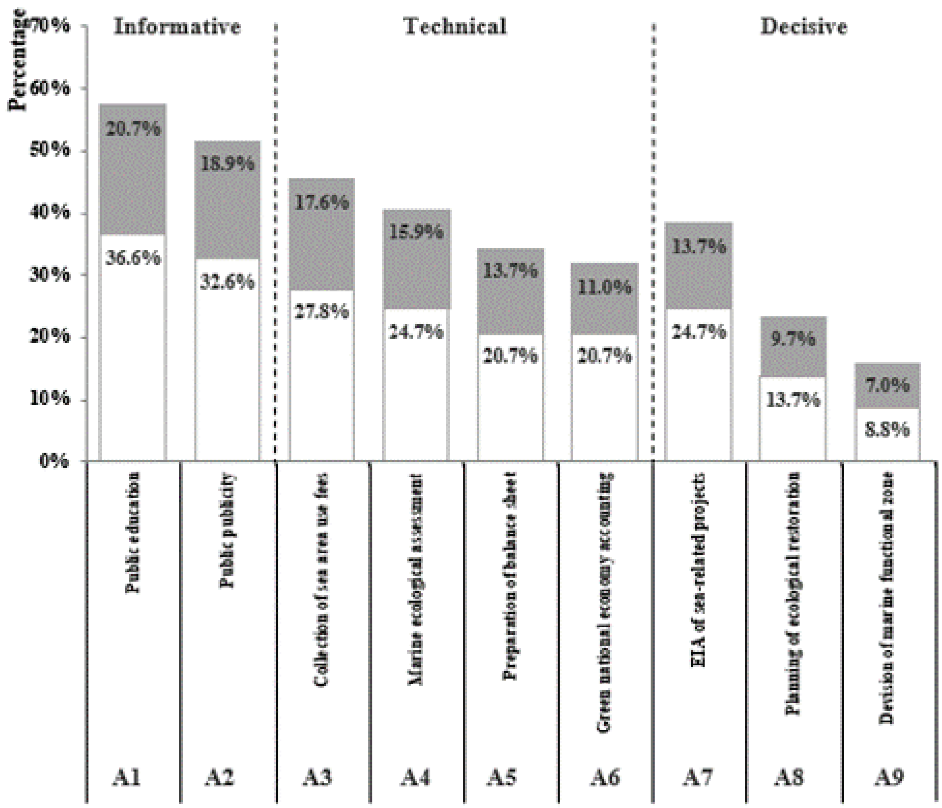


Fig. 4.12 China: Application of use and nonuse values in the nine management areas. White bars refer to management areas of use value information; grey bars refer to management areas of nonuse value information. Source: Li and Wang (2022: p. 7).

4.3.4.5 Factors limiting utilization of nonuse values

Given the limited application of nonuse value information in coastal and marine management in China, econometric models were run to examine the factors that could explain the low utilization. Please see Li and Wang (2022) for details on the methodology and results. As shown in Annex B (Copy of Survey, Part 4, Question 3), respondents were asked for their level of agreement with each of seven statements regarding possible reasons the "…non-use value of marine ecosystem services are rarely applied in marine management decisions" using a Likert scale of 1 to 5 ("Strongly disagree", "Moderately disagree", "Neutral", "Moderately agree", and "Strongly agree", respectively). Based on the results of four separate models, the variables "Science", "Accuracy", "Simplicity" and "Definition" significantly limited the application of nonuse value information in decision-making in China. "Science" representing the science underlying economic valuation of nonuse value is too uncertain; "Accuracy" representing the valuation results of nonuse value are too often inaccurate; "Simplicity" representing economic valuation of nonuse value is too simplistic to give the complex interlinkages between ecosystems and humans; and "Definition" representing the definition and classification of ecosystem services for nonuse valuation is not clear and consistent. Li and Wang (2022) provide a more detailed description of why these variables might limit the application of non-use value information, as represented in literature.

Other variables were not significant, specifically "Preference" and "Ethics" variables which reflect decision-makers' personal opinions of nonuse values, and the "Relevance" variable which is related to job duties.

4.3.5 Concluding remarks

A nationwide survey of what and how ecosystem services economic valuation is used in decision-making processes for the management of coastal and marine ecosystems in China showed: (a) ESV is being used, and while the application level of use value information is relatively high, nonuse value information appears to be rarely used. (b) Both use and nonuse value information was more frequently applied for informative use, followed by technical use, and was less frequently applied for decisive use. (c) Based on modeling results, respondents who had not applied nonuse value information more strongly agreed with statements regarding: uncertain science underlying economic valuation of nonuse values, inaccurate valuation results of nonuse values, the economic valuation of nonuse values being too simplistic to reveal the complex interlinkages between ecosystems and humans, and the lack of clear and consistent definition and classification of ES for nonuse valuation. Li and Wang (2022) provide suggestions on how to make better use of economic valuation of ecosystem services in policy-making.

4.4 USA's marine ESV survey

4.4.1 ESV in marine management and decision making

In the U.S. the 2010 Executive Order 13547 (referred to as the National Ocean Policy) and the National Ocean Policy Implementation Plan (National Ocean Council, 2013) both stress the need to further our understanding of ecosystem services provided by oceans and coasts. This was followed by the U.S. Executive Memorandum M-16-01 (2015), which instructed federal agencies that manage the nation's resources to incorporate ecosystem services into federal decision-making to the extent appropriate and practicable. These policies, coupled with shifts to ecosystem-based management (EBM), in particular the current shift from single-species to ecosystem-based fisheries management (EBFM) (Townsend *et al*., 2019), require information on marine ecosystem services and their values to provide the most comprehensive and efficient guidance in decision-making.

Subsequent to Executive Memorandum M-16-01 and the increasing promotion of frameworks that benefit from ESV information (*e.g.*, EBFM and integrated ecosystem assessment (IEA) frameworks), the Science Advisory Board of the National Oceanic and Atmospheric Administration (NOAA) conducted an assessment of the use and potential use of ESV within the agency (NOAA SAB, 2016). Two of the key findings from the assessment (among others) suggested that the agency should determine (a) whether and how ESV are relevant to different types of decision contexts that occur at different spatial and temporal scales, and (b) how to best integrate ESV as an organic and core part of NOAA's mission, and in what areas this is most appropriate (NOAA SAB, 2016). In response to the Science Advisory Board's recommendations, as well as other science assessments conducted for NOAA, the National Marine Fisheries Service (NMFS), the office of NOAA responsible for the management and stewardship of living marine resources, formed the Ecosystem Services Valuation Working Group (ESVWG) in 2017.

The ESVWG consists of social scientists and economists from NMFS Science Centers and Regional Offices, including the Alaska Fisheries Science Center, Northwest Fisheries Science Center, Northeast Fisheries Science Center, Pacific Islands Regional Office, Southeast Regional Office, and NMFS Headquarters. The group has six primary members and two advisory members. The main working group objectives were to (1) develop a set of standards and best practices for identifying and measuring ecosystem service values in coastal and marine systems, and (2) identify the challenges of systematically including these values in management and determine the most suitable avenues and approaches for their inclusion both in the near-term and longer-term research and management. This subsection describes the fulfillment of the second objective.

4.4.2 Survey design and implementation

To address the second objective of the ESVWG, working group members developed a web-based survey on marine ESV specifically designed for NMFS federal employees. Survey development began in 2018 and occurred during a three-year period. The objectives of the survey were to understand, from the perspective of NMFS staff and leadership, (a) general opinions of and familiarity with ESV, (b) decision contexts that are most appropriate for using ESV, and (c) challenges and opportunities of using ESV in management. Utilizing input from NMFS scientists and policy analysts on the working group and staff in regional offices and science centers, the ESVWG developed an online survey containing three sections and a short introductory video. A brief overview of the survey is below, and the complete survey instrument is contained in Annex C.

Prior to beginning the survey, respondents watched a 40-second introductory video that provided a general overview of marine ecosystem services and described why it was important to participate in the survey.

The first section of the survey asked respondents about their familiarity with the concept of ESV and their experience using ESV in their work.

The second section of the survey asked respondents for their opinions about the utility of ESV for policy, management, and decision-making. Respondents were asked about six categories of ecosystem service values: food sources, non-food material sources, supporting functions, recreational opportunities, social/cultural/religious benefits, and non-use benefits. Each category contained two to six specific services. Respondents were then asked about the utility of ESV for improving specific types of regulatory and non-regulatory analyses and several types of management frameworks (*e.g.*, IEA, Coastal and Marine Spatial Planning [CMSP]). The last set of questions in the section asked respondents about their general opinions about ESV and valuation.

The final section of the survey asked respondents about the type of work they do and the geographic region of focus for most of their work. Respondents were also asked about their highest level of education and the number of years they have worked in the field of marine resources/management.

The survey underwent several reviews by ESVWG members prior to programming for online implementation. After the instrument was programmed, a formal survey review was conducted in the spring of 2019 with staff from each region of NMFS. The survey instrument was revised based on feedback from the NMFS reviewers, and then provided to the North Pacific Marine Science Organization (PICES) Working Group on *Marine Ecosystem Services* (WG 41) for additional review. Feedback from Working Group members was used to further revise the instrument. In September and

December 2021, two high-level briefings were provided to NMFS leadership and key NMFS staff working on EBFM and IEA. Feedback from both briefings was incorporated into the final survey instrument and a survey FAQ document was developed by Working Group members to provide additional information to respondents.

4.4.3 Sampling and response

An email invitation to participate in the survey was sent from the NMFS Acting Science Advisor to all NMFS federal employees (total population size of 2,860) on April 26, 2022. The population includes all federal employees who work at the NMFS regional offices, regional science centers, field offices and labs, and at the headquarters. A follow-up reminder to complete the survey was sent in the last week of May 2022, and the survey closed on June 3, 2022. A total of 672 responses were returned; however, 168 of those returns did not contain any valid responses and were considered unit non-responses. The remaining 505 individuals partially or fully completed the survey for a response rate of 17.66%. These responses are included in the analysis.

4.4.4 Results

Our analysis of survey responses for each question is limited to "item respondents." Item respondents for a given question refer to individuals who answered the question; that is, they did not skip or otherwise not provide an answer to the question. For each question, we note the number of item respondents.

4.4.4.1 Respondent characteristics

Across the 377 item respondents to the questions asking about length of employment, the average respondent had worked in their current position for 12.4 years (median = 10 years) and 15.2 years (median = 14 years) in any marine resource management agency. The average respondent had also worked on marine resource issues for 16.1 years (median = 16 years) and had at least a master's degree (~75% of respondents). The survey included a question to elicit the type of work respondents do in their position, including research in different disciplines, management focused on fisheries, protected species, habitat, or social science, and other positions focused on communications, stakeholder coordination, planning, administrative support, and others. Respondents were able to select more than one of these areas. The nature of work (work function) of survey respondents is summarized in Figure 4.13 (item respondents = 391). For 61% of item respondents, their work involves conducting research, with two-thirds of those in research positions conducting research in biology or ecology (41% of all item respondents) and a smaller number conducting research in economics or other social sciences (10% of item respondents). Seventy-one percent of item respondents indicated that they work in management or policy, which suggests many who conduct research also contribute or work on policy or management activities. Unsurprisingly, the management or policy area in which the most people indicated their work is focused on is related to fisheries (29% of item respondents), with another 21% and 16% working on management and policy related to protected species and habitat, respectively. Twenty-three percent of item respondents indicated being in coordination or planning roles, and 20% indicated working in communication, stakeholder facilitation, or outreach. Twenty percent indicated working in administrative or support roles.

Figure 4.14 presents the breakdown of responses to a question aimed at understanding the geographic areas in which respondents' work was focused. The geographic areas included in the question were New England, Mid-Atlantic, Southeast, Gulf of Mexico, West Coast, Pacific Islands, Alaska, and Great Lakes. In addition, respondents could also indicate if their work was national or international. Respondents were able to select multiple regions if their work was focused in more than one region. Of 387 item respondents, 29% indicated their work was focused on the West Coast (California, Oregon, and Washington), 21% on New England, 17% on Alaska, and 16% each on the Mid-Atlantic and Southeast regions. Lower numbers of item respondents focus on the Pacific Islands (14%), Gulf Coast (11%), Caribbean (4%), and Great Lakes (2%). Sixteen percent of item respondents also indicated their work focuses on national issues, and 11% indicated working on international issues.

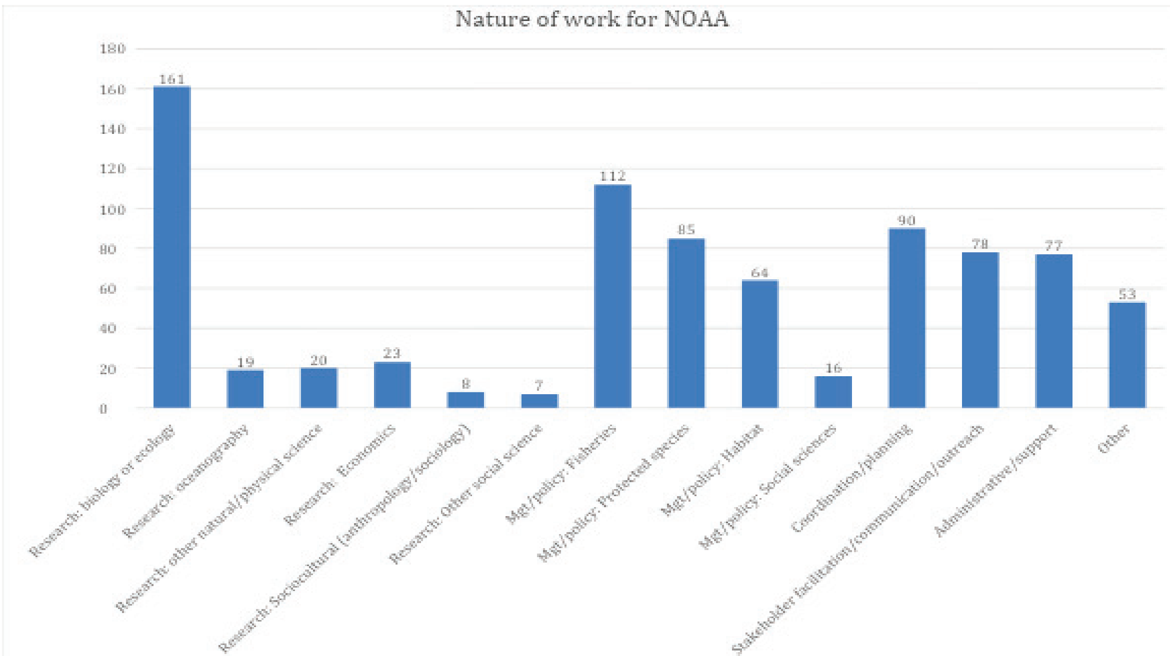


Fig. 4.13 USA: Nature of survey respondents' work. Item respondents = 391. Respondents were able to select all relevant areas for which their work is focused, so the total responses exceeds the number of respondents.

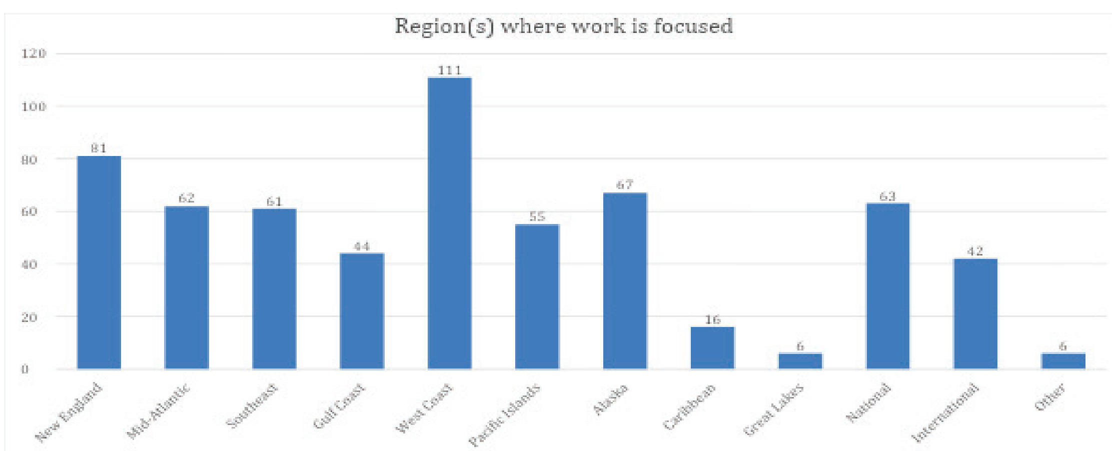


Fig. 4.14 USA: Geographic regions in which respondents' work is focused. Item respondents = 387. Respondents were able to select all regions in which their work is focused, so the total responses exceeds the number of respondents.

4.4.4.2 Familiarity with ecosystem services and ecosystem service values

The first section of the survey asked respondents about their experience and familiarity with ecosystem services and ESV. The concept of ecosystem services was "very familiar" for 37% of all respondents and "moderately familiar" to another 31% (Fig. 4.15). The remaining 32% of respondents were either "only a little familiar" (15%) or "not at all familiar" (17%) with the concept.

Familiarity with the concepts involving the valuation of ecosystem services (ecosystem service valuation and ESV) was less strong overall, relative to the familiarity with the broader ecosystem service concept, with less than 20% indicating they were "very familiar" with the concepts, 34% indicating being "moderately familiar", and 23% indicating not being familiar at all (Fig. 4.16).

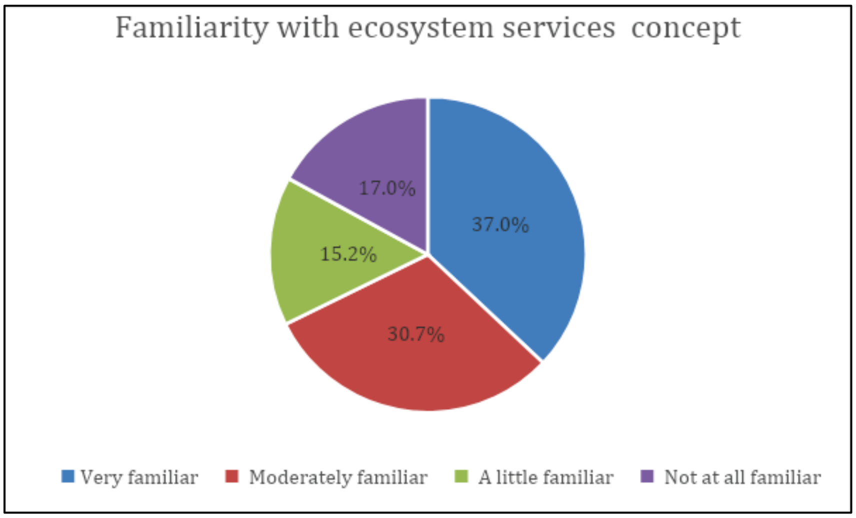


Fig. 4.15 USA: Familiarity with the ecosystem services concept. Total item respondents = 505.

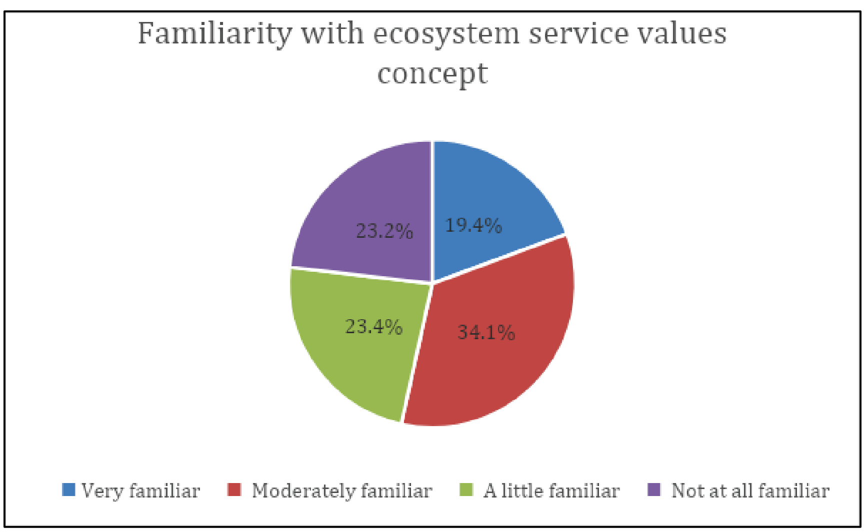


Fig. 4.16 USA: Respondent experience with ecosystem service values (ESV) information. Item respondents = 422.

Only about 8% of respondents (out of 422 item respondents) indicated they conduct research on ESV, but about 31% indicated having used ESV information before and another 33% indicated having discussed or consulted on the use of such information (but not directly involved in the analysis or decision-making where the values would potentially be used) (Fig. 4.17). About 39% indicated not having any experience with ESV information.

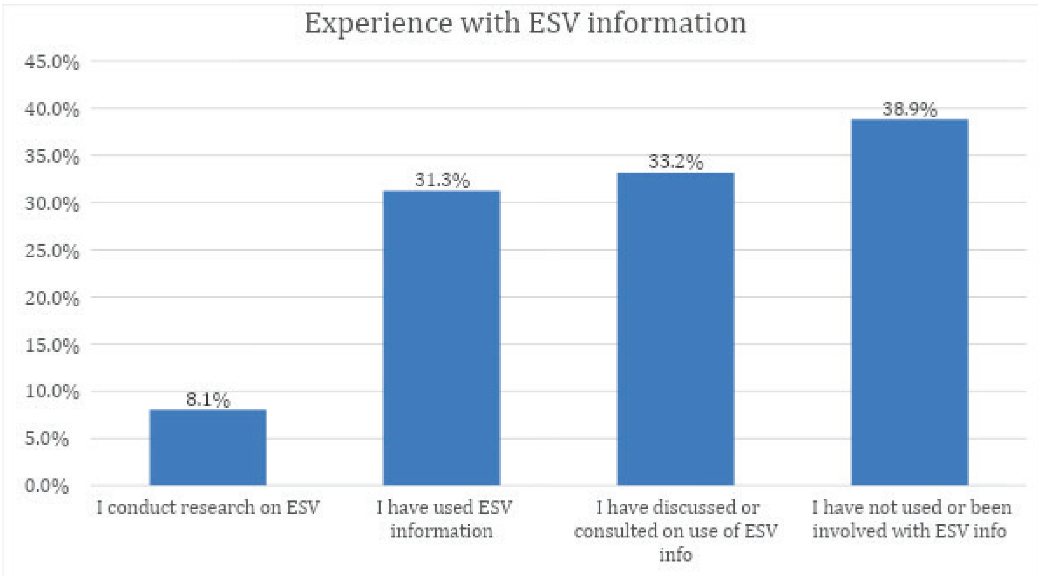


Fig. 4.17 USA: Familiarity with the ecosystem service valuation and/or ecosystem service value concept. Total item respondents = 505.

Two follow-up questions were asked of respondents who have at least some experience with ESV information (*i.e.*, excluding those who indicated “I have not used or been involved with ecosystem service values”). The first question asked for more details about the respondent’s work experience with ESV information. Of the respondents to this question (item respondents = 422), 28% indicated having used ESV information in analyses supporting a management framework (EBFM, management strategy evaluation, coastal and marine spatial planning, integrated ecosystem assessments, *etc*.) and 19% indicated having used ESV information in analyses supporting regulatory or management actions. About 11% of item respondents indicated being involved in research that produces ESV information, 31% indicated they had discussed ESV information only for context in their work, and 20% indicated they had more detailed discussions or initially considered ESV information but ultimately did not use it in analyses (Fig. 4.18).

The second follow-up question asked how useful, in general, ESV information would be to the respondent’s work. Half of respondents to this question (item respondents = 258) indicated that the information would be “very useful”, with another 37% indicating it would be “moderately useful” (Fig. 4.19). Thus, almost 90% of respondents indicated ESV information would be at least moderately useful in their work.

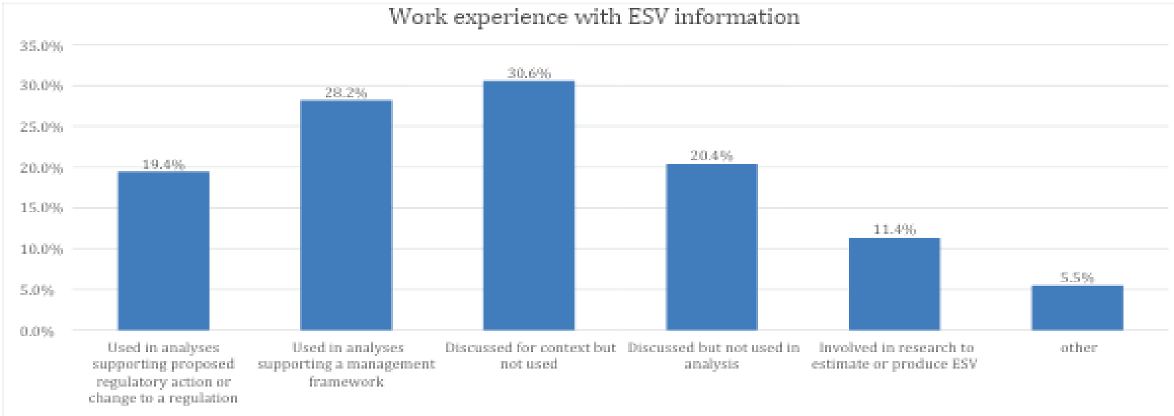


Fig. 4.18 USA: Work experience with ESV information. As respondents were able to select multiple answers, the percentages do not add up to 100%. Item respondents = 422.

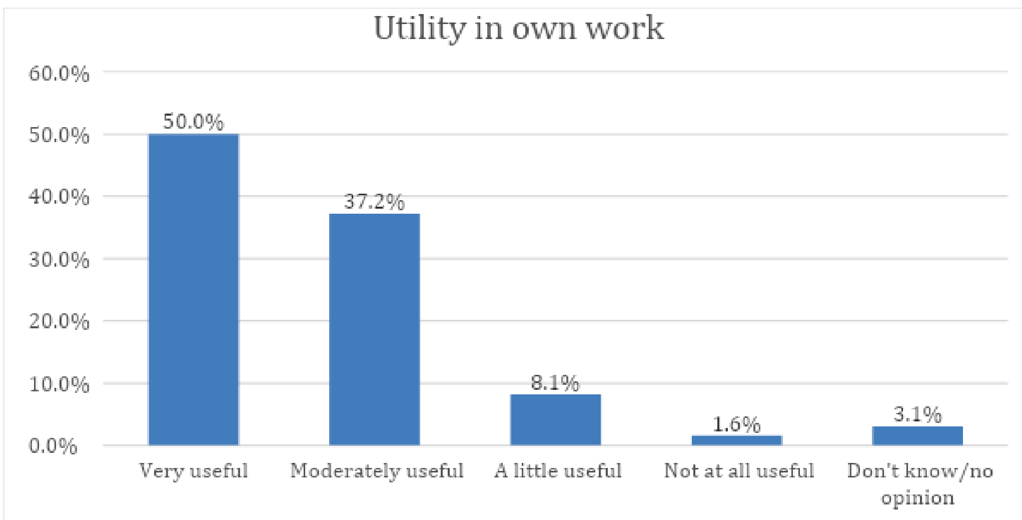


Fig. 4.19 USA: Usefulness of ESV information in respondent's own work. Item respondents = 258.

4.4.4.3 Usefulness of specific coastal and marine ecosystem service values

The second section of the survey elicited opinions about the usefulness of specific coastal and marine ESV for policy, management, and decision-making. This involved asking respondents questions to identify how useful values for specific ecosystem services would be for management and decision-making. The types of ecosystem services asked about were grouped into the Millennium Ecosystem Assessment (MA, 2005) categories of provisioning services (Table 4.3), supporting and regulating services (Table 4.4), and cultural ecosystem services (Table 4.5). The provisioning service category includes food and non-food materials provided by the ecosystem. ESV information on food provisioning ecosystem services (fish and other living marine resources harvested or collected for human consumption), as well as for human production processes (fish and other living marine resources used to produce other food people eat) were viewed as "very useful" by a large majority of respondents

(78 and 69%, respectively, for the 381 item respondents). For both, over 92% of the respondents indicated these values would be at least "moderately useful" for management and decision-making.

Table 4.3 USA: How useful economic value information – in the form of ecosystem service values – is for management and decision-making for specific provisioning ecosystem services.

Type of ecosystem service	Very useful (%)	Moderately useful (%)	Only a little useful (%)	Not at all useful (%)	Unsure/no opinion (%)
Food source (item respondents = 381)					
Fish, other animals, and plants harvested for human consumption via commercial fishing, aquaculture, hunting, and subsistence/artisanal fishing	77.7	15.0	3.4	0.8	3.1
Fish, other animals, and plants used as inputs in human production process (*e.g.*, bait, feed used in agriculture) or other ecosystem production processes (*e.g.*, forage fish)	69.0	23.1	3.7	0.8	3.4
Source of non-food materials (item respondents = 381)					
Minerals, rare earth elements, petroleum/oil, natural gas, and other valuable materials that can be mined, dredged, or harvested	37.0	31.5	14.2	8.4	8.9
Materials needed for, or potentially useful for, medicine or pharmaceuticals	38.1	33.1	17.3	3.4	8.1
Wave, wind, and geothermal energy that can be harnessed (incl. off-shore solar)	51.4	31.0	7.9	2.9	6.8
Fish, other animals, and plants harvested for ornamental use (*e.g.*, aquariums)	29.4	27.8	26.8	8.9	7.1

While non-food provisioning ecosystem service values were also viewed by a majority of respondents as at least "moderately useful", a majority of respondents (51%) indicated that ESV information on ocean and coastal renewable energy services (*e.g.*, off-shore wind and solar) is "very useful." Less than 9% of respondents indicated that the non-food material values were "not at all useful."

At least 80% of respondents indicated that ESV information for supporting/regulating ecosystem services like pollutant filtration, shoreline protection, and storm buffering were at least "moderately useful" for management and decision-making purposes (Table 4.4). Values for shoreline protection and erosion control, and for habitat for coastal and marine plants and animals, had the most respondents indicating "very useful" (75 and 78%, respectively). Values associated with the oceans being used as a medium for transportation (maritime uses) received the lowest support by respondents with less than a third indicating these values would be "very useful."

Table 4.4 USA: How useful economic value information – in the form of ecosystem service values – is for management and decision-making for specific supporting/regulating ecosystem services. Item respondents = 367.

Type of supporting/regulating ecosystem service	Very useful (%)	Moderately useful (%)	Only a little useful (%)	Not at all useful (%)	Unsure/no opinion (%)
Carbon sink (*i.e.*, carbon sequestration)	63.2	22.3	8.4	0.8	5.2
Pollutant filtration and remediation	68.4	22.1	5.2	0.8	3.5
Shoreline protection and erosion control	74.9	16.6	4.1	0.8	3.5
Storm buffering	68.7	22.6	4.4	0.5	3.8
Medium for transportation of goods and people	32.7	35.4	21.8	3.3	6.8
Habitat for coastal and marine plants and animals	78.2	17.4	2.2%	0.3	1.9

Table 4.5 USA: How useful economic value information – in the form of ecosystem service values – is for management and decision-making for specific cultural ecosystem services.

Type of Ecosystem Service	Very useful (%)	Moderately useful (%)	Only a little useful (%)	Not at all useful (%)	Unsure/no opinion (%)
Recreational opportunities (item respondents = 367)					
Water recreation (*e.g.*, scuba diving, snorkeling, swimming, surfing, paddle boarding, kayaking, sailing, motor-boating, *etc*.)	46.6	34.9	12.3	2.5	3.8
Sport fishing opportunities	51.0	33.8	9.0	1.6	4.6
Wildlife and scenic viewing opportunities	51.2	33.5	10.4	1.1	3.8
Onshore/coastal recreation activities (*e.g.*, tide pooling, sunbathing)	42.2	33.5	16.9	3.0	4.4
Social, cultural, and religious benefits (item respondents = 359)					
Cultural heritage	54.3	30.9	10.6	0.8	3.3
Spiritual or religious importance	42.6	33.4	13.9	3.9	6.1
Sense of place/identity	44.8	31.2	16.7	2.5	4.7
Educational opportunities	52.4	32.3	11.4	0.6	3.3
Nonuse benefits (item respondents = 359)					
Existence benefits (knowing that something exists even if it is never visited or used)	39.0	32.6	19.8	3.6	5.0
Bequest benefits (knowing that something will be available for future generations)	49.6	30.6	13.9	2.2	3.6

There were three types of cultural ESV asked about—those associated with recreational opportunities; social, cultural, and religious benefits; and nonuse benefits (Table 4.5). Among recreational ecosystem values, onshore/coastal recreation activities received the lowest support for being useful for management and decision-making (42% of respondents; 367 item respondents). Nevertheless, all four categories (water recreation, sport fishing, wildlife and scenic viewing, and onshore/coastal recreation activities) were at least “moderately useful” to at least 75% of respondents. Likewise, at least 75% indicated that ESV information about social, cultural, and religious benefits are at least “moderately useful” for management and decision-making. A slightly lower percentage of respondents indicated that the ESV information about nonuse benefits, specifically existence benefits, would be at least “moderately useful.” However, ESV information about the other major category of nonuse benefits, bequest benefits, were at least “moderately useful” in the minds of 80% of respondents.

4.4.4.4 Application of ESV information in policy and management

Respondents were asked how useful ESV information would be for a wide variety of policy and management applications, including specific regulatory analyses (Table 4.6), non-regulatory products (Table 4.7), protected species analyses (Table 4.8), ecosystem approaches to management (Table 4.9), and other applications (Table 4.10).

Across a wide range of U.S. regulatory-related analysis types, the majority of respondents indicated that ESV information would be “very useful” (generally greater than 60% of item respondents) with very few respondents (generally less than 1%) indicating that it would not be useful at all. This includes analyses done in support of management or policy decisions pertaining to marine fisheries (*e.g.*, fishery allocations, closures, and catch shares programs), aquaculture (*e.g.*, closures and siting decisions), protected species (*e.g.*, bycatch policies, dam re-licensing and removal, habitat modifications, and critical habitat designations), marine protected areas (*e.g.*, National Marine Sanctuaries designations and regulatory changes), non-fisheries coastal management (*e.g.*, coastal dredging, armoring, and habitat modification), off-shore non-fisheries activities (*e.g.*, energy production, marine mining), and environmental justice assessments. Of these, environmental justice assessment was the application that the lowest percentage of respondents felt ESV information would be “very useful” (58%), and the largest percentage of respondents (72%) indicating “very useful” for protected species-related analyses.

The usefulness of ESV information for non-regulatory products was also assessed. Non-regulatory products were classified into three types: (1) analyses done for program evaluation or internal assessment; (2) analyses done for white papers, research reports, or peer-reviewed publications; and (3) outreach or education materials. Of these, the usefulness of ESV information was highest for the latter two, with about 50% of respondents indicating ESV information would be “very useful” and 31% indicating it would be “moderately useful” for these types of products. For the first type of non-regulatory products, about 13% were unsure or had no opinion about whether ESV information would be useful. At the same time, about two-thirds indicated that they believed ESV information would be at least “moderately useful” for these types of products.

Having ESV information available for different types of protected species analyses was viewed by a majority of respondents as “very useful” with roughly a quarter more believing it would be “moderately useful”. This was fairly consistent regardless of whether the information would be used to inform Endangered Species Act-related analyses, other endangered and threatened species activities (*e.g.*, international agreements), or Marine Mammal Protection Act-related activities.

Table 4.6 USA: Usefulness of including ecosystem service value information in different types of regulatory analyses (EIS, EA, RFA, and similar formal analyses mandated by statute or regulation). Item respondents = 335.

	The inclusion of ecosystem service values would be…				
Type of regulatory analysis	**Very useful (%)**	**Moderately useful (%)**	**A little useful (%)**	**Not at all useful (%)**	**Unsure/no opinion (%)**
Related to any U.S. marine fisheries management/policy decisions (*e.g.*, allocations, spatial and temporal closures, catch shares, essential fish habitat (EFH), *etc*.)	69.6	16.7	7.2	0.6	6.0
Related to U.S. aquaculture management/policy decisions (*e.g.*, area closures, siting and permit decisions, *etc*.)	64.5	20.0	5.4	0.9	9.3
Related to protected species management/policy decisions (*e.g.*, protected species bycatch, area closures, dam re-licensing and removals, habitat modifications, ESA critical habitat designations, *etc*.)	72.8	16.7	6.0	0.3	4.2
Related to marine protected area decisions (*e.g.*, National Marine Sanctuaries designations, regulatory changes, *etc*.)	69.6	17.0	8.1	0.6	4.8
Related to other non-fisheries coastal management decisions (*e.g.*, coastal dredging, armoring, habitat modification, *etc*.)	65.1	23.3	5.4	0.6	5.7
Related to other non-fisheries off-shore activities management decisions (*e.g.*, energy production activities, marine mining operations, marine transportation, *etc*.)	62.1	25.4	5.4	0.9	6.3
Related to environmental justice assessments	58.2	23.6	10.1	1.8	6.3

EIS = Environmental Impact Statement, EA = Environmental Assessment, RFA = Regulatory Flexibility Act, ESA = Endangered Species Act

Broadly speaking, there are a variety of ecosystem approaches to management that NOAA Fisheries has become involved with or initiated in recent years. These include IEA, EBFM, CMSP, climate vulnerability analyses (CVA), and other decision-support tools (particularly ones related to climate change). The use of ESV information in all of these were viewed by a majority (about 60% or more) of respondents as “very useful,” with about 85% of respondents generally indicating ESV information would be at least “moderately useful.”

Table 4.7 USA: Usefulness of including ecosystem service value information in different types of non-regulatory products (policy and research-related products). Item respondents = 335.

	The inclusion of ecosystem service values would be…				
Type of non-regulatory product	**Very useful (%)**	**Moderately useful (%)**	**A little useful (%)**	**Not at all useful (%)**	**Unsure/no opinion (%)**
Non-regulatory analyses (*e.g.*, program evaluations, internal assessments)	31.9	35.5	17.3	2.7	12.5
Science Centers/Labs and NOAA Fisheries HQ analyses (*e.g.*, white papers, research reports, and peer-reviewed publications)	49.3	31.3	10.4	1.8	7.2
Outreach/educational materials	51.3	31.3	11.3	0.9	5.1

Table 4.8 USA: Usefulness of including ecosystem service value information in different types of protected species analyses. Item respondents = 335.

	The inclusion of ecosystem service values would be…				
Type of protected species analysis	**Very useful (%)**	**Moderately useful (%)**	**A little useful (%)**	**Not at all useful (%)**	**Unsure/no opinion (%)**
Endangered Species Act (ESA)-related activities (*e.g.*, developing and evaluating recovery plans, critical habitat designations, and/or ESA consultations)	55.4	23.7	9.2	3.1	8.6
Other endangered and threatened species activities (*e.g.*, international agreements, *etc.*)	51.1	25.2	9.8	1.8	12.0
Marine Mammal Protection Act-related activities (*e.g.*, regulations, spatial/temporal area closures)	54.5	24.6	8.6	2.2	10.2

Table 4.9 USA: Usefulness of including ecosystem service value information in different types of ecosystem approaches to management. Item respondents = 335.

	The inclusion of ecosystem service values would be…				
Type of ecosystem-based management approach	**Very useful (%)**	**Moderately useful (%)**	**A little useful (%)**	**Not at all useful (%)**	**Unsure/no opinion (%)**
Integrated ecosystem assessments (IEAs)	64.0	19.1	3.7	1.2	12.0
Ecosystem-based fisheries management (EBFM)	70.5	16.6	3.7	0.9	8.3
Coastal and marine spatial planning (CMSP)	64.9	20.6	3.7	1.2	9.5
Decision-support tools related to climate change	64.0	19.4	7.1	1.5	8.0
Climate vulnerability analyses (CVA)	59.4	18.5	9.2	2.2	10.8

Table 4.10 USA: Usefulness of including ecosystem service value information in other activities. Item respondents = 322.

	The inclusion of ecosystem service values would be…				
Other activity type	**Very useful (%)**	**Moderately useful (%)**	**A little useful (%)**	**Not at all useful (%)**	**Unsure/no opinion (%)**
Management Strategy Evaluation (MSE)	40.1	23.3	9.0	2.2	25.5
Social-ecological models and coupled human and natural systems (CHANS) frameworks	51.9	18.0	6.2	1.2	22.7
Information, education, or outreach material	51.9	32.3	9.3	1.2	5.3

Respondents were also asked to assess how useful ESV information would be in the application of management strategy evaluation (MSE) models, which are used to evaluate the effects of policy or management changes. Only about 40% indicated that ESV information would be "very useful" in MSE applications, though in total over 63% indicated it would be at least "moderately useful." It should be noted, however, that one-quarter of respondents were unsure or had no opinion on this, which may be indicative that they did not know what MSE is. A similar percentage of respondents were unsure or had no opinion about how useful ESV information would be for application of socio-ecological systems (SES) models and coupled human and natural systems (CHANS) frameworks. However, about 70% of respondents did indicate that ESV information would be at least "moderately useful" in those frameworks. Almost 85% of respondents, however, felt that ESV information would be at least "moderately useful" for education and outreach materials.

4.4.4.5 General opinions about ESV information usage, need, and limitations

The final set of questions asked respondents to indicate the extent to which they agreed or disagreed with 10 statements about ESV information and its usage (Tables 4.11–4.12). Responses were presented on a 5-point Likert scale ranging from "strongly agree" to "strongly disagree". There were 308 item respondents to these questions. Below, we group these questions into two groups: (1) statements regarding the general usage and need for ESV information and (2) statements about limitations and constraints to produce or use ESV information.

A large majority (almost 77%) disagreed with the fourth statement, "Current practices are good enough for sound marine management so ecosystem service values are unnecessary," indicating they do feel like the addition of ESV information could benefit policy and management. However, about 6% agreed with the statement suggesting that the current practices that may ignore ESV information are good enough. Finally, about 73% agreed with the fifth general usage statement, "Using ecosystem service values is a good way to evaluate trade-offs associated with alternative management scenarios." Thus, a large majority of respondents viewed the use of ESV information for evaluating trade-offs positively. This is in contrast to almost 8% who disagreed with it. About 12% neither agreed nor disagreed, and 8% were unsure or had no opinion.

Table 4.11 USA: Likert scale responses to statements about general usage of and need for ESV information. Item respondents = 308.

Statement	Strongly agree (%)	Moderately agree (%)	Neutral (%)	Moderately disagree (%)	Strongly disagree (%)	Unsure/no opinion (%)
Using ecosystem service values is an appropriate way to include human preferences in decision-making	21.1	47.4	16.6	4.5	2.9	7.5
Including ecosystem service values is best done on a case-by-case basis.	9.7	32.8	19.2	19.8	4.9	13.6
Ecosystem service values should be included to the greatest extent possible when making decisions about the marine environment.	33.1	38.3	14.3	6.8	1.6	5.8
Current practices are good enough for sound marine management so ecosystem service values are unnecessary.	2.9	2.9	9.1	36.0	40.9	8.1
Using ecosystem service values is a good way to evaluate trade-offs associated with alternative management scenarios.	29.9	42.9	12.3	3.9	2.6	8.4

The second group of statements address the limitations and constraints for producing or using ESV information. The first statement related to the science underlying the valuation of ecosystem services. The majority of respondents (55%) indicated they disagreed with the statement that "The science underlying the economic valuation of marine ecosystem services is too uncertain to use ecosystem service values in management." About 19% agreed with the statement and almost 11% offered no opinion. About 16% were neutral to this statement, indicating they neither agreed nor disagreed with it. The second statement addressed the concern about the cost of undertaking research to produce ESV information. About 63% of respondents disagreed, and about 8% agreed, with the statement, "Estimating the value of ecosystem services is too expensive to make the undertaking worthwhile for management." Almost 15% were unsure or had no opinion. The third statement, like the first one, related to the underlying science but focused on what is known about the biophysical ecosystem functions and processes necessary to understand ecosystem services. About 50% disagreed, while 26% agreed with the statement, "We currently do not know enough about physical/biological/ecological relationships within ecosystems to be able to estimate most ecosystem service values." An additional 15% were neutral, and 8% had no opinion or were unsure. The fourth statement addressed another potential obstacle to the use of ESV information, time and resource constraints. Fifty-nine percent agreed with the statement, "Time and resource constraints are a large impediment to systematically using ecosystem service values in management." This suggests a majority of respondents viewed using ESV information as a costly endeavor, which may influence whether or not they would actually pursue doing so. About 15% disagreed with the statement and another 15% were unsure or had no opinion. The final statement regarding ESV information concerns whether it is ethical to monetize the benefits of ecosystem services. Seventy-two percent disagreed with the statement, "It is unethical to put an economic value on ecosystem services," while about 10% agreed with it. Thirteen percent were neutral, and 6% were unsure or had no opinion.

Table 4.12 USA: Likert scale responses to statements about ESV information. Item respondents = 308.

Statement	Strongly agree (%)	Moderately agree (%)	Neutral (%)	Moderately disagree (%)	Strongly disagree (%)	Unsure/no opinion (%)
The science underlying the economic valuation of marine ecosystem services is too uncertain to use ecosystem service values in management.	3.9	14.6	15.6	38.3	16.9	10.7
Estimating the value of ecosystem services is too expensive to make the undertaking worthwhile for management.	3.2	4.5	14.6	29.5	33.1	14.9
We currently do not know enough about physical/biological/ecological relationships within ecosystems to be able to estimate most ecosystem service values.	8.4	18.2	15.3	36.7	13.6	7.8
Time and resource constraints are a large impediment to systematically using ecosystem service values in management.	22.4	36.7	11.4	9.1	5.8	14.6
It is unethical to put an economic value on ecosystem services.	4.5	5.2	13.3	25.6	45.8	5.5

4.4.5 Concluding remarks

Several caveats are important to mention for properly interpreting the survey findings and their implications. First, the survey was limited to the population of NOAA Fisheries federal employees. Thus, contractors and grantees who often work side-by-side with federal employees in the agency and who contribute to its mission in important ways were not surveyed. Also excluded were management partners who work at the regional fishery management councils, who are not considered federal employees for the purposes of federal survey data collection. Extending the survey to these non-federal employees, as well as to federal employees in other NOAA line offices (National Ocean Service, Office of National Marine Sanctuaries, National Weather Service, *etc.*) and other federal agencies (USDA, EPA, *etc*.), are being considered for future versions of the survey to get a more complete understanding of how the usefulness of ESV information is viewed beyond NOAA Fisheries. However, the current survey was tailored to collect information from NOAA Fisheries federal employees and should be viewed within this more limited scope.

Second, the extent to which the sample results can be generalized to the population is difficult to assess. Less than 18% of the eligible population of NOAA Fisheries federal employees responded to the survey. Whenever response rates fall below 100%, but especially in cases of low response rates such as the 18% achieved here, non-response bias is a potential concern (Groves, 2006). Non-response bias occurs when respondents to the survey differ in key aspects from non-respondents. This would imply the pattern of responses may differ had the non-respondents' views been collected, suggesting the survey sample is not representative of the population in those aspects. Non-response bias is typically evaluated by comparing auxiliary information known about both respondents and non-respondents, such as demographic or geographic information. When characteristics of respondents and non-respondents are found to differ, the sample results can be weighted based on those observable differences to better reflect the population (*e.g*., Lew *et al*., 2015). This is a fairly common practice in survey research (Brick and Kalton, 1996).

In this survey, however, there is little information about respondents that could be used to assess non-response bias, as anonymity was prioritized to ensure respondents could freely express their views. One potential variable that could be used for the purpose of weighting the survey results is position title, which was collected. However, only 371 of the 550 unit respondents provided this information, which limits our ability to evaluate the extent to which non-response bias may be an issue. While we continue to examine ways of better understanding this issue, the auxiliary data limitations may preclude fully understanding the extent to which non-response bias may be present in the data. Thus, while we do not have a reason to suspect a strong presence of this bias in the survey data, any generalizations of the survey findings presented here should be viewed cautiously. Additionally, any future extensions of the survey should prioritize collection of information that can be used for assessing this issue.

Third, the results presented in this report are for the full sample of respondents only. We leave for future work more detailed breakdowns of responses by respondent types of interest. These include examining how responses differ by type of work performed (research, policy/management, support, communications, leadership, *etc*.), disciplinary area (biologist/ecologist *versus* economist/social scientist), and length of tenure at NOAA Fisheries. A closer examination of the correlation these characteristics have with responses, as well as the correlation between responses provided by individuals, will provide a richer understanding that is beyond the scope of the present report.

And finally, on a related note, there are limits to examining sample-level response distributions for understanding trade-offs between different ecosystem service values and the policy and management settings in which they could apply. For this, an analysis of the patterns of responses individuals make is necessary and left for future research.

While much research remains to be done, and acknowledging the above caveats, the present analysis provides a useful overview of the general trends in views of ESV information and its usefulness in policy and management decision-making contexts. While there was not universal familiarity with the concepts of ecosystem services or ESV, a large majority were at least a little familiar with the concepts. There was also a fairly diverse set of experiences with ESV information, which is unsurprising given the diversity of job responsibilities represented among the survey respondents. Of those with some experience with ESV information, almost all indicated that the information is at least a little useful in their work.

How respondents viewed the utility of ESV information depended in part on the particular ecosystem service in question, with fisheries-focused provisioning ecosystem services, namely the harvest of fish and other living coastal and marine resources for human uses being viewed as particularly useful in policy and management decision-making. Likewise, ESV information about two supporting/regulating ecosystem services, habitat services and shoreline protection and erosion control, were viewed by over 90% as being very useful for policy and management decision-making. Other types of coastal and marine ecosystem services generally scored lower in their perceived usefulness levels, but in almost all cases, ESV information about all ecosystem services were thought to be at least moderately useful to a large majority of respondents (70% and above). Interestingly, ESV information about cultural ecosystem services like recreational, social, religious, and nonuse benefits provided by the ecosystem were viewed as at least moderately useful by three-quarters or more respondents, except for existence benefits, which was slightly lower (about 71%). For some of the ecosystem services for which NOAA Fisheries has a lesser role, like those related to maritime uses for the ocean and non-living resources (*e.g.*, minerals), valuation information was viewed as being less useful. These results are suggestive that most NOAA Fisheries federal employees generally consider ESV information valuable for decision-making in relation to ecosystem services that are of principal concern to the agency.

Views on the usefulness of ESV information to specific types of policy or management-related activities were also enlightening. The results showed that respondents generally viewed this type of information very useful for the main NOAA Fisheries policy and management-related analyses and documents produced. Specifically, about 65% or more respondents believed the inclusion of ESV values in regulatory analyses related to policy or management of marine fisheries, aquaculture, and protected species was very useful. A similarly strong sentiment applied to views of the usefulness of this type of information in ecosystem approaches to management, like EBFM, IEA, and CMSP. This information being used in management strategy evaluations, however, was viewed as useful by a slightly lower percentage of respondents, which could indicate the need for better communication about MSEs and their capabilities for integrating ESV information in a way consistent with CHANS or other SES model frameworks. This was also evidenced by the substantial percentage of respondents who responded "unsure/no opinion" when asked about this. ESV information was also viewed as useful generally for outreach and educational materials and non-regulatory research products.

There was evidence that most respondents believed using ESV information in policy and management processes was appropriate and a useful way of incorporating human preferences and values and facilitating an improved understanding of trade-offs. The results indicated that most respondents believed that the scientific understanding and methods to produce reliable ESV information existed and that the costs of producing this information are outweighed by their utility. There was, however, evidence that most felt that there were time and resource constraints that could impede the incorporation of ESV information in policy and management.

Overall, these results suggest that NOAA Fisheries federal workers are generally aware and supportive of the use of ESV information in a wide variety of applications in which the agency engages, particularly as it relates to ecosystem services of primary interest to the work done by NOAA Fisheries. There appears to be a broad understanding of the importance of using this type of information in policy and management, though support varied across the different types of application settings. Increased education about why, how, when, and in what contexts to apply ESV information could enhance and improve its usage.

Over the past 20 years, NOAA Fisheries has undertaken a number of initiatives aimed at understanding and estimating values for an array of ecosystem services (Lipton *et al*., 2014). Arguably the largest effort has focused on estimating values associated with recreational fin-fishing and shell-fishing, with studies completed in every NMFS management region that provide values for additional harvest, regulatory changes, or other policy attributes of interest in a specific region (examples include Lew and Larson, 2015; Anderson and Plummer, 2016; Lee *et al*., 2017; Carter *et al*., 2020). Additionally, non-use values for protected marine species have been estimated for a number of species under the stewardship of NMFS (examples include Lew *et al*., 2010; Wallmo and Lew, 2012), and values for supporting services such as habitat areas of particular concern (a part of essential fish habitat) have also been estimated (Wallmo and Edwards, 2008). While the recreational fishing program (under NMFS' Marine Recreational Information Program) has a fairly well-developed mechanism for funding studies that generate values needed for policy, values for other ecosystem services have generally been one-off studies, as noted by the Science Advisory Board in their 2016 report on NOAA's use of ecosystem service values. Additional investments in people and projects that generate ESV information for ecosystem services of importance to the agency (as identified in part in this report) are needed to build an inventory of ESV information that informs decision-making and benefits policy and management settings.

4.5 Overall conclusions

Three member countries—Canada, China, and USA—of the PICES Working Group on *Marine Ecosystem Services* (WG 41) conducted surveys to gauge marine and coastal management decision-makers perceptions of ecosystem service values (ESV), application of ESV, and potential constraints to broader application. While the three surveys were similar in design, as they were based on an earlier survey in China and a template shared by the U.S. (NOAA), the survey instrument and implementation of the survey differed in some key ways, and the results are not directly comparable. However, it is striking how similar the results are despite the differences in survey implementation and sample.

The largest implementation of the survey was in the USA where all NOAA National Marine Fisheries Service (NMFS) federal employees were invited to participate in the survey (2,860 population size) with 505 individuals partially or completely completing the survey. In China, survey participants were from a diverse set of management and research agencies and institutes; 227 respondents participated in the survey. Canada had the smallest implementation of the survey, with a non-random sample of 330 intermediate-to-senior level federal employees within the department of Fisheries and Oceans Canada (DFO) invited to participate; 81 invitees completed the survey. China was the first country to complete their survey (2020), followed by Canada (2021) and the U.S. (2022). All three surveys were conducted online, with geographically dispersed participation in each country.

In general, the respondents to the surveys in all three countries were highly educated and had substantial experience working in marine and coastal management and decision-making. In Canada, China, and USA, respectively, 79%, 70% and 75% of respondents had at least a master's degree. Respondents had an average of slightly more than 11 years and 16 years of total experience in Canada and USA, respectively, and 73% of respondents in China had more than 10 years of total experience. Respondents in Canada had significantly less experience in DFO (average of 4 years) than respondents from USA had in NMFS (average of 12 years); similar information is not available for China. The type of work or work function of the respondents differed substantially between Canada and USA, with only 6% of respondents in the survey in Canada indicating research as one of their roles, while 61% of respondents in USA did so; in China 38% of respondents indicated they worked in research.

One of the key objectives of all three surveys was to gauge the level of awareness and application of ESV within marine and coastal decision-making. In terms of familiarity with ecosystem services, 71% and 68% of respondents in Canada and USA, respectively, were at least moderately familiar with ecosystem services. In China, the average level of familiarity was moderate for all types of ecosystem services, ranging from 2.47 for supporting services to 3.67 for provisioning services, with 4 being very familiar.

The level of familiarity with ESV was lower than that for ecosystem services, with 55% and 53% of respondents being at least moderately familiar with ESV in Canada and USA, respectively. In China, the average level of familiarity (on a 5-point scale) was moderate but lower than that for ecosystem services with a range of 2.25 for non-use values to 3.46 for direct use values. In terms of experience with ESV, 89%, 60% and 61% of respondents in Canada, China, and USA, respectively, indicated they had some experience with ESV; for China the value represents use values with experience with non-use ESV lower. In all three countries respondents indicated they used ESV to support a range of activities, including information and analysis, to support decision-making. Canada and USA included questions asking respondents to identify the importance of specific ESV in their work; while the specific services included were similar, they varied to address national needs. While the level of importance varied by ESV and country, for almost all services the majority of respondents in both countries rated ESV information as “very” or “moderately” important to their work; Canada had three ESV (wave and wind energy, onshore recreation, and ornamental species) for which the majority rated the ESV as “a little” or “not at all” important to their work.

Finally, all three surveys included opinion questions related to ESV. Respondents were asked to indicate the level to which they agreed or disagreed with a series of statements related to the use and potential limitations of ESV. The statements in the survey for China focused on non-use values, while the statements in the surveys in Canada and USA did not specify non-use values and instead talked about “ecosystem service values.” The results for Canada and USA were broadly similar, while the responses from the survey in China were analyzed with regression models to identify statements that were significant in the lack of application of non-use values.

The surveys in the three countries had slightly different motivations and recommendations, although in all three cases the intent was to better understand the use of ESV in marine and coastal management decision-making. This objective was met; the next steps should include each country utilizing the survey results to explore feasible and preferable pathways for integrating ESV into decision-making.

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Annex A. Canada – Supplemental Materials

A.1 Transcript of the video participants were asked to review prior to completing the survey

Fisheries and Oceans Canada is sponsoring a survey to understand your opinions about ecosystem service values.

The survey goal is to understand if and how you use these values in your work and your opinions on their utility for decision-making. Although the term “value” has many connotations, for this survey the term refers specifically to economic value. The survey will begin after this short introductory video.

Ecosystem services (ES) are the outcomes of ecosystem structures and functions that provide value to people. Some examples of services provided by coastal and marine ecosystems include provision of food and medicine, buffers from storms or other weather events, aesthetic or inspirational benefits, and habitat for marine life.

The economic value for ecosystem services that are bought and sold in traditional markets is reflected in the price that people pay for the service. An example of this is what people pay for fish and shellfish harvested by commercial fisheries. Other ecosystem services that aren’t traded in markets may still be valuable to humans, yet they don’t possess a traditional market price. An example of this may be wildlife viewing, recreating in marine environments, and protecting for future generations. For services that don’t have a traditional market price, ecosystem service valuation methods have been developed to measure their economic value.

While you may not use or have extensive experience with ecosystem service values, you were selected to participate in this survey due to the nature of your work in marine resource management. Your input is very important and will help inform research and planning related to ecosystem service values at the Department of Fisheries and Oceans Canada.

We appreciate your participation.

A.2 Text of Canada's Survey:

Marine Ecosystem Services Valuation Survey

Thank you for participating in this survey. This survey is meant to assess the knowledge of ecosystem services among DFO staff as well as how frequently this knowledge is applied to DFO business. Please view the introductory video prior to taking this survey.

A reminder that in this survey when we refer to ecosystem service values (ESV) we are referring to economic values for ecosystem services.

Included with this survey is a FAQs which also includes a "cheat sheet" of terms used in this survey _you may wish to have this open as you complete the survey.

Please view the following video on marine ecosystem services before starting the survey (please open on Microsoft Edge):

Link to video on DFO internal drive

Questions marked with a red asterisk (*) are required.
* Required

Section I

The first section is about your experience and familiarity with ecosystem services and ecosystem service values.

1. Before today, how familiar were you with the concept of Ecosystem Services? Check one box *

☒Very familiar

☐Moderately familiar

☐Only a little familiar

☐Not at all familiar

2. What types of ecosystem service values are you familiar with outside of the economic value? Please explain in the text box below.

*REMINDER

From this point on, all discussion and mentions of Ecosystem Service Values (ESV) are in reference to economic values for ecosystem services.

3. Before today, how familiar were you with the economic valuation of Ecosystem Services? Check one box. *

☐Very familiar

☐Moderately familiar

☐Only a little familiar

☐Not at all familiar

4. Which of the following describes your experience with ESVs in a professional setting? Check all that apply. *

☒I have investigated or conducted research on the topic of ESV

☐I have used ESV in my work at DFO

☐I have used ESV in my work elsewhere

☒I have discussed or have been consulted on the use of ESV but was not personally involved in analysis or decision-making related to the value

☐I learnt about ESV in an alternate setting but have not directly applied this knowledge in my work at DFO or elsewhere.

☐I have not used or been involved with ESV

5. In your experience with ecosystem service values, which of the following apply? Check all that apply.

If you choose "other," please briefly explain the circumstances in which ESVs were used.

☐ESVs were used in analyses supporting a proposed regulatory action or change to a regulation (e.g., MPA designation, SARA listing, AIS listing, etc.)

☐ESVs were used in the development of non-regulatory policy (i.e. operational policy or guidance, strategic policy or advice, etc.)

☐ESVs were used in analyses supporting decision-making in a management framework (e.g. Integrated Fisheries Management, Ecosystem Based Management, Marine Spatial Planning, Management Strategy Evaluation, SARA recovery planning, AIS risk assessment, etc.)

☐ESVs were discussed for context for any of the above but not used in the analysis

☐I have not used ESVs

☐Other

6. If you have had experience with economic ecosystem services, please explain what methodologies you used to calculate ecosystem service values in your work.

If you do not have experience with ESV, please skip to the next question

Section II

The second section is about your opinions on the utility of coastal and ocean ecosystem service economic values for regulation, policy, management, and decision-making.

7. In <u>your opinion</u> how useful is it (or would it be) <u>for DFO management decisionmakers</u> to have economic value information - in the form of Ecosystem Service Values for the ecosystem services below? (Check one box for each item)

	Very important	Moderately important	Only a little important	Not at all important	Unsure
Fish, other animals, and plants harvested for human consumption via commercial fishing or aquaculture	☐	☐	☐	☐	☐
Fish, other animals, and plants harvested for human consumption via hunting and subsistence/artisanal fishing	☐	☐	☐	☐	☐
Fish, other animals, and plants used as inputs in human food production process (e.g., food ingredients, bait, feed used in aquaculture/agriculture	☐	☐	☐	☐	☐
Materials needed for, or potentially useful for, medicine or pharmaceuticals	☐	☐	☐	☐	☐
Wave and wind energy that can be harnessed	☐	☐	☐	☐	☐
Fish, other animals, and plants harvested for ornamental use (e.g., aquariums)	☐	☐	☐	☐	☐
Medium for transportation of goods and people	☐	☐	☐	☐	☐
Carbon sink (i.e., carbon sequestration)	☐	☐	☐	☐	☐
Filtration and remediation	☐	☐	☐	☐	☐
Shoreline protection and erosion control	☐	☐	☐	☐	☐
Storm buffering for areas other than shore	☐	☐	☐	☐	☐
Habitat for marine and coastal plants and animals	☐	☐	☐	☐	☐

8. (Continuation of previous question)

In your opinion, how useful is it (or would it be) for DFO management decision-makers to have economic value information - in the form of Ecosystem Service Values - for the ecosystem services below ? (Check one box for each item)

	Very important	Moderately important	Only a little important	Not at all important	Unsure
Water recreation (e.g., scuba diving, swimming, surfing, kayaking, etc.)	☐	☐	☐	☐	☐
Sport fishing opportunities	☐	☐	☐	☐	☐
Wildlife and scenic viewing opportunities (e.g. bird watching, whale watching, etc.)	☐	☐	☐	☐	☐
Onshore/coastal recreation activities (e.g., tide pooling, sunbathing)	☐	☐	☐	☐	☐
Eco-tourism	☐	☐	☐	☐	☐
Cultural heritage	☐	☐	☐	☐	☐
Spiritual, or religious importance	☐	☐	☐	☐	☐
Sense of place/identity	☐	☐	☐	☐	☐
Educational opportunities	☐	☐	☐	☐	☐
Traditional ecological knowledge	☐	☐	☐	☐	☐
Sense of place/identity for Indigenous peoples	☐	☐	☐	☐	☐
Existence benefits (knowing that something exists even if it is never visited or used)	☐	☐	☐	☐	☐
Bequest benefits (knowing that something will be available for future generations)	☐	☐	☐	☐	☐

9. In <u>your current position at DFO</u>, would information on economic values of the following ecosystem services improve <u>your ability</u> to produce valuable information for decision-makers? (Check one box for each item)

	Very important	Moderately important	Only a little important	Not at all important	Unsure
Fish, other animals, and plants harvested for human consumption via commercial fishing or aquaculture	☐	☒	☐	☐	☐
Fish, other animals, and plants harvested for human consumption via hunting and subsistence/artisanal fishing	☐	☐	☐	☐	☐
Fish, other animals, and plants used as inputs in human food production process (e.g., food ingredients, bait, feed used in aquaculture/agriculture	☐	☐	☐	☐	☐
Minerals, rare earth elements, petroleum/oil, natural gas, and other valuable materials that can be mined, dredged, or harvested	☐	☐	☐	☐	☐
Materials needed for, or potentially useful for, medicine or pharmaceuticals	☐	☐	☐	☐	☐
Wave and wind energy that can be harnessed	☐	☐	☐	☐	☐
Fish, other animals, and plants harvested for ornamental use (e.g., aquariums)	☐	☐	☐	☐	☐
Medium for transportation of goods and people	☐	☐	☐	☐	☐
Carbon sink (i.e., carbon sequestration)	☐	☐	☐	☐	☐
Filtration and remediation	☐	☐	☐	☐	☐
Shoreline protection and erosion control	☐	☐	☐	☐	☐
Storm buffering for areas other than shore	☐	☐	☐	☐	☐
Habitat for marine and coastal plants and animals	☐	☐	☐	☐	☐

10. (Continuation of previous question)

In <u>your current position at DFO</u>, would information on economic values of the following ecosystem services improve <u>your ability</u> to produce valuable information for decisionmakers (Check one box for each item)

	Very Important	Moderately important	Only a little important	Not at all important	Unsure
Water recreation (e.g., scuba diving, swimming, surfing, kayaking, etc.)	☐	☐	☐	☐	☐
Sport fishing opportunities	☐	☐	☐	☐	☐
Wildlife and scenic viewing opportunities (e.g. bird watching, whale watching, etc.)	☐	☐	☐	☐	☐
Onshore/coastal recreation activities (e.g., tide pooling, sunbathing)	☐	☐	☐	☐	☐
Eco-tourism	☐	☐	☐	☐	☐
Cultural heritage	☐	☐	☐	☐	☐
Spiritual, or religious importance	☐	☐	☐	☐	☐
Sense of place/identity	☐	☐	☐	☐	☐
Educational opportunities	☐	☐	☐	☐	☐
Traditional ecological knowledge	☐	☐	☐	☐	☐
Spiritual significance/Sacred landscape for Indigenous peoples	☐	☐	☐	☐	☐
Sense of place/identity for Indigenous peoples	☐	☐	☐	☐	☐
Existence benefits (knowing that something exists even if it is never visited or used)	☐	☐	☐	☐	☐
Bequest benefits (knowing that something will be available for future generations)	☐	☐	☐	☐	☐

11. In your <u>opinion</u> how valuable would having reliable information on the economic value of ecosystem services be for improving the following activities within DFO? (Check one box for each item)

	Very valuable	Moderately valuable	A little valuable	Not at all valuable	Unsure/No opinion
Treasury Board submissions, memoranda to Cabinet, budget proposals, and regulatory analyses (i.e. triage statement or Regulatory Impact Analysis Statement (RIAS))	☐	☐	☐	☐	☐
Non-regulatory management, policy products and research related products (e.g. IFMP, aquaculture, habitat activities, recovery strategies, risk assessments, MSP, Indigenous fisheries programs, infrastructure, Science activities, policy development)	☐	☐	☐	☐	☐

12. Please describe any other DFO activities that would benefit from ecosystem service economic values or elaborate on any of the items described above.

13. Please indicate your level of agreement with each of the following statements (Check one box for each item).

A reminder that in this survey ecosystem service values refer to the economic values for any ecosystem services. *

	Strongly agree	Moderately agree	Neutral	Moderately disagree	Strongly disagree	Unsure
The science underlying the economic valuation of marine ecosystem services is too uncertain to use ecosystem service values in management.	☐	☐	☐	☐	☐	☐
Using ecosystem service values is an appropriate way to include human use in decision-making.	☐	☐	☐	☐	☐	☐
Estimating the value of ecosystem services is too expensive to make the undertaking worthwhile for management.	☐	☐	☐	☐	☐	☐
Including ecosystem service values is best done on a case-by-case basis.	☐	☐	☐	☐	☐	☐
Ecosystem service values should be included to the greatest extent possible when making decisions about the marine environment.	☐	☐	☐	☐	☐	☐
We currently do not know enough about physical/biological/ecological relationships within ecosystems to be able to estimate most ecosystem service values.	☐	☐	☐	☐	☐	☐
Current practices are good enough for sound marine management so ecosystem service values are unnecessary.	☐	☐	☐	☐	☐	☐
Time and resource constraints are a large impediment to systematically using ecosystem service values in management.	☐	☐	☐	☐	☐	☐
Using ecosystem service values is a good way to evaluate tradeoffs associated with alternative management scenarios.	☐	☐	☐	☐	☐	☐
It is unethical to put an economic value on ecosystem services.	☐	☐	☐	☐	☐	☐

Section III

The final section will help us understand responses across different types of respondents.

14. Which sector or group do you currently work in at DFO? *

☐Aquatic Ecosystems

☐ Ecosystems and Ocean Science

☐ Fisheries and Harbour Management

☐ Strategic Policy

☐ Coast Guard

☐ Other

15. Under which area does the majority of your work at DFO fall? Check one box. *

☐ Research

☐ Management support

☐ Policy or Science advice

☐ Economic analysis or advice

☐ Policy or program development

☐ Other

16. Which programs, policies, or initiatives within DFO does your work influence? Check all that apply. If you choose other please specify.

☐ Fisheries

☐ Aquaculture

☐ Small craft harbours

☐ Fish and Fish Habitat Program

☐ Species at risk

☐ Aquatic Invasive Species

☐ Marine Spatial Planning

☐ Marine Conservation Targets

☐ Ocean Protection Plan

☐ Indigenous affairs, reconciliation

☐ Trade and international fisheries

☐ Aquatic Climate Change and Adaptation Program

☐ Other

17. In which region of the Canada is your work primarily focused? Check one box *

☐ Arctic

☐ Newfoundland and Labrador

☐ Maritimes

☐ Gulf

☐ Quebec

☐ Ontario and Prairie

☐ Pacific

☐ National Capital

18. How long have you worked in your current position? (years) *

The value must be a number

19. How long have you worked in any marine resource agency? (years)

The value must be a number

20. What level is your current position classified as at DFO? Please choose the most compatible response. If you choose other please specify. *

☐ ADM/RDG

☐ DG/RD

☐ Director

☐ Manager

☐ Senior Analyst/Researcher

☐ Intermediate Analyst/Researcher

☐ Other

21. What is the highest educational level you have attained? Check one box *

☐ Some college, Associate's or Technical Degree

☐ Bachelor's degree (BA, BS, or equivalent)

☐ Master's degree (MA, MS, MBA, MPH, etc.)

☐ Professional degree (JD, MD, DVM, etc.)

☐ Doctorate degree (PhD)

☐ Other

You're Done!

Thank you for taking the time to complete this survey — your responses are appreciated. Please submit your survey response before leaving this page.

22. Please make any additional comments in the box below before submitting your survey response.

A.3 Results testing the difference in response regarding importance of specific ESV for general DFO management compared to individual work

MES	P-value (Mann-Whitney U)	P-value (Chi-squared)
Commercial consumption	0.03 **	0.13
Subsistence consumption	0.02 **	0.09 *
Food production inputs	0.03 **	0.09 *
Mined goods	0 ***	0.01 ***
Medicinal materials	0 ***	0 ***
Wave and wind energy	0 ***	0 ***
Ornamental species	0.01 ***	0.04 **
Transportation medium	0.01 ***	0.04 **
Carbon sink	0 ***	0 ***
Filtration	0 ***	0 ***
Erosion control	0 ***	0 ***
Storm buffering	0 ***	0 ***
Marine habitat	0.01 ***	0.06 **
Water recreation	0 ***	0 ***
Sport fishing	0.02 **	0.04 **
Wildlife viewing	0.01 ***	0.04 **
On-shore recreation	0 ***	0.01 ***
Ecotourism	0 ***	0.01 ***
Cultural heritage	0 ***	0 ***
Spiritual importance	0 ***	0.03 **
Identity	0.01 ***	0.02 **
Educational opportunities	0.01 ***	0.05 **
Traditional knowledge	0.04 **	0.07 **
Indigenous sacred land	0.01 ***	0.01 ***
Indigenous identity	0.04 **	0.04 **
Existence benefits	0.1 *	0.32
Bequest benefits	0 ***	0.02 **

* = significant at 0.1, ** = significant at 0.05, *** = significant at 0.01.

Annex B. English Translation of Survey used in China

The Questionnaire on the use of marine ecosystem services economic valuation for decision making in China

Dear Sir/Madam,

In order to better understand the application of marine ecosystem services economic valuation in management in China, we designed and implemented this questionnaire. The results of this survey are used exclusively for scientific research purposes and are not used for any commercial purposes. The survey is conducted anonymously, which will not have any adverse impact on you personally, and there is no right or wrong answer. Please give a true answer according to your own understanding. Thank you for your cooperation and help!

Part 1 Background information

Ecosystem Services economic Valuation (ESV) can effectively express the usefulness and scarcity of marine ecosystem, as a result, it has been widely recognized by the academic community. In recent years, fruitful valuation results have emerged. However, in the government decision making process, it is still unknown whether the valuation results have become an important reference for actual use. Therefore, our research group designed a questionnaire to investigate how did staffs from the government departments and scientific research institutes understand ESV, and aimed to research on the Use of Ecosystem Services economic Valuation (UESV) in decision making in China.

Part 2 Cognition of marine ecosystem and its service value

1. **The marine ecosystem not only provides an important carrier for the reproduction and evolution of life, but also makes great contributions to the development of human society and economy. Please indicate your understanding of marine ecosystem services:**

	Know it very well—— Don’t know				
Marine ecosystem services is a collection of all effects beneficial to human beings, which is based on the marine ecosystem and its biodiversity and is realized through the ecological process within the system.	5	4	3	2	1
The marine ecosystem has the function of provisioning services, including providing fish, shrimp, crab, algae and other marine food directly for human beings, and providing productive raw materials for food and daily necessities indirectly for human beings, as well as gene resources carried by marine organisms.	5	4	3	2	1
The marine ecosystem has the function of regulating services, including CO_2 fixation, O_2 release, waste disposal, water purification, storm surge protection, etc.	5	4	3	2	1
Marine ecosystem has the function of cultural services, including the unique landscape and aesthetic value of the ocean and the contribution of marine ecosystem to human spirit, art and education.	5	4	3	2	1
The marine ecosystem has the function of supporting services, including the primary production provided by marine plants and microorganisms, the material circulation process to maintain the stability of the ecosystem and generate other services, and the living space and shelter provided by mangroves and coral reefs for other organisms.	5	4	3	2	1

2. **Please indicate your understanding of the type of marine ecosystem services economic valuation:**

	Know it very well—— Don’t know				
The economic value of marine ecosystem services mainly includes use value and non use value.	5	4	3	2	1
Marine ecosystem services have direct use value, including direct use of fishery resources, marine drug raw material resources and other consumptive resource values, and consumption and appreciation of marine scenery, participation in marine entertainment and leisure sports and other non-consumptive resource values.	5	4	3	2	1
Marine ecosystem services have indirect use value, that is, people get indirect benefits from marine ecosystem services and products, including the ecological values of climate gas regulation, storm buffering, human and property security, biodiversity maintenance and habitat provision.	5	4	3	2	1
Marine ecosystem services have non-use value, which is expressed as the existence value of a species, the value of preserving ecosystem services for future generations, or the altruistic value of contemporary people.	5	4	3	2	1

3. **Please provide at least one channel by which to obtain information about marine ecosystem services and their values.**
   - Classes and Lectures
   - Broadcast and television
   - Newspaper or magazine
   - Internet news
   - Others (Please specify)：

4. **Do you think it is necessary to assess the value of marine ecosystem services in marine management decisions?**
   - Very necessary
   - Necessary
   - Moderately necessary
   - Not necessary
   - Not necessary at all

Part 3 Application of use values in coastal and marine management

1. **Has your department used the evaluation results of the use value of marine ecosystem services?**
   - Never used it before
   - Used it before but not often
   - Used it often.

2. **Has your department used the evaluation results of the direct use value of marine ecosystem services (such as food raw material supply and entertainment)?**
   - Never used it before
   - Used it before but not often
   - Used it often.

3. **Which of the following areas does your department use the evaluation results of the direct use value of marine ecosystem services? (Please select at least one item)**
   - Public education of marine ecological protection
   - Public publicity of marine ecological civilization construction
   - Green national economy accounting
   - Collection of sea area use fees
   - Marine ecological compensation
   - Preparation of a marine resources balance sheet
   - Environmental impact assessment (EIA) of sea-related engineering construction projects
   - Planning of marine ecological restoration
   - Division of marine functional zones and marine protected areas

4. **Has your department used the evaluation results of the indirect use value of marine ecosystem services (such as climate gas regulation, water purification, storm surge protection)?**
   - Never used it before
   - Used it before but not often
   - Used it often.

5. **Which of the following areas does your department use the evaluation results of the indirect use value of marine ecosystem services? (Please select at least one item)**
    - Public education of marine ecological protection
    - Public publicity of marine ecological civilization construction
    - Green national economy accounting
    - Collection of sea area use fees
    - Marine ecological compensation
    - Preparation of a marine resources balance sheet
    - Environmental impact assessment (EIA) of sea-related engineering construction projects
    - Planning of marine ecological restoration
    - Division of marine functional zones and marine protected areas

6. **Do you think it is necessary to improve the application level of the use value of marine ecosystem services in marine management decision-making?**
    - Very necessary
    - Necessary
    - Moderately necessary
    - Not necessary
    - Not necessary at all

7. **In the future, how likely do you think that the use value of marine ecosystem services will be used in your management decisions-making process?**
    - Very impossible
    - Impossible
    - Moderately impossible
    - Not impossible
    - Not impossible at all

Part 4 Application of non-use values in coastal and marine management

1. **Has your department used the evaluation results of non-use value of marine ecosystem services?**
    - Never used it before
    - Used it before but not often
    - Used it often

2. **Which of the following areas does your department use the evaluation results of the non-use value of marine ecosystem services? (Please select at least one item)**
    - Public education of marine ecological protection
    - Public publicity of marine ecological civilization construction
    - Green national economy accounting
    - Collection of sea area use fees
    - Marine ecological compensation
    - Preparation of a marine resources balance sheet
    - Environmental impact assessment (EIA) of sea-related engineering construction projects
    - Planning of marine ecological restoration
    - Division of marine functional zones and marine protected areas

3. At present, the evaluation results of non-use value of marine ecosystem services are rarely applied in marine management decisions. Do you agree with the following reasons?

	Strongly agree—— Strongly disagree				
The science underlying economic valuation of nonuse value is too uncertain	5	4	3	2	1
The valuation results of nonuse value are too often inaccurate	5	4	3	2	1
Economic valuation of nonuse value is too simplistic to give the complex interlinkages between ecosystems and humans	5	4	3	2	1
The definition and classification of ecosystem services for nonuse valuation are not clear and consistent	5	4	3	2	1
Decision-makers prefer to make decisions based on other types of information	5	4	3	2	1
It is unethical to put an economic value on marine ecosystem services	5	4	3	2	1
Nonuse value information is not relevant with the management need of decision-makers	5	4	3	2	1

4. Do you think it is necessary to improve the application level of the non-use value of marine ecosystem service in marine management decision-making?

□ Very necessary
□ Necessary
□ Moderately necessary
□ Not necessary
□ Not necessary at all

5. In the future, how likely do you think that the non-use value of marine ecosystem service will be used in your management decisions-making process?

□ Very impossible
□ Impossible
□ Moderately impossible
□ Not impossible
□ Not impossible at all

Part 5 Respondents' Socio-economic Characteristics

1. Your gender：

Man	Woman

2. Your age：

<=18	19～30	31～40	41～50	51～60	>=60

3. Your education level：

Bachelor degree	Master degree or above	Others

4. Your academic background：

Economics	Law	Management	Agronomy	Science	Engineering	Others

5. The type of your work：

Top manager	Middle manager	First-line manager	Researcher

6. Your management field of work：

□ Marine ecological restoration
□ Marine ecological conservation and supervision
□ Marine environmental impact assessment
□ Marine development strategies, policies and regulations
□ Marine resource investigation, registration and supervision
□ Land-use planning and control
□ Marine disaster forecasting and monitoring
□ Others

7. How long have you been working?

Less than 5 years	6 to 10 years	11 to 20 years	More than 20 years

8. Your working area:

Liaoning	Hebei	Tianjin	Shandong	Jiangsu	Shanghai
Zhejiang	Fujian	Guangdong	Guangxi	Hainan	Others

9. Do you have any suggestions on improving the use of ESV results in decision making?

Annex C. Copy of survey instrument used in the United States

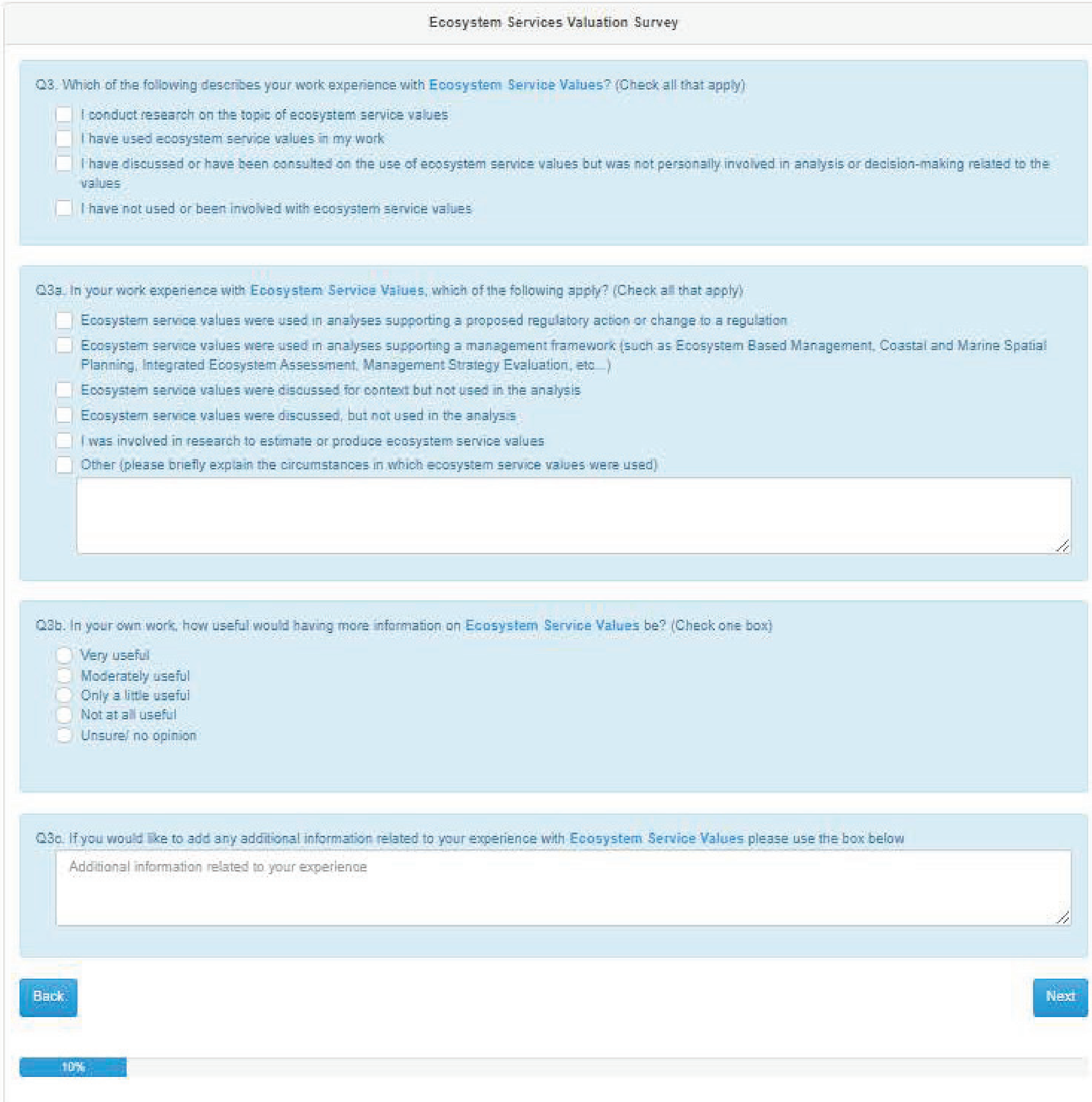
Ecosystem Services Valuation Survey

Welcome to the Ecosystem Services Valuation Survey! You and other NOAA Federal employees have been invited to participate in this survey to help us better understand how those in NOAA view ecosystem services and ecosystem service valuation. Even if your work doesn't directly involve using these concepts (or they are new to you), please take a moment to complete the survey, and thank you for helping NOAA sustainably manage our nation's marine resources.

Questions?

kristy.wallmo@noaa.gov

Start the Survey



Ecosystem Services Valuation Survey

Q3. Which of the following describes your work experience with Ecosystem Service Values? (Check all that apply)

- [ ] I conduct research on the topic of ecosystem service values
- [ ] I have used ecosystem service values in my work
- [ ] I have discussed or have been consulted on the use of ecosystem service values but was not personally involved in analysis or decision-making related to the values
- [ ] I have not used or been involved with ecosystem service values

Q3a. In your work experience with Ecosystem Service Values, which of the following apply? (Check all that apply)

- [ ] Ecosystem service values were used in analyses supporting a proposed regulatory action or change to a regulation
- [ ] Ecosystem service values were used in analyses supporting a management framework (such as Ecosystem Based Management, Coastal and Marine Spatial Planning, Integrated Ecosystem Assessment, Management Strategy Evaluation, etc...)
- [ ] Ecosystem service values were discussed for context but not used in the analysis
- [ ] Ecosystem service values were discussed, but not used in the analysis
- [ ] I was involved in research to estimate or produce ecosystem service values
- [ ] Other (please briefly explain the circumstances in which ecosystem service values were used)

Q3b. In your own work, how useful would having more information on Ecosystem Service Values be? (Check one box)

- Very useful
- Moderately useful
- Only a little useful
- Not at all useful
- Unsure/ no opinion

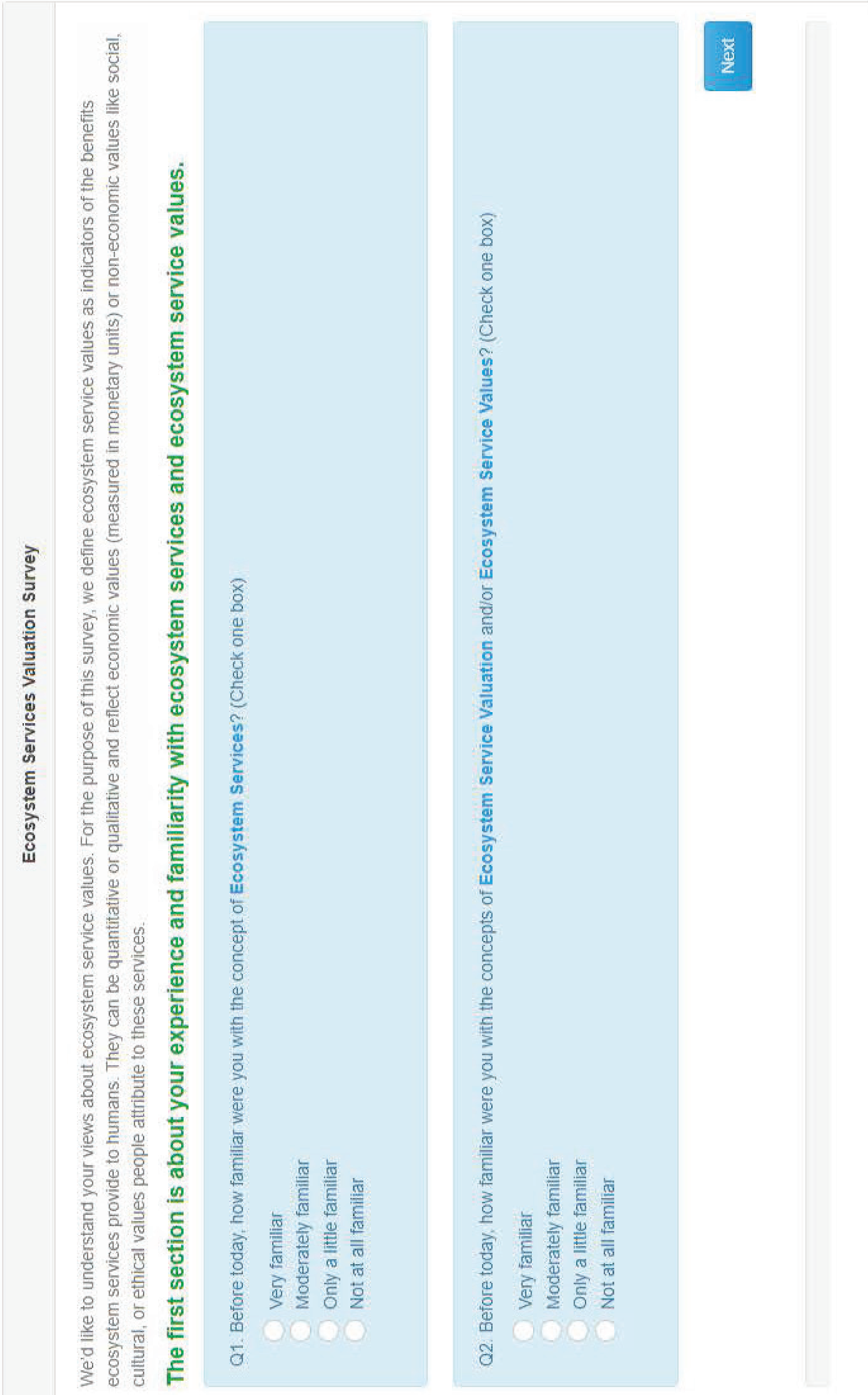
Q3c. If you would like to add any additional information related to your experience with Ecosystem Service Values please use the box below

Additional information related to your experience

Back

Next

10%


Ecosystem Services Valuation Survey

We'd like to understand your views about ecosystem service values. For the purpose of this survey, we define ecosystem service values as indicators of the benefits ecosystem services provide to humans. They can be quantitative or qualitative and reflect economic values (measured in monetary units) or non-economic values like social, cultural, or ethical values people attribute to these services.

The first section is about your experience and familiarity with ecosystem services and ecosystem service values.

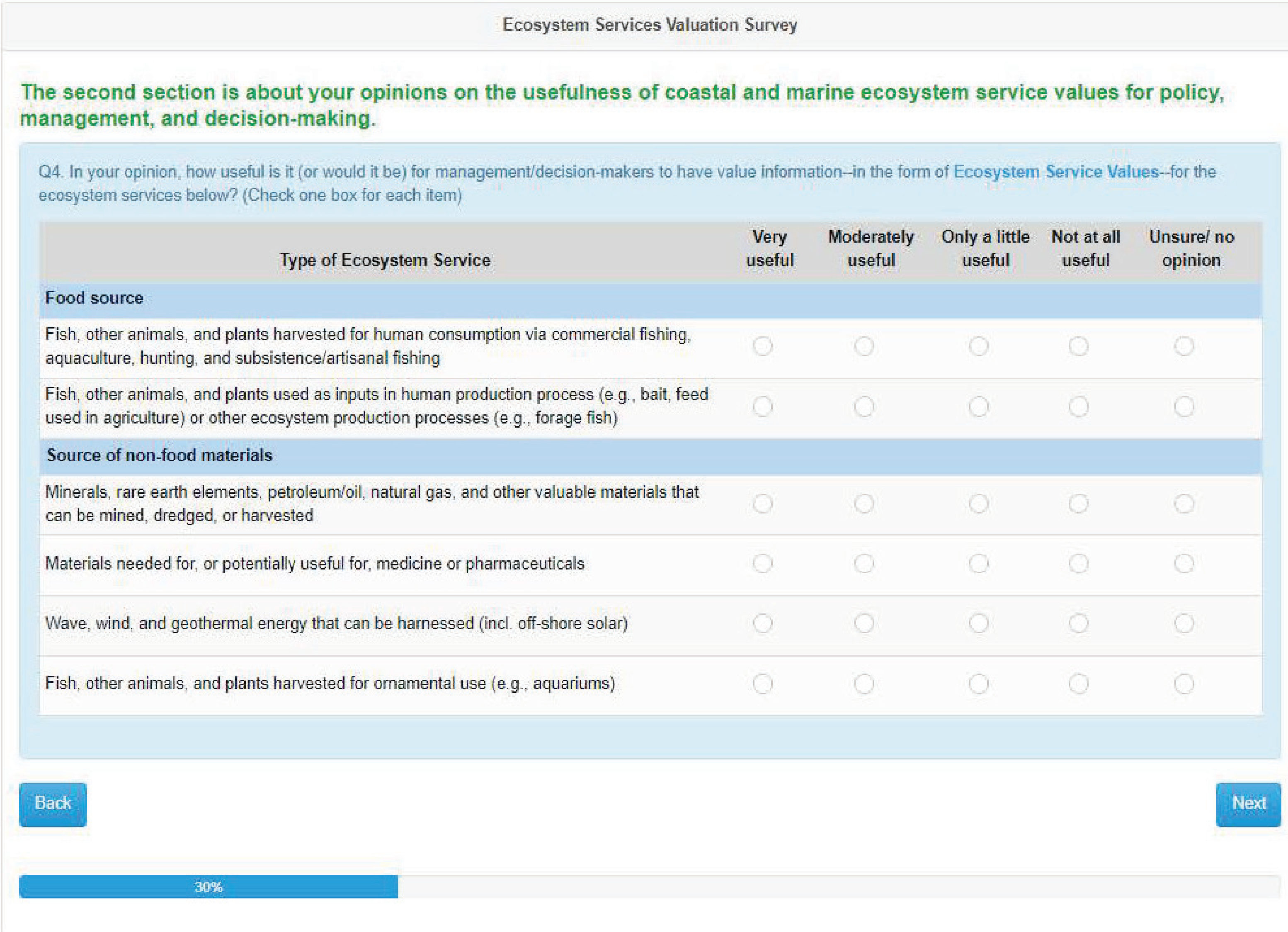
Q1. Before today, how familiar were you with the concept of **Ecosystem Services**? (Check one box)

- Very familiar
- Moderately familiar
- Only a little familiar
- Not at all familiar

Q2. Before today, how familiar were you with the concepts of **Ecosystem Service Valuation** and/or **Ecosystem Service Values**? (Check one box)

- Very familiar
- Moderately familiar
- Only a little familiar
- Not at all familiar

Next



Ecosystem Services Valuation Survey

The second section is about your opinions on the usefulness of coastal and marine ecosystem service values for policy, management, and decision-making.

Q4. In your opinion, how useful is it (or would it be) for management/decision-makers to have value information--in the form of **Ecosystem Service Values**--for the ecosystem services below? (Check one box for each item)

Type of Ecosystem Service	Very useful	Moderately useful	Only a little useful	Not at all useful	Unsure/ no opinion
Food source					
Fish, other animals, and plants harvested for human consumption via commercial fishing, aquaculture, hunting, and subsistence/artisanal fishing	○	○	○	○	○
Fish, other animals, and plants used as inputs in human production process (e.g., bait, feed used in agriculture) or other ecosystem production processes (e.g., forage fish)	○	○	○	○	○
Source of non-food materials					
Minerals, rare earth elements, petroleum/oil, natural gas, and other valuable materials that can be mined, dredged, or harvested	○	○	○	○	○
Materials needed for, or potentially useful for, medicine or pharmaceuticals	○	○	○	○	○
Wave, wind, and geothermal energy that can be harnessed (incl. off-shore solar)	○	○	○	○	○
Fish, other animals, and plants harvested for ornamental use (e.g., aquariums)	○	○	○	○	○

Back Next

30%

Ecosystem Services Valuation Survey

Q4. In your opinion, how useful is it (or would it be) for management/decision-makers to have value information--in the form of Ecosystem Service Values--for the ecosystem services below? (Check one box for each item) [Continued].

Type of Ecosystem Service	Very useful	Moderately useful	Only a little useful	Not at all useful	Unsure/ no opinion
Supporting functions					
Carbon sink (i.e., carbon sequestration)	○	○	○	○	○
Pollutant filtration and remediation	○	○	○	○	○
Shoreline protection and erosion control	○	○	○	○	○
Storm buffering	○	○	○	○	○
Medium for transportation of goods and people	○	○	○	○	○
Habitat for coastal and marine plants and animals (incl. salmon and steelhead)	○	○	○	○	○
Recreational opportunities					
Water recreation (e.g., scuba diving, snorkeling, swimming, surfing, paddle boarding, kayaking, sailing, motor-boating, etc.)	○	○	○	○	○
Sport fishing opportunities	○	○	○	○	○
Wildlife and scenic viewing opportunities	○	○	○	○	○
Onshore/coastal recreation activities (e.g., tide pooling, sunbathing)	○	○	○	○	○

Back

Next

34%

Ecosystem Services Valuation Survey

Q4. In your opinion, how useful is it (or would it be) for management/decision-makers to have value information--in the form of **Ecosystem Service Values**--for the ecosystem services below? (Check one box for each item) [Continued].

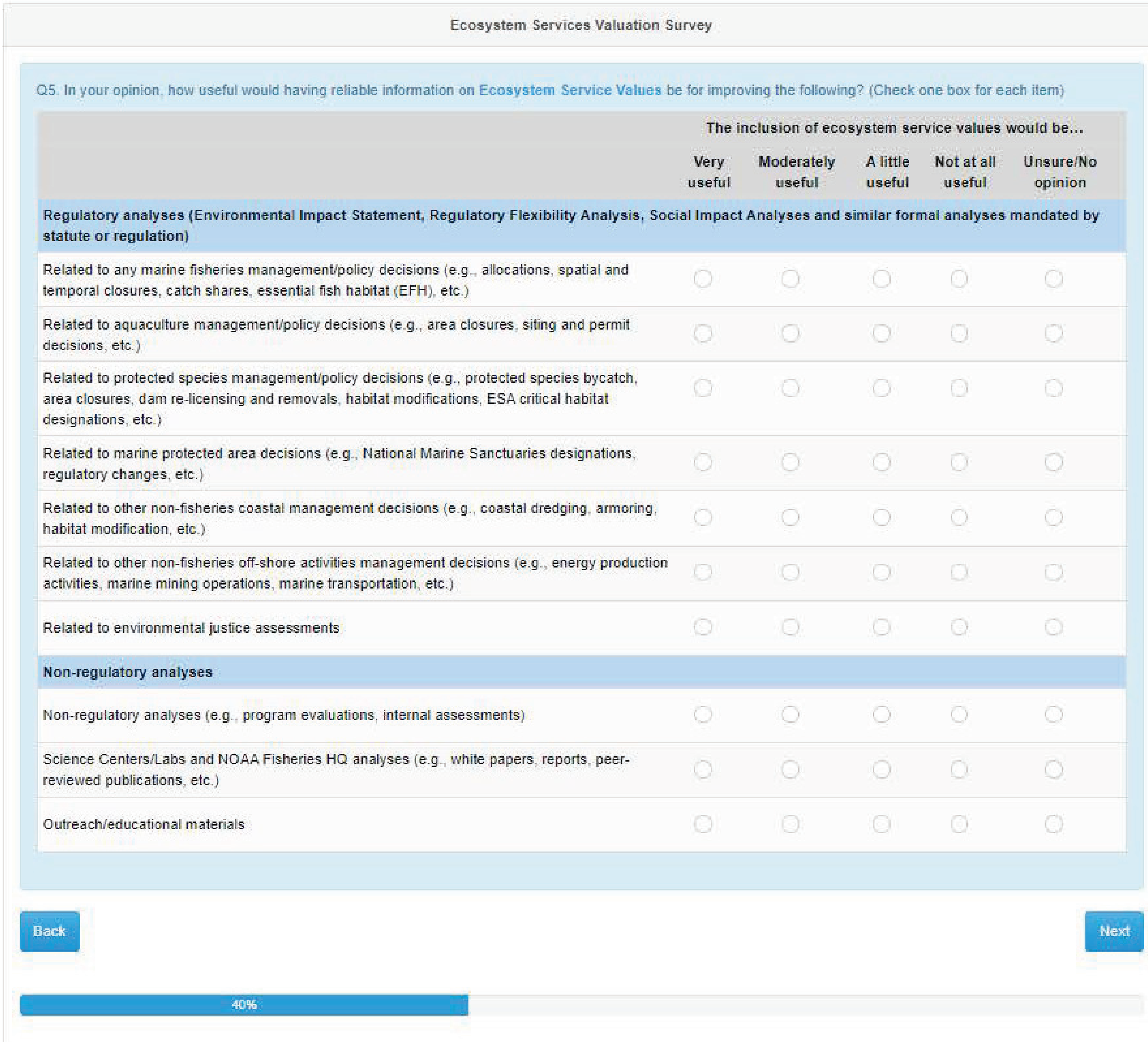
Type of Ecosystem Service	Very useful	Moderately useful	Only a little useful	Not at all useful	Unsure/ no opinion
Social, cultural, and religious benefits					
Cultural heritage					
Spiritual or religious importance					
Sense of place/identity					
Educational opportunities					
Nonuse benefits					
Existence benefits (knowing that something exists even if it is never visited or used)					
Bequest benefits (knowing that something will be available for future generations)					

Q4a. Please list any other coastal and marine **Ecosystem Service Values** that you feel are important for management or decision-making purposes:

List any other coastal and marine ecosystem service

Back Next

36%



Ecosystem Services Valuation Survey

Q5. In your opinion, how useful would having reliable information on Ecosystem Service Values be for improving the following? (Check one box for each item)

	The inclusion of ecosystem service values would be...				
	Very useful	Moderately useful	A little useful	Not at all useful	Unsure/No opinion
Regulatory analyses (Environmental Impact Statement, Regulatory Flexibility Analysis, Social Impact Analyses and similar formal analyses mandated by statute or regulation)					
Related to any marine fisheries management/policy decisions (e.g., allocations, spatial and temporal closures, catch shares, essential fish habitat (EFH), etc.)	○	○	○	○	○
Related to aquaculture management/policy decisions (e.g., area closures, siting and permit decisions, etc.)	○	○	○	○	○
Related to protected species management/policy decisions (e.g., protected species bycatch, area closures, dam re-licensing and removals, habitat modifications, ESA critical habitat designations, etc.)	○	○	○	○	○
Related to marine protected area decisions (e.g., National Marine Sanctuaries designations, regulatory changes, etc.)	○	○	○	○	○
Related to other non-fisheries coastal management decisions (e.g., coastal dredging, armoring, habitat modification, etc.)	○	○	○	○	○
Related to other non-fisheries off-shore activities management decisions (e.g., energy production activities, marine mining operations, marine transportation, etc.)	○	○	○	○	○
Related to environmental justice assessments	○	○	○	○	○
Non-regulatory analyses					
Non-regulatory analyses (e.g., program evaluations, internal assessments)	○	○	○	○	○
Science Centers/Labs and NOAA Fisheries HQ analyses (e.g., white papers, reports, peer-reviewed publications, etc.)	○	○	○	○	○
Outreach/educational materials	○	○	○	○	○

Back

Next

40%

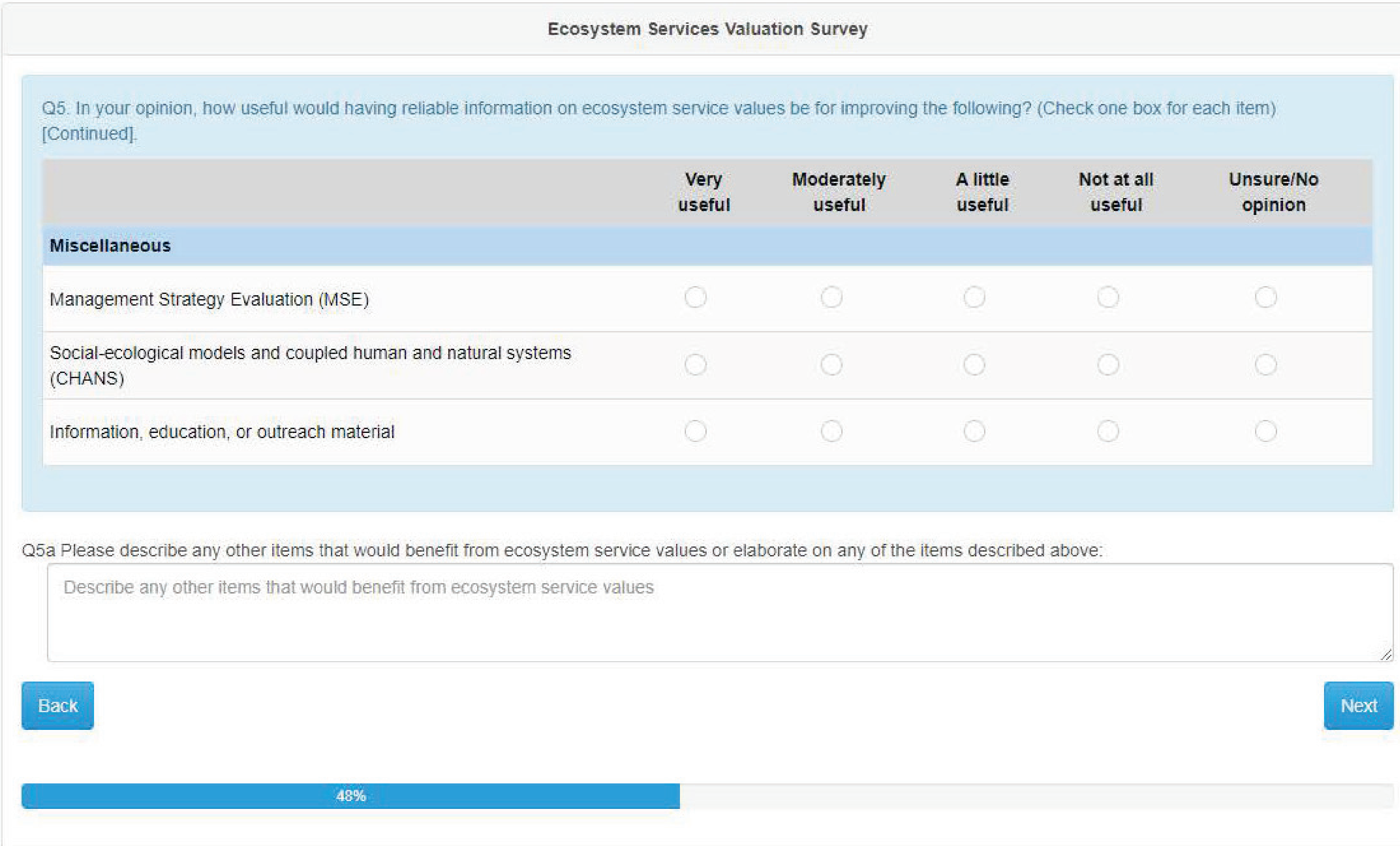
Ecosystem Services Valuation Survey

Q5. In your opinion, how useful would having reliable information on ecosystem service values be for improving the following? (Check one box for each item) [Continued].

	Very useful	Moderately useful	A little useful	Not at all useful	Unsure/No opinion
Protected species analyses					
Endangered Species Act (ESA)-related activities (e.g., developing and evaluating recovery plans, critical habitat designations, and/or ESA consultations)	○	○	○	○	○
Other endangered and threatened species activities (e.g., international agreements, etc.)	○	○	○	○	○
Marine Mammal Protection Act-related activities (e.g., regulations, spatial/temporal area closures)	○	○	○	○	○
Ecosystem approaches to management					
Integrated ecosystem assessments (IEAs)	○	○	○	○	○
Ecosystem-based fisheries management (EBFM)	○	○	○	○	○
Coastal and marine spatial planning (CMSP)	○	○	○	○	○
Decision-support tools related to climate change	○	○	○	○	○
Climate Vulnerability Analyses (CVA)	○	○	○	○	○

Back Next

44%



Ecosystem Services Valuation Survey

Q5. In your opinion, how useful would having reliable information on ecosystem service values be for improving the following? (Check one box for each item) [Continued].

	Very useful	Moderately useful	A little useful	Not at all useful	Unsure/No opinion
Miscellaneous					
Management Strategy Evaluation (MSE)	○	○	○	○	○
Social-ecological models and coupled human and natural systems (CHANS)	○	○	○	○	○
Information, education, or outreach material	○	○	○	○	○

Q5a Please describe any other items that would benefit from ecosystem service values or elaborate on any of the items described above:

Describe any other items that would benefit from ecosystem service values

Back

Next

48%

Ecosystem Services Valuation Survey

Q6. Please indicate your level of agreement with each of the following statements (Check one box for each item):

	Strongly agree	Moderately agree	Neutral	Moderately disagree	Strongly disagree	Unsure/no opinion
The science underlying the economic valuation of marine ecosystem services is too uncertain to use ecosystem service values in management.	○	○	○	○	○	○
Using ecosystem service values is an appropriate way to include human preferences in decision-making.	○	○	○	○	○	○
Estimating the value of ecosystem services is too expensive to make the undertaking worthwhile for management.	○	○	○	○	○	○
Including ecosystem service values is best done on a case-by-case basis.	○	○	○	○	○	○
Ecosystem service values should be included to the greatest extent possible when making decisions about the marine environment.	○	○	○	○	○	○
We currently do not know enough about physical/biological/ecological relationships within ecosystems to be able to estimate most ecosystem service values.	○	○	○	○	○	○
Current practices are good enough for sound marine management so ecosystem service values are unnecessary	○	○	○	○	○	○
Time and resource constraints are a large impediment to systematically using ecosystem service values in management.	○	○	○	○	○	○
It is unethical to put an economic value on ecosystem services.	○	○	○	○	○	○
Using ecosystem service values is a good way to evaluate trade-offs associated with alternative management scenarios.	○	○	○	○	○	○

Back Next

50%

Ecosystem Services Valuation Survey

The final section will help us understand responses across different types of respondents.

Q7. Which of the following do you do for your work at NOAA or the Fishery Management Council? (Check all that apply)

- Research: biology or ecology
- Research: physical or chemical oceanography
- Research: other natural or physical science
- Research: economics
- Research: socio-cultural (e.g., anthropology or sociology)
- Research: other social science
- Management and/or policy analysis: fisheries
- Management and/or policy analysis: protected species
- Management and/or policy analysis: coastal or marine habitat
- Management and/or policy analysis: social sciences
- Coordination/planning
- Stakeholder facilitation/communication/outreach
- Administrative/support
- Other (please specify)

Back Next

60%

Appendix 1

WG 41 Terms of Reference

WG 41 term: 2017–2020
Extended 1 year to 2021
Parent Committee: FUTURE SSC

1. Review MES studies of North Pacific marine ecosystems, identifying the scientific tools and methodologies employed, and the role these studies have played in policy analyses, management, or natural resource damage assessment.
2. Develop a typology of marine ecosystem services, tools and methodologies (*e.g.*, environmental accounting/natural capital, non-market values, replacement cost/Natural Resource Damage Assessment, productivity change methods, *etc*.) that can be used to analyze marine ecosystem services, and the strengths and weaknesses of those tools and methodologies.
3. Illustrate (2) by applying two or more methods to the assessment of marine ecosystem services in identical case studies in multiple regions of the North Pacific.
4. Collaborate with WG 36 (Common Ecosystem Reference Points) and WG 40 (Climate and Ecosystem Predictability) to explore development of an indicator-based framework to study the resilience of social ecological systems and to advance integration envisioned in the FUTURE science program.
5. Complete a detailed technical report on the results of the analyses detailed in TORs (1), (2), and (3) and scoping requested in (4). The report should include practical recommendations for characterizing the status and trends of marine ecosystem services in the North Pacific. In addition, the WG will contribute articles on ecosystem services to PICES Press.

Appendix 2

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Appendix 3

Workshop/Session Summaries and Meeting Reports from Past Annual Meetings Related to WG 41

PICES-2017
September 22–October 1, 2017, Vladivostok, Russia

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2017

HD Workshop (W2)
Coastal ecosystem services in the North Pacific and analytical tools/methodologies for their assessment

Co-Convenors: *Shang Chen (China), Mitsutaku Makino (Japan), Daniel K. Lew (USA), Minling Pan (USA, Sebastian Villasante (Spain)*

Background

Coastal ecosystem services are the benefits people obtain from the coastal ecosystem. These services include seafood, regulation of climate, reduction of storm impacts, waste assimilation, recreation and leisure, and biodiversity maintenance. The identification, quantification, and valuation of ecosystem services and understanding the impacts of human activities and climate change on ecosystem services are key scientific questions. The ecosystem services-based approach to marine ecosystem management is a new approach meant, in part, to enhance human well-being. The goals of this workshop were: (1) to present research that enhances understanding of the interactions between human activities and ecosystem services; (2) to provide a venue for natural scientists and social scientists to exchange results from research on identification, assessment, management and investment of ecosystem services, and (3) to provide Study Group on *Marine Ecosystem Services* (SG-MES) members and scientists around the North Pacific an opportunity to discuss collaboration on scientific projects within the North Pacific Ocean. This workshop made an important contribution to a greater understanding of the status of human dimensions of the North Pacific ecosystem and filled some gaps to achieve the objectives outlined by the FUTURE integrative science program.

Summary of presentations

This ½-day workshop arranged 5 high quality presentations and was chaired by Dr. Shang Chen. A total 14 people, including Dr. Hiroaki Saito (Science Board Chair) and Dr. Keith Criddle (HD Chair) attended this workshop. Three oral presentations were presented followed by in-depth discussion. Professor Jingmei Li made a report on the assessment of ecological damages from land reclamation. She pointed out the increasing amount of land reclamation in China and its negative impact on resources and marine ecosystems. She noted that assessing marginal ecological damage costs incorporated into management will prevent operators from conducting reclamation. There were two methods to choose from to evaluate environmental costs. Then, based on the choice of experiment method, the loss of ecological benefits caused by wetland reclamation in Jiaozhou Bay was analyzed. Results showed that the change of wetland area is the first most important concern of local residents, followed by improvement in water quality. Based on these concerns, the government should make a proper restoration policy in which enlarging the wetland area should be the key priority. Dr. Shang Chen presented his study on marine ecological services capital assessments. First, he introduced some basic concepts on marine ecological capital (MEC), such as MEC value and Marine Ecosystem Services (MES). Then he described his assessment methods for evaluating standing stock of marine living resources and marine ecosystem services which have been issued as a national standard in China. The Chinese coastal ecosystem provided 1,034 billion CNY of ecosystem services in 2008, which supported 1,740 billion CNY of marine industrial products. His studies showed that the service value decreased from onshore to offshore, with high value in maricultured and tourism areas, and that service value depended highly on utilization methods. Finally, the MES theory can be used as one of the principles to make functional zoning and marine development planning, as assessment indicators of marine management effectiveness and blue economic policy, as a baseline of eco-compensation or payment for ecosystem service policy. Kazumi Wakita talked about what influences people's value of marine ecosystem services and their motivation for conservation. Dr. Wakita's study took an interdisciplinary approach that combined environmental economics and social psychology in examining relationships between people's value of marine ecosystem services and factors which influence their value, using responses to a questionnaire from 945 residents in Japan. The analysis reveals that the groups of respondents with a higher willingness to pay (WTP) to conserve marine ecosystem services have higher public spirit and stronger connections with other people and invisible things such as spirits. On the other hand, the groups of free riders who have no WTP to conserve marine ecosystem services have lower public spirit and weaker connections with others, both humans and nonhumans. The respondents' degree of support for the theory of global warming caused by an increase in carbon dioxide and that for forecasting the increase of carbon dioxide did not seem to influence their WTP. Considering that the scenario provided to the respondents was about the status of marine ecosystem services in the next 100 years, the respondents' WTP can interpreted as representing a kind of altruism.

List of papers

Oral presentations

Valuing the loss of ecological benefits of wetland reclamation in Jiaozhou Bay based on choice experiments
Jingmei Li, Qi Chen

Marine ecosystem services assessment methods
Shang Chen, Wei Liu, Tao Xia and Linghua Hao

What influences people's value of marine ecosystem services: A case study of Japan
Kazumi Wakita, Hisashi Kurokura, Taro Oishi, Zhonghua Shen, and Ken Furuya

PICES-2018
October 25–November 4, 2018, Yokohama, Japan

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2018

HD Workshop (W8)
Taking stock of Marine Ecosystem Services in the North Pacific - Exploring examples and examining methods

Convenors: *Shang Chen (China), Daniel K. Lew (USA)*

Background

The purpose of this workshop was to advance understanding of the character and value of marine ecosystem services under the aegis of the Working Group on *Marine Ecosystem Services* (WG 41/WG-MES). Participation by local scientists was encouraged. The main tasks of this workshop included: (1) reviewing MES studies from the North Pacific region; (2) identifying gaps in understanding the status and trends of MES in North Pacific region; (3) developing a draft typology of marine ecosystem services and various approaches and methods for assessing those services and their value.

Summary of presentations

On Saturday, October 27, 2018, The Working Group on *Marine Ecosystem Services* (WG 41) convened a workshop (W8) on "Taking stock of marine ecosystem services in the North Pacific–Exploring examples and examining methods." The workshop was a half-day in length and included presentations and an extended discussion. The workshop was co-convened by Dr. Dan Lew (USA) and Dr. Shang Chen (China) and was sponsored by the HD committee. Dr. Chen was unable to attend the workshop in person, so it was chaired by Dr. Lew, who provided an introduction that included a statement of the workshop goals, history and purpose of the WG, and some additional background material on marine ecosystem services. There were 12 attendees, including four presenters and five WG 41 members (Lew, Wallmo, Li, Sugimoto, and Dudas).

Originally, six presentations were scheduled, but two were cancelled at the last minute. The remaining four presentations included presentations by the following:

Yousuke Fujii presented on the effects of changes in kelp farming practices in the Fukushima region of Japan. Prof. Jingmei Li presented a study to assess the recreational and ecological damages from green algae tides in Jiaozhou Bay in China. Dr. Kristy Wallmo presented a survey of researchers, managers, and policy analysts and other staff working on topics related to marine ecosystem services who work within entities involved in fishery management in the U.S. (*e.g.*, NOAA Fisheries and Regional Fishery Council staff). Dr. Dan Lew presented an evaluation of the stated preference valuation literature valuing marine ecosystem services

Following the presentations, the speakers and participants engaged in a discussion about challenges related to ecosystem service valuation (ESV), principally scale (small region, state, nation, *etc*.), double counting of values across ESV, and what ESVs should be valued (final outcomes *vs.* intermediate ones). Challenges to the validity of MES value information resulting from non-market valuation methods were discussed, as was the literature to develop best practices for minimizing biases associated with the methods. Events like the Deepwater Horizon oil spill were discussed as events that had driven general research and science on MES valuation, but the difficulty of industry-sponsored research as an unbiased source of MES information was also acknowledged.

List of papers

Oral presentations

Labor situation of kelp farmers and the change in farming practice
Yousuke Fujii

Ecological damage assessment of green tide blooms based on double-bounded dichotomous bias correction model
Jingmei Li, Jingzhu Dan

Challenges and opportunities for using ecosystem service values in NOAA Fisheries
Kristy Wallmo and Daniel K. Lew

Marine ecosystem service values and valuation in the U.S.: An assessment of the literature through the lens of recent best practice guidelines
Daniel K. Lew, Leif Anderson, Doug Lipton, Tammy Murphy, and Kristy Wallmo

Poster presentations

Economic value of ecosystem services and utility of coastal fisheries in Indramayu, Indonesia
Takaaki Mori, Ayumi Kanaya, Naoki Tojo, Mitsutaku Makino, Mark Wells, Vladmir Kulik, Joon-Soo Lee, Shion Takemura, Charles Trick, Chang-an Xu, Suhendar Sachoemar

HD Topic Session (S9)
Integration of science and policy for sustainable marine ecosystem services

Convenors: *Shang Chen (China), Daniel K. Lew (USA), Jungho Nam (Korea)*

Background

The provisioning, cultural, regulating and supporting services are the major benefits people obtain from the coastal and marine ecosystems. The identification, quantification, valuation and management of ecosystem services are key scientific questions, and have attracted more concerns from both the major intergovernmental organizations (such as PICES, ICES, IMBeR, IPBES) and the environmental organizations (such as WWF, TNC, ESP). The goals of this session were: (1) to provide a venue for marine scientists and social scientists to exchange results from research on identification, quantification, valuation and management of ecosystem services, and (2) to provide a platform to share and discuss the integration of ecosystem service science into policy-making of marine affairs. This session will continue providing strong support to the TORs of the HD committee and contribute a greater understanding of social and economic status of the North Pacific ecosystem and fill the gaps to achieve the FUTURE Objectives.

Summary of presentations

On Tuesday, October 30, 2018, the Working Group on *Marine Ecosystem Services* (WG-MES) convened a 1-day topic session on “Integration of science and policy for sustainable marine ecosystem services.” Co-Convenors, Dr. Shang Chen (China) and Jungho Nam (South Korea) were unable to attend, so the session was chaired by Dr. Dan Lew (USA), who provided an introduction that included a description of the session and its goals and introductory material on marine ecosystem services. The session was well-attended, with 30+ people in the morning session and about 25 in the afternoon session. Thirteen speakers were originally scheduled to give presentations, but three cancelled and one that was expected did not show up. Following the morning presentations, the presenters and audience engaged in a discussion about challenges related to ecosystem-based management (EBM), including challenges in the measurement of values (economic as well as cultural ones), challenges to engaging indigenous peoples in the EBM process, and other key topics. The afternoon presentations resulted in extended discussions during the question and answer time for each speaker.

List of papers

Oral presentations

Arctic Council and Ecosystem Approach to Management: Integrating ecosystem service science into guidelines
Elizabeth Logerwell, Hein Rune Skjoldal

Evolution of district marine policies in China: The case of Shandong Province
Meng Su, Ying Yang

Vulnerability to impacts of climate change on marine fisheries and food security
Qi Ding, Xinjun Chen, Ray Hilborn and Yong Chen

Environment and culture in an island community: some insights for re-building the framework of cultural ecosystem service
Aoi Sugimoto

Study on eco-compensation mechanism based on valuation of ecosystem services in Marine Protected Areas
Keliang Chen, Yuliang Li, Heng Liu

Estimating the potential of Japanese fisheries: Upside bioeconomic analysis
Gakushi Ishimura, Kanae Tokunaga, Shigehide Iwata, Keita Abe, Jennifer Couture, Merrick Burden, Kristin Kleisner, Rod Fujita, Kazuhiko Otsuka

Maritime spacial planning in Russia: Problems and prospective
Iana Blinovskaia, Elena Mazlova

Crafting science-based ocean policy for sustained ecosystem services: balancing place, people, and profits
Franklin B. Schwing

Using choice models to assess the economic value of large marine protected areas off the U.S. west coast
Kristy Wallmo and Rosemary Kosaka

Poster presentations

Preliminary analysis of the Jimo coastal ecosystem with the Ecopath model
Meng Su

The value of ecosystem services of the West Bering Sea
Artyom Y. Tadzhibaev, Olga N. Lukyanova

Report of Working Group on *Marine Ecosystem Services*

The PICES Working Group on *Marine Ecosystem Services* (WG 41/WG-MES) conducted its first business meeting on October 27 and 28, 2018, at PICES-2018 in Yokohama, Japan. Dr. Dan Lew presided over the meeting as interim Co-Chair. Dr. Shang Chen is the other interim Co-Chair but was unable to attend in person but attended portions of the meeting through Skype. Five working group members were in attendance (***WG 41 Endnote 1***). In addition to WG 41 members in attendance, members of other working groups with which WG-MES anticipates working with participated. Specifically, Dr. Jongseong Ryu (South Korea) of WG 36 and Dr. Caihong Fu (Canada) of WG 40 were in attendance and both indicated an enthusiasm for the Working Group's activities and willingness to contribute actively to the group's projects.

Participants of the first meeting of WG 41 at PICES-2018 in Yokohama, Japan. Back row, from left: Alan Haynie, Shang-Yuan Teng, Jingmei Li, Meng Su, Caihong Fu, Yosuke Fujii; front row, from left: Kristy Wallmo, Sarah Dudas, Dan Lew, Aoi Sugimoto. Missing from photo: Shang Chen who participated by Skype.

AGENDA ITEMS 1 AND 2
Welcome/introductions and adoption of agenda

The meeting began with a welcome from Dr. Lew. This was followed by introductions from those in attendance, a review of the proposed agenda, and a vote to adopt the meeting agenda (***WG 41 Endnote 2***).

AGENDA ITEM 3
Background

Dr. Lew presented some background information on the origins of the Working Group, its purpose and terms of reference, and other background information about marine ecosystem services (MES) intended to help frame subsequent discussion.

AGENDA ITEM 4
WG nominations of co-chairs

Dr. Lew and Dr. Chen outlined the process for appointment of PICES Working Group co-chairs and how the Working Group would need to vote for individuals who would be put forward from the Working Group as suggested co-chairs. Dr. Lew and Dr. Chen had previously been identified as potential co-chairs. Additional nominations were requested via e-mail prior to the meeting and requested again during the meeting, but there were no additional nominations. The working group member countries in attendance voted unanimously for Dr. Dan Lew and Dr. Sunny Chen to be co-chairs.

AGENDA ITEM 5
Review of Terms of Reference and identification of key tasks

Dr. Lew walked through each of the WG 41 terms of reference (TOR) – see https://meetings.pices.int/members/working-groups/wg41. The TOR had been sent to Working Group members prior to the meeting as well.

The specific tasks outlined in the Terms of Reference were the following:

(1) **Review MES studies of North Pacific marine ecosystems**, identifying the scientific tools and methodologies employed, and the role these studies have played in policy analyses, management, or natural resource damage assessment.
(2) **Develop a typology of marine ecosystem services, tools and methodologies** (*e.g.*, environmental accounting/natural capital, non-market values, replacement cost/Natural Resource Damage Assessment, productivity change methods, *etc*.) that can be used to analyze marine ecosystem services, and the strengths and weaknesses of those tools and methodologies.
(3) **Illustrate (2) by applying two or more methods to the assessment of marine ecosystem services in identical case studies** in multiple regions of the North Pacific.
(4) **Collaborate with WG 36 (Common Ecosystem Reference Points) and WG 40 (Climate and Ecosystem Predictability)** to explore development of an indicator-based framework to study the resilience of social ecological systems and to advance integration envisioned in the FUTURE science program.
(5) **Complete a detailed technical report** on the results of the analyses detailed in TORs (1), (2), and (3) and scoping requested in (4). The report should include practical recommendations for characterizing the status and trends of marine ecosystem services in the North Pacific. In addition, the WG will contribute articles on ecosystem services to PICES Press.

AGENDA ITEM 6
Development of proposed projects

The group engaged in a lengthy discussion about how to complete the tasks outlined in the TOR. Ultimately, two projects arose in the discussion that were deemed feasible and that the group reached consensus on. The two projects the working group developed in the meeting are briefly described below:

1. Review of MES studies in member countries

The first project is a review of MES studies in PICES member countries, which is anticipated to result in a review paper. This project is intended to address Terms of Reference #1, #2, and #3 by assessing the scope of MES available in the North Pacific, reviewing the methods for assessing MES along the ecological, economic, and sociocultural dimensions, and presenting a select set of case studies of applications of methods for assessing MES in the North Pacific member countries. The review paper will provide insights into the range of quantitative and quality methods used to measure and value MES in the North Pacific (review of MES types and methods) as well as illustrate how different countries apply them (case studies). Thus, the paper will address the following questions:

- What is the range of MES in the North Pacific?
- What methods are currently available to assess MES, both in terms of measuring their levels and valuing them individually and collectively?
- What are the similarities and differences between North Pacific member countries in terms of the range of MES and methods used to measure and value them (as illustrated through case studies)?

2. Country-specific surveys of agencies and decision makers

The second project is an expansion of existing projects currently in development in both China and USA. Dr. Jingmei Li (China) and Dr. Kristy Wallmo (USA) indicated they are each working on a project to develop and implement a survey intended to understand how people in their respective countries view MES and its application in policy. The draft survey instruments for these projects will be used as starting points for identifying a set of common (core) questions about MES that would form the basis of a survey that would be customized to each country and administered to decision makers, analysts, and scientists involved in ocean and coastal management and research. The goal of the study would be to collect information necessary to understand how they view and use MES information, as well as the prospects and challenges currently facing each country for advancing its usage in policy and management and its integration into more integrative management frameworks (like ecosystem-based management).

Additionally, there was discussion about moving away from the typology of MES used by SG-MES and adopt a conceptual framework more similar to the NRC (2005) view of the relationship between the ecosystem, ecosystem services, values, and human behavior.

AGENDA ITEM 7

Proposals of Topic Sessions or workshops at PICES-2019

The working group agreed that a workshop at PICES-2019 in which progress updates about the two projects could be presented for each member country would be most beneficial for advancing the goals of the working group. An outline of the goals and structure of the workshop were developed (see ***WG 41 Endnote 3***).

AGENDA ITEM 8

Membership

The group discussed the need for additional members to fill in gaps in expertise, specifically for Canada, U.S., and China. Several people were suggested as possible additions to the Working Group, either as official members or as externals:

Giselle Magnusson (DFO, Vancouver, Canada) – Economist
Kirsten Leong (NOAA Fisheries/PIFSC, USA) – Social scientist
Nathan Bennett (UBC, Canada) – Social scientist
Kai Chang (UBC, Canada) – Social scientist
Nathalie Ban (University of Victoria, Canada)* – Social ecologist
Siri Hakala (NOAA Fisheries/PIFSC) – Social ecologist
Keliang Chen (Third Marine Research Institute SOA, China) – Economist

* Member of the Human Dimensions Committee.

AGENDA ITEM 9
Other business

Dr. Keith Criddle (HD Committee Chair) answered several questions about PICES and its structure and organization and the role that the HD sees for WG 41. He was encouraging of the projects that had been outlined for the group.

AGENDA ITEM 10
Concluding remarks

Dr. Lew thanked the members and attendees for their valuable contributions and indicated he was looking forward to fruitful collaborations on the projects. The meeting then adjourned as per the agenda.

WG 41 Endnote 1

WG 41 participation list

Members

Shang Chen (China/interim Co-Chair)*
Sarah Dudas (Canada)
Dan Lew (USA, interim Co-Chair)
Jingmei Li (China)
Aoi Sugimoto (Japan)
Kristy Wallmo (USA)

*Participated remotely

Members unable to attend

China: Wei Liu, Benrong Peng
Korea: Hye Seon Kim, Changsu Lee, Seung-Hoon Yoo

Observers

Alan Haynie (USA)
Caihong Fu (Canada)
Keith Criddle (USA/HD Chair)
Yosuke Fujii (Japan)
Steve Kasperski (USA)
Olga Lukyanova (Russia)
Jongseong Ryu (Korea)
Meng Su (China)
Shang-Yuan Teng (Chinese-Taipei)

WG 41 Endnote 2

WG 41 meeting agenda

1. Welcome/introductions
2. Adoption of the agenda
3. Background
4. WG nominations of co-chairs
5. Review of Terms of Reference and identification of key tasks
6. Discussion and development of proposed projects
7. Proposals of Topic Sessions or workshops at PICES-2019
8. Membership discussion
9. Other business
10. Concluding remarks

WG 41 Endnote 3

Proposal for a workshop on
"Assessing Marine Ecosystem Services: A comparative view across the North Pacific"
at PICES-2019

Duration: 1 day

Convenors: Daniel K. Lew (USA), Shang Chen (China)

The PICES Working Group on *Marine Ecosystem Services* (WG-MES/WG 41) was established to facilitate exchange of information and share the experiences and approaches used to identify, measure, value, and use marine ecosystem services (MES) information in North Pacific waters in order to promote ecosystem service science and improve the consideration of MES in decision making related to marine integrated management. To accomplish this, the working group is conducting two projects. One reviews the range and types of MES found in the North Pacific region and compares the methods used to measure and value them using case studies for a subset of MES across countries. The second is a survey project that will collect information on the opinions and experiences with MES of resource managers, researchers, policy analysts, and decision makers from multiple North Pacific countries that will provide country-specific insights into how MES information is currently viewed and utilized, prospects and potential for future use and integration in policy analyses and decision processes, and identification of challenges and opportunities for improving the utility of MES information. This workshop has two primary goals: (1) to share and synthesize results of country-specific reviews of the MES literature in the North Pacific region and (2) to update progress on development of the survey to collect information on the knowledge, current and future utilization, challenges, and opportunities related to MES ecological, economic, and sociocultural information. To this end, the workshop presentations will focus on the progress and results for the working group's projects. Although the focus of the workshop presentations and discussion are on the working group's activities, other interested scientists interested in MES are highly encouraged to attend and participate.

PICES-2019
October 16–27, 2019, Victoria, Canada

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2019

HD Workshop (W6)
Assessing marine ecosystem services: A comparative view across the North Pacific

Convenors: *Daniel K. Lew (USA), Shang Chen (China)*

Invited Speaker:
Chanda Littles (US Army Corps of Engineers, USA)

Background

The PICES Working Group on Marine Ecosystem Services (WG-MES/WG 41) was established to facilitate exchange of information and share the experiences and approaches used to identify, measure, value, and use marine ecosystem services (MES) information in North Pacific waters in order to promote ecosystem service science and improve the consideration of MES in decision making related to marine integrated management. To accomplish this, the working group is conducting two projects. One task is to review the range and types of MES found in the North Pacific region and compares the methods used to measure and value them using case studies for a subset of MES across countries. The second is a survey project that will collect information, opinions and experiences from resource managers, researchers, policy analysts and decision makers from multiple North Pacific countries. The information collected will provide country-specific insights into how MES information is valued and utilized in decision making, and provide guidance on prospects and potential for future use and integration in policy analyses and decision processes. The results of the survey should identify challenges and opportunities for improving the utility of MES information. This workshop has two primary goals: (1) to share and synthesize results of country-specific reviews of the MES literature in the North Pacific region and (2) to update progress on development of the survey to collect information on the knowledge, current and future utilization, challenges, and opportunities related to MES ecological, economic, and sociocultural information. To this end, the intent of the workshop presentations was to focus on the progress and results for the working group's projects. Although the focus of the workshop presentations and discussion are on the working group's activities, other interested scientists interested in MES were highly encouraged to attend and participate.

Summary of presentations

On Saturday, October 19, 2019, the Working Group on *Marine Ecosystem Services* (WG-MES/WG 41) convened the workshop, "Assessing marine ecosystem services: A comparative view across the North Pacific." The session was a full day in length and included presentations and discussion. The morning session consisted of presentations and an extended discussion period. The afternoon session involved focused discussions on MES, primarily by members of WG-MES and the invited speaker.

The workshop was co-convened by Dr. Dan Lew (USA) and Dr. Shang Chen (China) and was sponsored by the HD committee. At the last minute, Dr. Chen was unable to attend in person, so it was chaired by Dr. Lew, who provided an introduction that included a description of the session and its goals and introductory material on marine ecosystem services. The session was well-attended, with 17+ people in the morning session and a smaller group in the afternoon. Five speakers were originally scheduled to give presentations, but three cancelled. One WG-MES member (Dr. Gisele Magnusson) volunteered to fill the spot left vacant by the last-minute cancellation by Dr. Chen. Her presentation was a good fit for the workshop and complemented one of the other presentations, since it was on the same subject (environmental economic accounting in system of national accounts).

There were three presentations in the morning session. The first was by the invited speaker, Dr. Chanda Littles, who presented work she and her colleagues had done while at the U.S. Environmental Protection Agency (EPA). Her presentation focused on work to assess final ecosystem goods and services (FEGS) in coastal habitats in the temperate North Pacific. They took a weight of evidence (WOE) approach for assessing habitat-FEGS linkages that was applied to a systematic review of the ecosystem services literature, wherein each study found in the literature was evaluated on several scoring criteria to assess linkages between FEGS and coastal habitats. Their analysis demonstrated the varying degrees to which coastal habitats contribute to human well-being through the lens of existing knowledge, as represented by the published ecosystem services literature. Ten types of beneficiaries and twelve types of coastal habitats were examined. The most prevalent habitat-FEGS linkages were found between three types of coastal habitats (estuarine waters, saltmarsh, and mangroves) and three types of beneficiaries (industry, recreation, and indirect services). Most published evidence for FEGS beneficiaries was for the Cortezian and Yellow Sea ecoregions.

The second morning presentation was by Dr. Peng Zhao (Fourth Institute of Oceanography, China), who made a presentation about China's efforts to extend environmental-economic accounting to oceans. He provided background about the United Nations' System of Environmental-Economic Accounting (SEEA) and China's National Resources Asset Accounting frameworks. He then described some of the difficulties with extending these frameworks to the ocean, noting specifically the deficiencies in data availability and the multi-dimensionality of the ocean that make extending these frameworks challenging. His presentation summarized efforts to develop an inventory of the oceanic environmental assets and ecosystem services, as well as progress on efforts to engage stakeholders. He then illustrated the application of these concepts to a pilot study in the Behai Golden Bay Mangrove Reserve in Behai, Guangxi.

The third morning presentation was by Dr. Gisele Magnusson (Department of Fisheries and Oceans, Canada), who described Canada's efforts to develop ocean accounts for environmental-economic accounting purposes. This work was intended to update a 2006 report ("Economic Impact of Marine Related Activities in Canada") that had most recently been updated in 2015 and that had used existing input-output regional economic models to estimate economic impacts of marine-related activities on Canada's economy. Their "Ocean Accounts Pilot" was an effort to develop a satellite account based on the SEEA that would systematically group information for assessing the capacity of ocean ecosystems to deliver services to present and future generations and to monitor and value the flows of services. Dr. Magnusson discussed a number of challenges they faced in this task, including issues raised in Dr. Zhao's earlier talk, such as gaps in data related to access, timeliness, and confidentiality; spatial resolution; and geographic and temporal inconsistencies in time series. She also discussed other challenges related to the need to agree upon definitions (ocean *vs*. coastal *vs*. marine, ecosystem classifications, MES classifications) and valuation (concepts of value and treatment of "non-market" exchange values). In addition, she mentioned that her work was part of the Global Ocean Accounts

Partnership (GOAP) and that there was an upcoming meeting to discuss the regional pilots in November 2019 and develop technical guidance documents for the various pilots.

Following the morning presentations, the presenters and audience engaged in a discussion about challenges related to ecosystem service values, including challenges in the measurement and application of these values (economic as well as cultural ones). The afternoon discussion expanded on topics brought up in the morning discussion and covered topics of interest to WG-MES projects. Of particular note is the focus on the concept of final ecosystem goods and services (FEGS) and the classification of ecosystem services that has evolved over the last decade.

List of papers

Oral presentations

Coastal ecosystem services in the Temperate Northern Pacific: An emphasis on beneficiaries (Invited)
Chanda J. Littles, Chloe Jackson, Theodore DeWitt and Matthew Harwell

Developing a system of environmental-economic accounting for oceans: A Chinese perspective
Peng Zhao, Feixue Li and Yunlan Zhang

Ocean accounts for Canada
Gisele Magnusson

Report of Working Group on *Marine Ecosystem Services*

The PICES Working Group on *Marine Ecosystem Services* (WG 41/WG-MES) conducted its second business meeting on October 21, 2019, at PICES-2019 in Victoria, Canada. Dr. Dan Lew presided over the meeting as Co-Chair. Dr. Shang Chen is the other Co-Chair but at the late minute was unable to attend in person. Five working group members were in attendance (***WG 41 Endnote 1***). In addition to WG 41 members in attendance, Dr. Chanda Littles (USA), a coastal ecologist and the invited speaker for the workshop organized by the WG 41 Co-Chairs (HD Workshop W6), and Dr. Meng Su (China), an economist, were in attendance. Dr. Littles indicated an enthusiasm for the working group's activities and willingness to contribute actively to the group's projects moving forward. Dr. Su had been an active participant in the PICES-2018 working group meeting.

AGENDA ITEMS 1 AND 2

Welcome/introductions and adoption of agenda

The meeting began with a welcome from Dr. Lew. This was followed by introductions from those in attendance, a review of the proposed agenda, and a vote to adopt the meeting agenda which was adopted without change (***WG 41 Endnote 2***).

AGENDA ITEM 3

Review of terms of reference and description of WG projects

Dr. Lew presented some background information on the origins of the Working Group, its purpose and terms of reference (TOR), and other background information about marine ecosystem services (MES) intended to help frame subsequent discussion. This included a review of each of the WG 41 TOR (see https://meetings.pices.int/members/working-groups/wg41). It also included a review of the projects the Working Group agreed upon to achieve the TOR during PICES-2018.

The two Working Group projects as developed during the PICES-2018 meeting are:

1. Review of MES studies in member countries

The first project is a review of MES studies in PICES member countries, which is anticipated to result in a review paper. This project is intended to address TOR #1, #2, and #3 by assessing the scope of MES available in the North Pacific, reviewing the methods for assessing MES along the ecological, economic, and sociocultural dimensions, and presenting a select set of case studies of applications of methods for assessing MES in the North Pacific. The review paper will provide insights into the range of quantitative and qualitative methods used to measure and value MES in the North Pacific (review of MES types and methods) as well as illustrate how different countries apply them (case studies). Thus, the paper will address the following questions:

- What is the range of MES in the North Pacific?
- What methods are currently available to assess MES, both in terms of measuring their levels and valuing them individually and collectively?
- What are the similarities and differences between PICES member countries in terms of the range of MES and methods used to measure and value them (as illustrated through case studies)?

2. Country-specific surveys of agencies and decision makers

The second project entails the development of country-specific surveys that will be administered to decision makers, analysts, and scientists involved in ocean and coastal management and research in each PICES member country. The goal of the study is to collect information necessary to understand how they view and use MES information, as well as the prospects and challenges currently facing each country for advancing its usage in policy and management and its integration into more integrative management frameworks (like ecosystem-based management).

AGENDA ITEM 4

Status updates and discussion of challenges and progress

Dr. Sarah Dudas provided an update on the Ecological sub-group's efforts to understand the way ecosystem services are assessed from the perspective of ecology. She indicated that no other member countries provided input despite her requests, so the update was primarily a Canada update. It included details of her search methods for identifying ecological assessment methods. The results suggest most studies use ecological value transfer (drawing from existing literature) to inform ecological assessment of ecosystem services. There were also some field surveys done, plus usage of large modeling approaches like InVEST, Ecopath, and Ecosim. "Ecosystem services" appears in the literature often simply as a buzzword, which can be misleading concerning the content of those articles. She discussed a couple case studies, one being conducted by a Canada/U.S. research team and the other by Karen Hunter and Ian Perry of Canada on the Ocean Health Index. Dr. Dudas also raised issues related to defining boundaries between marine and non-marine.

Dr. Jingmei Li presented the results from a survey that is a precursor to the Project 2 MES survey. This presentation was an abridged version of her presentation in a HD Topic Session (S4) on "*The impacts of marine transportation and their cumulative effects on coastal communities and ecosystems*" later in the week. The survey included a number of questions asked of decision-makers and scientists (in research and government institutions) related to ecosystem service valuation and its acceptance for decision-making. The survey was completed in October 2018 and administered during the following winter; 151 surveys were distributed and 126 valid responses were received. The results suggested that the majority of respondents understand the concept of ecosystem service values (EVS), but that the valuation methods are not understood by the majority of respondents. About 52% view ESV information as useful for "informative" purposes, 31% for "technical" purposes, and 17% for "decisions." Results also suggest there is a distrust of these values. The Working Group was enthusiastic about her survey and results and felt it was a good companion study to the Project 2 survey.

Dr. Lew provided an update on the Project 2 MES survey. This included a discussion of how a survey template had been developed with cooperation between U.S. and China, which had been developing separate, but somewhat similar, surveys already. The update included a presentation of the test-version of the web-based MES survey developed by the U.S. and detailed discussion of the questions and content of the survey and the plan for testing and administering it. An important departure in the U.S. version from the original project description and survey template was that the questions about ecosystem-based management (EBM) were dropped due to feedback from reviewers during initial testing indicating that these questions were problematic in the context of a survey primarily oriented towards MES values (*i.e.*, economic values and valuation of MES). He indicated that the U.S. has some programming budget flexibility that will allow the programming of other PICES country-specific surveys so long as they are translated and conform somewhat closely (though not identically) to the U.S.

version. It is anticipated that the list of MES and decision contexts in the survey will be different across PICES member countries and that there may also be a few other minor differences in some questions. Each country would need to create their own introductory video to be shown at the beginning of the survey as well. They would also need to do their own qualitative pretesting of the survey that would ensure comprehension of questions and increase the chances of getting valid and desired data. The Canada representatives indicated enthusiasm for using the U.S. survey resources and will provide Canada-specific translations for programming during the coming year. Some discussion of methods for qualitatively pretesting the surveys before they are administered occurred and a preliminary timeline was discussed (need translated versions within next 6 months).

WG 41 members also provided some useful suggestions for wording and flow changes that would improve the survey. Considerable time was spent discussing how to identify the sampling frame (list of the respondent universe)—currently being identified through a combination of snowball sampling methods and using public lists of agency/council members. This approach seemed reasonable to the group. There was also a discussion about the merit of asking additional demographic questions (age, gender) and balancing the added value *versus* sensitivity of those questions that may affect response rates. There was agreement that expanding the survey beyond NOAA Fisheries to NOAA would be useful in the future.

In addition to Canada's desire to utilize the U.S. version web infrastructure, China indicated that they would use some of the questions from the U.S. template in a follow-up survey of their own. There was also discussion about whether we should exert any effort trying to get other, currently non-participating, PICES member countries to administer the survey. There was a sentiment among Working Group members that it is likely unfeasible to get other countries to commit to participate in the Project 2 survey. Note: After the meeting, Dr. Lew spoke with Dr. Aoi Sugimoto, a Working Group member representing Japan. She indicated that due to time limitations, Japan probably would not be administering a Japan-specific survey.

Dr. Lew also presented an update on Economic sub-group activities, which similarly to the Ecological sub-group, was really a one-country update, given a lack of participation by other member countries. He presented an outline of the economic assessment section, and the group engaged in a useful discussion of several components that were mentioned (especially the need for issues related to scale, discount rates, and temporal/spatial issues to be discussed). He also discussed some uses for MES economic values, which would provide context to show the importance of these economic values in the report. Dr. Dudas noted that the ecosystem section would be very different structurally from the economic one, which everyone agreed would be fine. Dr. Kirsten Leong indicated that in her related work, she and colleagues have been struggling with well-being measures being used as endpoints *versus* ecosystem services being endpoints as it relates to sociocultural ecosystem service valuation.

Note: Dr. Lew made a presentation during the afternoon of the HD Workshop (W6) on "*Assessing marine ecosystem services: A comparative view across the North Pacific*" (October 19) on the definition and classification of MES in the scientific literature and argued for the inclusion of that content in the Project 1 MES review.

AGENDA ITEMS 5–7

Projects and project-related tasks

Discussion continued about how to complete the two Working Group projects. As noted above, for Project 2 Canada agreed to use the U.S. web survey infrastructure. China will use pieces of the U.S. survey to supplement the work they have done and are doing in China. Thus, China will handle its own implementation of a supplemental survey. Dr. Lew will provide paper versions of the U.S. survey for translation and testing by Canada (and China, to an extent). Canada will be responsible for developing its own video, customizing the survey to the MES and decision-contexts relevant for Canada, translating all materials to facilitate programming by the U.S. contractors, and pretesting the survey before final implementation. Within the next 6 months, Canada agreed to provide a translated version for programming.

The Project 1 (review of MES) basic outline established at PICES-2018, and that continues to be the working outline for the review, was the following:

1. Introduction
2. What are MES?
3. Assessing MES (quantifying, measuring, and valuing)
4. Case studies
5. Discussion
6. Conclusion

For Project 1, the Section 3 methodology (ecological, economic, and sociocultural methods) reviews would be general and not geographically constrained to what is done in individual countries (though discussion of this would help provide context). The main focus should be on providing a review of the methods used to assess MES, with particular emphasis on best practices. This need not be a fully exhaustive literature search and review, but rather a review that highlights the main methods and applications. Dr. Lew indicated he would take the lead on Section 2 and incorporate the materials he presented on the definition and classification of ecosystem services presented during the W6 discussion. He is also the lead for the economic assessment portion of Section 3. Dr. Dudas is the lead on the ecological assessment portion, and Dr. Sugimoto and Dr. Leong will coordinate the sociocultural assessment portion of Section 3.

For Section 4 (case studies), the group discussed several options. Initial discussion was about defining geographic-based (*e.g.*, specific region) case studies *versus* landscape (*e.g.*, ecosystem type) case studies. Dr. Lew pointed the group back to an earlier suggestion about basing the case studies on a specific ecosystem service. The group agreed this was a useful approach and aquaculture was selected as the MES to use in the case studies. The form of the case studies will be mini-literature reviews of the methods used in each PICES member country to assess the ecosystem service. Dr. Dudas suggested we come up with a matrix that can be filled in. Dr. Lew will work with her to develop the matrix and then distribute it to the group.

AGENDA ITEM 8

Proposals of Topic Sessions or workshops at PICES-2020

Working Group members agreed that a topic session at PICES-2020 would be beneficial for advancing the goals of the Working Group. Dr. Dudas (Canada) and Dr. Li (China) volunteered to co-convene the topic session. An outline of the goals and description of the session was developed (see ***WG 41 Endnote 3***).

AGENDA ITEM 9
Other business

The Working Group briefly discussed a couple other issues. Concerns about membership were talked about in the context of there being a lack of participation by several member countries (Russia and Korea) and the uneven expertise the group has with respect to certain subject areas, sociocultural expertise in particular. It was recognized that additional sociocultural experts would be beneficial, but that trying to get participation by those PICES member countries currently not participating would not be too helpful at this point, given only one year remains in WG 41's term. Additional concerns were expressed about communication problems (*e.g.*, members not participating in helping with projects and not responding to e-mails) that have thwarted progress, and a discussion about how to improve that communication occurred. It was recognized that there could be staffing time, resource constraints, language limitations, and other issues that underlie these issues, so the Working Group will focus on sustaining efforts by the active participating countries and members. Some ideas were put forward as a way for us to communicate electronically beyond e-mail, *e.g.*, weChat, Zoom, and WebEx? No one was sure what limitations there may be with respect to different platforms (*e.g.*, being prohibited for use by specific governments), so this item needs follow-up.

In addition, the Working Group discussed the possibility of asking for a one-year extension to enable completion of both projects. In particular, there was concern that the Project 2 survey would not be able to be both fielded and then analyzed and reported on before the end of the Working Group's term. The group agreed an extension was needed. Dr. Lew presented the request to the HD committee meeting later in the evening.

AGENDA ITEM 10
Concluding remarks

Dr. Lew thanked the members and attendees for their valuable contributions and indicated he was looking forward to fruitful collaborations on the projects. The meeting then adjourned as per the agenda.

WG 41 Endnote 1

WG 41 participation list

Members

Dan Lew (USA, Co-Chair)
Kirsten Leong (USA)*
Sarah Dudas (Canada)
Gisele Magnusson (Canada)
Jingmei Li (China)
Wei Liu (China)

*Participated remotely

Members unable to attend

China: Shang Chen (Co-Chair), Benrong Peng
Japan: Aoi Sugimoto
Korea: Hye Seon Kim, Changsu Lee, Jungho Nam, Seung-Hoon Yoo
USA: Kristy Wallmo

Observers

Chanda Littles (USA)
Meng Su (China)

WG 41 Endnote 2

WG 41 meeting agenda

1. Welcome/introductions
2. Adoption of the agenda
3. Review of terms of reference and description of WG projects
4. Status updates and discussion of challenges and progress
5. Discussion of lists of MES and planning Project 1 (Review of MES) case studies
6. Project 1 (Review of MES) – breakout groups (ecological and economic/socio-cultural)
7. Project 2 (MES Survey) – discussion of survey design, testing, and implementation
8. Proposals of Topic Sessions or workshops at PICES-2020
9. Other topics
10. Concluding remarks (next steps, assignments, *etc*.)

WG 41 Endnote 3

Proposal for a Topic Session on
"*Marine Ecosystem Services – Connecting science to decision making*" at PICES-2020

Duration: ½ day

Convenors: Sarah Dudas (Canada), Jingmei Liu (China)

Marine Ecosystem Services provide a conceptual framework to understand and communicate the value our coastal and marine ecosystems have from ecological, economic, and socio-cultural perspectives. All species and habitats provide ecosystem functions and produce 'services'. This session seeks to bring together natural scientists (ecologists, biologists, oceanographers, *etc*.) studying species and habitats that provide these services with the social scientists (economists, anthropologists, sociologists, *etc*.), policy makers, managers, and others that use the concept of MES to affect decision making. The session will include discussions on ecological, economic, and socio-cultural metrics to identify synergies between them. An objective of this session will be to help bridge the gaps in communication and understanding about ecosystem services between natural and social scientists in PICES nations and to illustrate the range of applications studying marine ecosystem services.

PICES-2020
Virtual Annual Meeting

Report of Working Group 41 on *Marine Ecosystem Services*

The PICES Working Group on *Marine Ecosystem Services* (WG 41/WG-MES) conducted its third meeting over two days, September 28–29, 2020. The meeting was held virtually via WebEx. Dr. Dan Lew presided over the meeting as Co-Chair. Dr. Shang Chen is the other Co-Chair but was unable to attend. Ten Working Group members were in attendance (*WG 41 Endnote 1*). In addition to the WG 41 members, Dr. Meng Su (China) and Julia Yazvenko (PICES) were in attendance. Dr. Su has been an active participant and contributor in the working group's activities. This was the best attended WG41 business meeting in terms of working group member participation.

Day 1, September 28, 2020

AGENDA ITEM 1

Welcome/introductions, adoption of agenda, terms of reference, goals

The meeting began with a welcome and detailed introduction about the meeting goals and format from Dr. Lew. He explained that the meeting will take place over two days, with Day 1 dedicated primarily to progress updates on the working group projects and Day 2 focusing on identifying next steps for the projects and the working group generally. This was followed by introductions from those in attendance, a review of the proposed agenda, and a vote to adopt the meeting agenda (it was adopted without change; *WG 41 Endnote 2*). During introductions, Dr. Sugimoto indicated she will be stepping down from the Working Group due to obligations to other PICES expert groups. However, she pointed out that Dr. Wakamatsu was just appointed and will be of great help to the group. Dr. Lew then presented some background information on the origins and timeline of the Working Group, its purpose and terms of reference, and a brief description of the projects. This background included a short discussion of where marine ecosystem services (MES) fit in the FUTURE social-ecological-environmental system framework (Bograd *et al*., 2019).[1]

[1] Bograd, S. J., Kang, S., Di Lorenzo, E., Horii, T., Katugin, O. N., King, J. R., Lobanov, V. B., Makino, M., Na, G., Perry, R. I., Qiao, F., Rykaczewski, R. R., Saito, H., Therriault, T. W., Yoo, S. and Batchelder, H. (2019). Developing a Social-Ecological-Environmental System Framework to Address Climate Change Impacts in the North Pacific. Frontiers in Marine Science, 6, 333.

AGENDA ITEM 2
Review of project descriptions

The two Working Group projects intended to fulfill the TOR are the following:

1. Review of MES studies in member countries

The first project is a review paper. This project is intended to address Terms of Reference #1, #2, and #3 by assessing the scope of MES available in the North Pacific, reviewing the methods for assessing MES along the ecological, economic, and sociocultural dimensions, and a case study of the application of methods for assessing aquaculture-related MES in the North Pacific member countries. The review paper will provide insights into the range of quantitative and qualitative methods used to measure and value MES in the North Pacific (review of MES types and methods) as well as illustrate how different countries apply them (case studies). Thus, the paper will address the following questions:

- What are ecosystem services and MES and why are they important?
- How are they defined and classified?
- What is the range of MES in the North Pacific?
- What methods are currently available to assess MES, both in terms of measuring their levels and valuing them individually and collectively?
- What are the similarities and differences between North Pacific member countries in terms of the range of MES and methods used to measure and value them (as illustrated through the case study)?

Note that for Project 1, it was agreed at PICES-2019 that the review of assessment methods (ecological, economic, and sociocultural methods) would be general and not geographically-constrained to what is done in individual countries (though discussion of this would help provide context). The main focus will be on providing a review of the methods used to assess MES, with particular emphasis on best practices. This is not intended as a fully exhaustive literature search and review, but rather a review that highlights the main methods and applications.

2. Country-specific surveys of agencies and decision makers

The second project is a survey project involving the development of country-specific surveys that will be administered to decision makers, analysts, and scientists involved in ocean and coastal management and research in each country. The goal of the study is to collect information necessary to understand how they view and use MES information, as well as the prospects and challenges currently facing each country for advancing its usage in policy and management and its integration into more integrative management frameworks (like ecosystem-based management).

AGENDA ITEM 3
Project updates

Project 1: Review of MES Report

Dr. Lew provided a detailed update about work he has done on the first several sections of the MES report. He thanked a number of members for providing feedback on those sections. The current outline for the report is as follows:

1. Introduction
2. The growth of ES and MES: Bibliometric Analysis
3. What are MES?
4. Assessing MES (quantifying, measuring, valuing, and understanding)
   a. Ecological
   b. Economic
   c. Sociocultural
5. Case study: Aquaculture
6. Discussion
7. Conclusion

He indicated that first drafts of sections 1–3 were completed, but require some revision and review. He explained that section 2 (Bibliometric Analysis) is new and was added to provide additional context about the growth of scientific knowledge and attention to ecosystem services generally and MES particularly (Figure 1). He asked the group whether they thought a similar analysis of the non-English language literature would be helpful. Dr. Sugimoto indicated that the Japanese language literature on ecosystem services is likely very small since Japanese researchers are more likely to publish in the English-language literature.

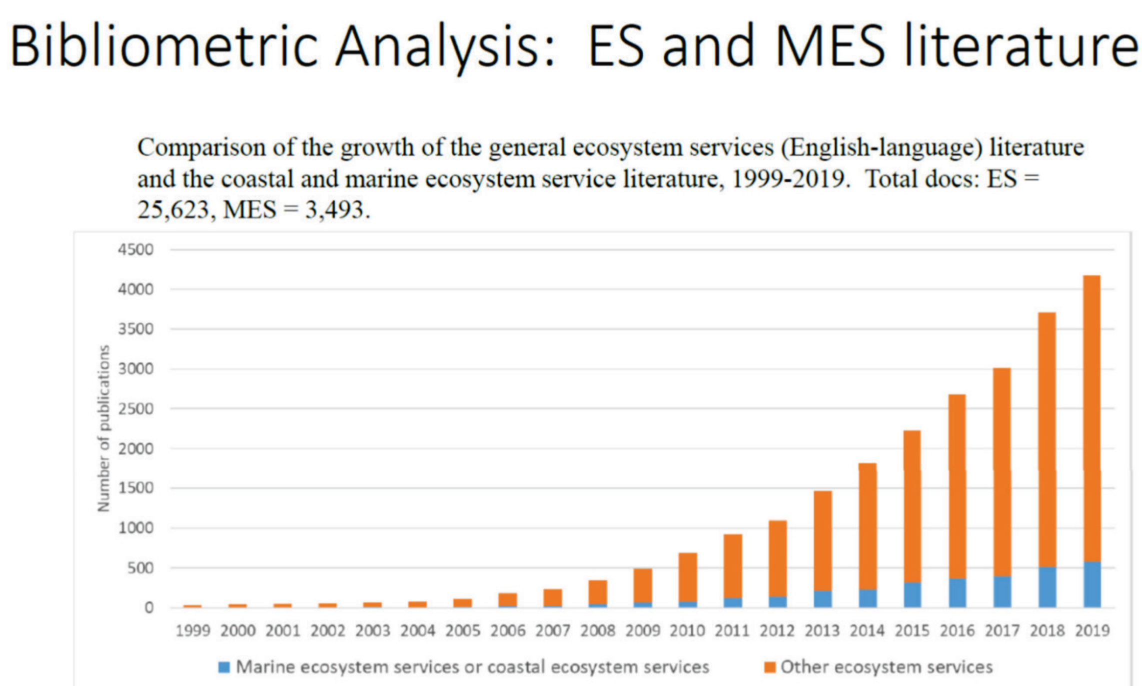

Figure 1. An illustration of the growth of scholarly research on ecosystem services and MES.

For section 3, he discussed the various definitions for ecosystem services that have been developed and used in the literature, the controversies with some of the early definitions, and efforts to move towards definitions that can be operationalized in efforts to quantitatively assess ecosystem services. In particular, he spent some time discussing the concept of final ecosystem goods and services (FEGS), which are the ecosystem services directly used by humans. It is a concept particularly useful for economic valuation of ecosystem services. FEGS were contrasted against intermediate ecosystem services (ones that contribute to production of FEGS but are not directly used by humans) and then put into a simple conceptual framework for ecosystem services (Figure 2).

Dr. Lew outlined his plans to write an introductory subsection to section 4 (assessing MES) that draws from numerous intergovernmental initiatives focused on ecosystem services like OpenNESS and IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) that have proposed frameworks that embrace a pluralistic or transdisciplinary approach to evaluation of ecosystem services. In particular, he suggested that section 4 of the report (Assessing MES) be motivated from this pluralistic or transdisciplinary perspective. Dr. Lew then described plans for the economics subsection (section 4b of the report).

And finally, Dr. Lew provided an overview of the aquaculture case study section, which is intended to illustrate the elements of the ecosystem service approach in different PICES nations. He indicated that a recent review article on aquaculture ecosystem services by Weitzman (2019)[2] will likely be helpful in the preparation of the case studies and provided a quick synopsis of the paper and its results.

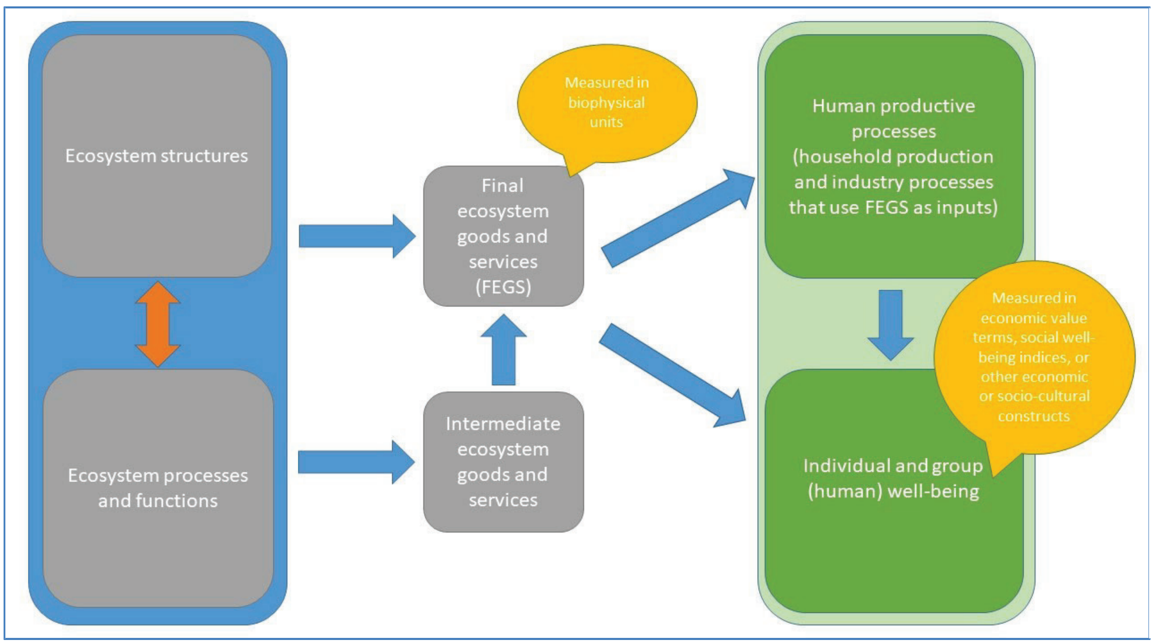

Figure 2. Conceptual diagram of relationship between the ecosystem, intermediate and final ecosystem services, and humans. On the left are the ecosystem structures and ecosystem processes and functions that represent the ecosystem. The bidirectional arrow between them represents the feedback mechanisms that occur between the ecosystem structures, processes, and functions. In the middle are ecosystem services, which represent a bridge between the ecosystem and humans. The ecosystem produces ecosystem goods and services (measured in biophysical units), some which are used directly by humans–the final ecosystem goods and services (FEGS)–and others that are intermediate in the sense that they contribute to the production of FEGS. On the right are the human dimensions, represented by individuals and groups in the lower box and productive processes in the upper box that take FEGS and combine them with human capital and labor to produce goods and services that are then used or enjoyed by humans. Thus, humans benefit from FEGS either directly or indirectly.

[2] Weitzman, J. (2019). Applying the ecosystem services concept to aquaculture: A review of approaches, definitions, and uses. Ecosystem services, 35, 194–206.

Dr. Sarah Dudas provided an update on the Ecological sub-group's efforts to understand the way ecosystem services are assessed from the perspective of ecology. She indicated that Dr. Caihong Fu provided some help, but that her schedule would likely prevent her further involvement. She had also reached out to Dr. Chen but had yet to hear back from him. However, Dr. Dudas mentioned that her colleague, Kieran, had helped conduct a selective review of the literature that was limited to studies that met the following criteria/considerations: (a) included an ecological assessment of MES, (b) diversity of applied assessment approaches, and (c) the assessment method and response metric were outlined. Studies meeting these criteria were reviewed to identify the following:

- Location, Ocean, Ecosystem, Habitat
- MES, Ecological Service Provided, Service Definition, Assessment Approach and Method, Aquaculture relevance
- Metadata: Article Type, Authors, Reference, DOI

Dr. Dudas indicated that it would be helpful to identify the key questions of interest and how to present information found in the review. She discussed that there are a lot of ways of presenting the information and as an example presented Table 1.

Table 1. An example of a draft summary table from the Ecological subsection, section 4a. The table describes the broad ecological service, the types of assessment applied to it, the metrics used in assessing it, and the MA ecosystem service category(ies) in which it falls.

Ecological Service	Assessment Category	Metrics	Ecosystem Service
Biodiversity	Biodiversity Maintenance	Index, Density, Diversity, Percentage	Provisioning, Supporting, Regulating
	Community Composition	Diversity, Density, Index	Supporting
	Functional Diversity	Fluctuations	Supporting
	Genetic Diversity	Diversity, Density	Regulating, Supporting
	Genetic Resources	Diversity, Genes	Provisioning
	Indicator Species	Index, Abundance, Biomass	Regulating, Supporting
	Non-Indigenous Species	Index, Abundance and Distribution	Supporting
	Resilience	Resilience	Regulating
	Spawning or Nursery Populations	Diversity and Density	Supporting
	Species Distributions	Distribution	Supporting
	Species Diversity	Density, Index, Diversity	Supporting
Climate	Carbon Sequestration	Concentration, Percentage, Tons and Rate, Models	Regulating
	Climate Regulation	Concentration, Flow Rate, Models	Provisioning, Regulating
	Temperature	Index	Supporting
Fish and Fisheries	Fish Biomass	Biomass, Trophic Level	Provisioning
	Fish Mortality	Survival	Provisioning
	Fishing Capacity	Hours per Year	Provisioning
	Foraging Area	Area	Provisioning
	Life Cycle Maintenance	Biomass, Area, Percentage	Supporting
	Population Composition	Population Average, Abundance and Biomass, Species Density	Provisioning, Supporting
	Seafood Quality	Index	Provisioning

Habitat	Biogenic Habitats	Abundance	Supporting
	Coastal Stability	Index, Quality, Abundance, Length, Mass, Model	Regulating, Supporting
	Habitat Provisions	Area, Density, Index	Supporting, Provisioning
	Migration Support	Contribution	Supporting
	Oxygen Demand	Capacity, Index	Regulating
	Sediment Quality	Index, Abundance and Composition	Supporting, Provisioning
	Water Quality	Concentration, Days, Liters, Flow Rate, Distribution, Index	Provisioning, Regulating, Supporting
Nutrients	Filtration	Concentration	Provisioning
	Nutrient Density, Regulation, and Cycling	Quality, Concentration, Index, Density, Mass	Supporting, Regulating
	Primary Production	Biomass, Index, Concentration	Regulating, Provisioning, Supporting
	Water Quality	Concentration, Dispersal, Joules, Index	Regulating, Provisioning, Supporting
Pollution	Ecotoxicology	Concentration	Regulating
Raw Material	Biotic Resources	Biomass, Concentration, Density	Provisioning
Renewable Energy	Energy Production	Area	Provisioning

Dr. Dudas also mentioned that for Project 2, she had prepared a video that would be used as an introduction to the survey.

Dr. Kirsten Leong made a presentation about the sociocultural subsection, section 4c. She indicated that Alohi Nakachi, a Ph.D. student working with her, had done a lot of the initial groundwork to review the literature on sociocultural valuation of ecosystem services. She also indicated that Dr. Sugimoto had provided useful input as well. Dr. Leong provided details about how they were thinking about ecosystem services in the context of larger social-ecological systems (SES) frameworks, and provided a number of examples of these frameworks and the role of ecosystem services and human well-being within them. She pointed to the IPBES's reframing of ecosystem services as nature's contributions to people (NCP), which include both positive and negative effects on humans. She advocated for more discussion of the role of human well-being and ecosystem services within a larger SES context, as well as the inclusion of relational values. She also shared a working list of aquaculture-related social values.

Dr. Gisele Magnusson provided a description of the environmental accounting subsection that will be incorporated into the report. There was some discussion about where to put the subsection, with the most likely section being the Discussion. In that section, applications of the ecosystem services approach like environmental accounting and coastal and marine spatial planning and management are likely to be central to the discussion.

Dr. Su presented the work she has done to develop the aquaculture case study for China. She explained that China is the world's largest aquaculture producer, accounting for 67% of the world's production. Its aquaculture production is greater (by volume) than its wild capture fisheries production. She noted that assessments of coastal and marine aquaculture, or mariculture, generally focus on understanding impacts of the density of operations and how it affects marine spatial planning. A literature review found 9 studies that used the keywords "mariculture ecosystem services" or "bay-mariculture". She analyzed these 9 studies to evaluate what types of mariculture operations are studied, the ecosystem services examined, and the types of assessment methods used. The mariculture-related ecosystem services examined in these studies are summarized in Figure 3. Dr. Su further examined the spatial distribution of the studies, the species involved in the mariculture operations, and the valuation methods used to generate monetary values for the individual ecosystem services. She then provided an assessment of the overall results, which included noting the focus on economic values of MES in specific regions and the inconsistent set of MES examined across studies.

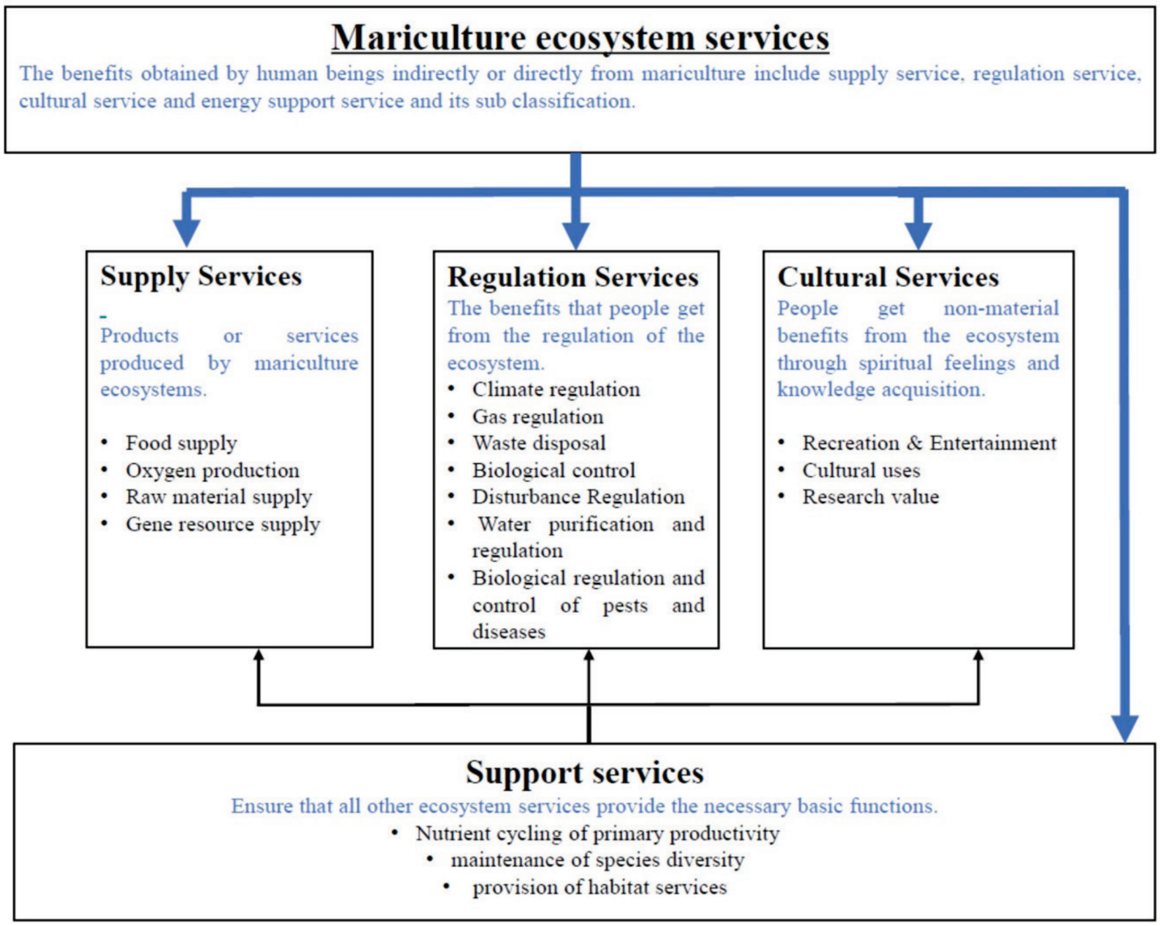

Figure 3. Types of ecosystem services related to mariculture in China.

Project 2: MES Survey

Dr. Lew provided a brief update on the Project 2 MES survey project in the U.S. Last year, a survey template had been developed with cooperation between U.S. and China and revised with input from the working group, but he indicated that due to some unexpected issues it is not clear whether the U.S. survey will be able to move forward and be fielded. Dr. Lew indicated that attempts will be made to continue with the survey if possible. Since Canada had been relying upon the U.S. to field their version as well, it is unclear whether the Canada survey will proceed. However, Dr. Magnusson has indicated that they may still be able to do it, particularly since most of the materials have been developed for the Canada version, though it still needs to be pretested.

Dr. Jingmei Li reported that China was able to revise their original survey to conform to the MES survey template. She was able to field the MES survey this year. She presented the preliminary results from the MES survey, which indicated that almost all respondents (95%) were familiar with the concept of marine ecosystem services, while about 57% were familiar with the concept of marine ecosystem service values. MES values were divided into direct use, indirect use, and nonuse values in the survey. Over half (52%) of respondents were familiar with use values, but only 39% were familiar with nonuse values. The use of MES value information differed across types of values, with the majority with experience using use values in their work and conversely the majority did not have experience with nonuse values. The lack of usage of nonuse values seems to be related to the distrust in the science of measuring these types of MES values and that how they are defined was too vague to be useful. Dr. Li indicated that further analysis of the data will be done.

Other related projects/research

Dr. Jungho Nam gave a presentation on work that South Korea is doing to incorporate MES information into marine spatial management and planning activities. He discussed the various types of MES valuation research done in South Korea and early efforts to incorporate non-market MES values into coastal and marine spatial management decision-making. In particular, he described the Marine Assessment and Planning Support System (MAPS) and how marine ecosystem service valuation research is used in that framework. Some issues discussed included the spatial mapping of ecosystem services, its use for the determination of conflicting uses, and the use of MES economic values in trade-off analysis.

AGENDA ITEM 4

Finalizing projects and assignments

Discussion continued about how to complete the working group projects. As noted above, given the uncertainty about Project 2 for Canada and U.S., the possibility of putting the results of the China survey into the Project 1 MES review report as part of the Discussion section was suggested. Most of the discussion about next steps occurred with respect to Project 1, the MES review. A discussion about the likely outlets for the MES review was discussed, with a PICES Press article and a PICES Scientific Report the first products expected to be generated from the report. A peer-reviewed journal article is also a possibility, but it was suggested that we wait to see how the report develops to evaluate the feasibility of that.

A timeline for completing Project 1 was established:

- A rough draft of the full MES report by PICES-2021
- Time at the business meeting at PICES-2021 will be used to deal with any remaining issues
- After PICES-2021
  - The lead writers will iterate to develop a final draft of the full MES report
  - The lead writers will develop the PICES Press article from the report (short summary/overview of MES)

Current assignments for reports sections are presented in the table in *WG 41 Endnote 3*. This includes a list of the lead writers for each section of the report and the other contributors for each section. This table was completed during the meeting after querying those in attendance about whether they would be able to contribute. Individuals in the table with a question mark (?) have not yet been confirmed. Note also that Dr. Nam indicated that he thinks he knows one or more people from South Korea who would be good to add as contributors. Dr. Lew indicated it would be most helpful for any new contributor from South Korea to help with the case study since we currently do not have anyone able to work on the case study for South Korea. Dr. Wakamatsu, the working group's newest member, agreed to help with the case study for Japan and with the economics sub-section.

Dr. Lew indicated that he will complete a revised draft of sections 1-3 and will distribute them to Drs. Dudas and Leong (and likely others) for comments in the near future. He also said that he plans to write up the discussion of pluralistic/transdisciplinary approaches for evaluating/assessing MES and will share it with the other section 4 leads.

A proposal was made to increase the intersessional communication within the working group to aid in completing the report, which had widespread support in the group. Specifically, an intersessional WG 41 virtual meeting held via WebEx was proposed for January 2021. That meeting would include progress updates and provide an opportunity for the working group to discuss specific issues that arise in the case studies and in writing the other sections of the report. Moreover, the "team" leads would try to attempt one or more team virtual meetings to aid with writing up individuals sections of the report.

Day 2: September 29, 2020

AGENDA ITEM 3

Next steps

The Working Group discussed several issues related to the future of the group. These included the Topic Session on "*Marine Ecosystem Services – Connecting science to decision making*", originally scheduled for PICES-2020, that has been postponed to PICES-2021. Dr. Dudas (Canada) and Dr. Li (China) are the co-conveners. There was support for using the topic session to report on the findings of the Working Group that will be reported in the Project 1 review of MES report and the write-up of the Project 2 MES surveys.

There was a short discussion about whether and how to continue the Working Group beyond a one-year extension. This talk was couched in terms of the UN Decade of Ocean Science (https://www.oceandecade.org) and PICES's desire to contribute to that. There was support for possibly proposing a working group related to implementing and operationalizing the ecosystem services approach in a transdisciplinary way, and generally, for advocating support for the inclusion of cultural ecosystem service information (either in the MES context or more broadly in terms of sociocultural ecosystem indicators). It was agreed that because we are requesting a one-year extension to finish our projects, the development of a new working group should wait until next year.

The Working Group did not collaborate with any other PICES expert groups during the past year.

AGENDA ITEM 4

Other business

No issues were raised.

AGENDA ITEM 5
Meeting adjournment

Dr. Lew thanked the members and attendees for their valuable contributions and indicated he was looking forward to continued collaboration on the projects. The meeting was then adjourned.

WG 41 Endnote 1

WG 41 participation list

Members

Dan Lew (USA, Co-Chair)
Sarah Dudas (Canada)
Changsu Lee (Korea)
Kirsten Leong (USA)
Jingmei Li (China)
Wei Liu (China)
Gisele Magnusson (Canada)
Jungho Nam (Korea)
Aoi Sugimoto (Japan)
Hiroki Wakamatsu (Japan)

Members unable to attend

China: Shang Sunny Chen, Benrong Peng
Korea: Hye Seon Kim, Seung-Hoon Yoo
USA: Kristy Wallmo

Observers

Meng Su (China)
Julia Yazvenko (PICES)

WG 41 Endnote 2

WG 41 meeting agenda

Day 1: September 28, 16:00–19:00 Pacific Time

1. Introduction: introductions, adoption of agenda, review of terms of reference, goals and structure of the business meeting
2. Review of project descriptions
    a. Project 1: Review of MES report
    b. Project 2: MES survey
3. Project updates (presentations by WG members)
    a. Project 1 (Lew, Leong, Dudas, Magnusson, Su)
    b. Project 2 (Lew, Li)
    c. Other related projects/research updates
4. Discussion of steps to take to finalize projects and assignments
5. Meeting adjourns until Day 2

Day 2: September 29, 16:00–19:00 Pacific Time

1. Introduction - recap of Day 1, goals for Day 2
2. Continue any discussions from Day 1 that are needed
3. Discussion of next steps for WG (also discuss what has worked and not worked about WG)
    a. Interactions/collaborations with other working groups
    b. 1-year extension to finish projects?
    c. Terms of reference for renewing WG-MES or setting up a new working group?
    d. Topic session scheduled for PICES-2021; any others?
4. Other business
5. Meeting adjourns

WG 41 Endnote 3

Current Assignments for Project 1

Section	Lead writer	Other contributors
1. Introduction	Lew	
2. Bibliometric analysis	Lew	
3. What are MES?	Lew	
4. Assessing MES (introduction)	Lew	Dudas, Leong
4a. Ecological	Dudas	Kieran, Fu(?), Littles(?), Chen(?)
4b. Economic	Lew	Magnusson, Li, Wakamatsu(?)
4c. Sociocultural	Leong	Nakachi, Sugimoto
5. Case study – Aquaculture	??	Lew, Su, Wakamatsu(?), maybe S. Korea (TBD), Magnusson, Dudas(?)
6. Discussion	Lew	Dudas, Leong
7. Conclusion	Lew	

PICES-2021
Virtual Annual Meeting

2021 Report of Working Group 41 on *Marine Ecosystem Services*

The PICES Working Group on *Marine Ecosystem Services* (WG 41/WG-MES) conducted its fourth and final annual meeting over two days, September 8–9, 2021. The meeting was held virtually via Zoom. Dr. Dan Lew presided over the meeting as co-chair. Ten Working Group members attended (*WG 41 Endnote 1*). In addition to the WG 41 members, six observers, including Dr. Meng Su (China), Dr. Kevin Ray (USA) and Dr. Alohi Nakachi (USA), were in attendance. Drs. Su, Ray and Nakachi have been active participants and contributors in the Working Group's activities.

Day 1, September 8, 2021

AGENDA ITEM 1

Welcome, meeting goals and organization, introductions, adoption of agenda, review of terms of reference

The meeting began with a welcome and description of the meeting goals and format from Dr. Lew. He explained that the meeting will take place over two days, with Day 1 dedicated primarily to final progress updates on the Working Group projects and Day 2 focusing on next steps towards finishing the projects and producing outputs (PICES Press article and PICES Scientific Report *et al*.) and discussing the future for MES and the Working Group generally. This was followed by introductions from those in attendance, a review of the proposed agenda, and a vote to adopt the meeting agenda (it was adopted without change). Dr. Lew then discussed the WG terms of reference and provided a brief description of the projects. This background included a short discussion of where marine ecosystem services (MES) fit in the FUTURE social-ecological-environmental system framework (Bograd *et al*. 2019)[1]. (The WG 41 terms of reference can be found online at https://meetings.pices.int/members/working-groups/wg41.)

AGENDA ITEM 2

Final project updates

The two Working Group projects intended to fulfill the terms of reference are the following:

Project 1. Review of MES studies in member countries

The first project is a review of MES. This project is intended to address terms of reference #1, #2, and #3 by assessing the scope of MES available in the North Pacific, reviewing the methods for assessing MES along the ecological, economic, and sociocultural dimensions, and a case study of the application of methods for assessing aquaculture-related MES in the North Pacific member countries. The review

[1] Bograd, S. J., Kang, S., Di Lorenzo, E., Horii, T., Katugin, O. N., King, J. R., ... & Qiao, F. (2019). Developing a Social-Ecological-Environmental System Framework to Address Climate Change Impacts in the North Pacific. Frontiers in Marine Science, 6, 333.

paper will provide insights into the range of quantitative and qualitative methods used to measure and value MES in the North Pacific (review of MES types and methods) as well as illustrate how different countries apply them (case studies). Thus, the paper will address the following questions:

- What are ecosystem services and MES and why are they important?
- How are they defined and classified?
- What is the range of MES in the North Pacific?
- What methods are currently available to assess MES, both in terms of measuring their levels and valuing them individually and collectively?
- What are the similarities and differences between North Pacific member countries in terms of the range of MES and methods used to measure and value them (as illustrated through the case study)?

Note that for Project 1, it was agreed at PICES-2019 that the review of assessment methods (ecological, economic, and sociocultural methods) would be general and not geographically-constrained to what is done in individual countries (though discussion of this would help provide context). The main focus will be on providing a review of the methods used to assess MES, with particular emphasis on best practices. This is not intended as a fully exhaustive literature search and review, but rather a review that highlights the main methods and applications.

The outline for the MES review is the following:

1. Introduction
2. The growth of ES and MES: Bibliometric Analysis
3. What are MES?
4. Assessing MES (quantifying, measuring, valuing, and understanding)
   a. Ecological
   b. Economic
   c. Sociocultural
5. Case study: Aquaculture
6. Discussion
7. Conclusion

Updates were provided on the first 5 sections. Sections 6–7 will be written after all other sections have been completed. Dr. Lew will take the lead on those sections.

Dr. Lew reported on his progress writing the first 3 sections. A draft of the first three sections has been completed. Dr. Lew also provided an update on the status of the introduction to the fourth section and the Section 4 economic assessment subsection. Both of those are completed and in draft form. All of the Section 4 subsections are organized loosely according to a diagram provided in the section's introduction that explains how assessment methods that are applied to MES depend upon the scientific worldview being utilized (see figure below).

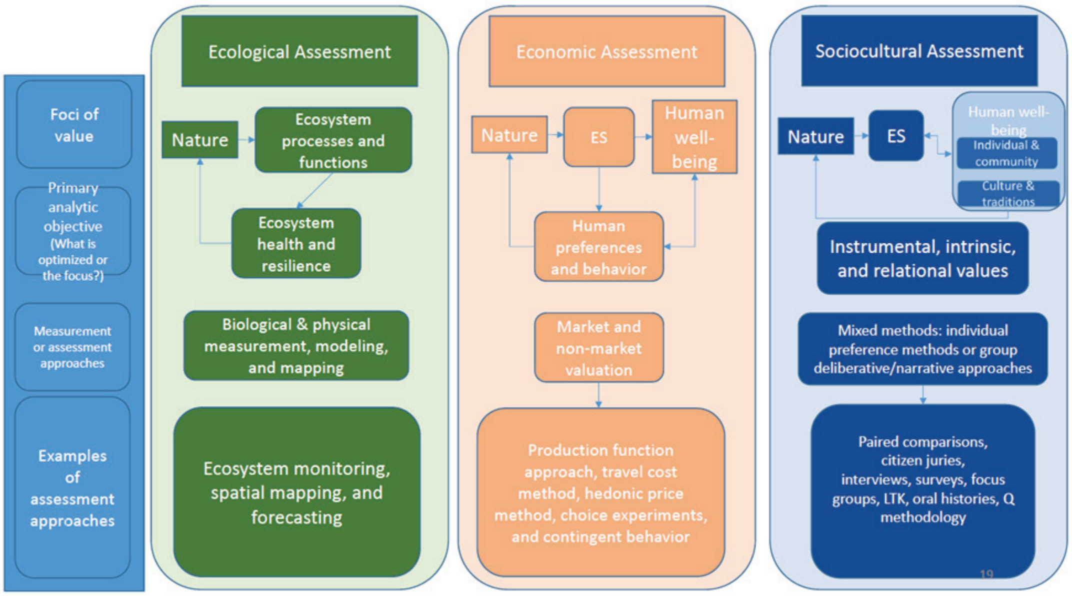

Figure. MES assessment approaches by scientific worldview

The economic subsection includes a discussion of what economic values are, the different types of economic values, and how they are derived and measured. The section culminates with a brief discussion of the types of methods and values associated with different types of MES (see table below).

Table. MES and economic valuation (similar to Goulder and Kennedy [2011][2])

Ecosystem Services (MEA classification)	Type of Economic Value	Valuation Method(s)
Food source (provisioning) Source of non-food materials (provisioning)	Direct use values • Consumptive use values	Direct market valuation Production function approach
Supporting and regulating functions (supporting and regulating)	Direct use values Indirect use values	Hedonic price methods Production function approach
Recreational benefits (cultural)	Direct use values • Non-consumptive use values Indirect use values	Travel cost method Hedonic price method Choice experiments Contingent valuation Contingent behavior
Nonuse benefits (cultural)	Existence value Bequest value Altruistic value	Choice experiments Contingent valuation 24

[2] Goulder, L. H. and Kennedy, D. (2011). Interpreting and estimating the value of ecosystem services in: Peter Kareiva, Heather Tallis, Taylor H. Ricketts, Gretchen C. Daily, and Stephen Polasky (Eds.), Natural Capital: Theory and Practice of Mapping Ecosystem Services, Oxford University Press.

The group then heard from Dr. Kirsten Leong on her efforts to complete the sociocultural assessment subsection. She indicated it is nearing completion and follows the framework indicated in the worldview figure above. Dr. Sarah Dudas then provided an update on the ecological assessment subsection. It is also nearing completion and follows the general intuition of the worldview figure. The section includes a general discussion of the broad set of tools that could be used to assess ecosystem services from a physical and biological science perspective and discusses the role of monitoring, mapping, modeling, and forecasting as assessment approaches. See figure below.

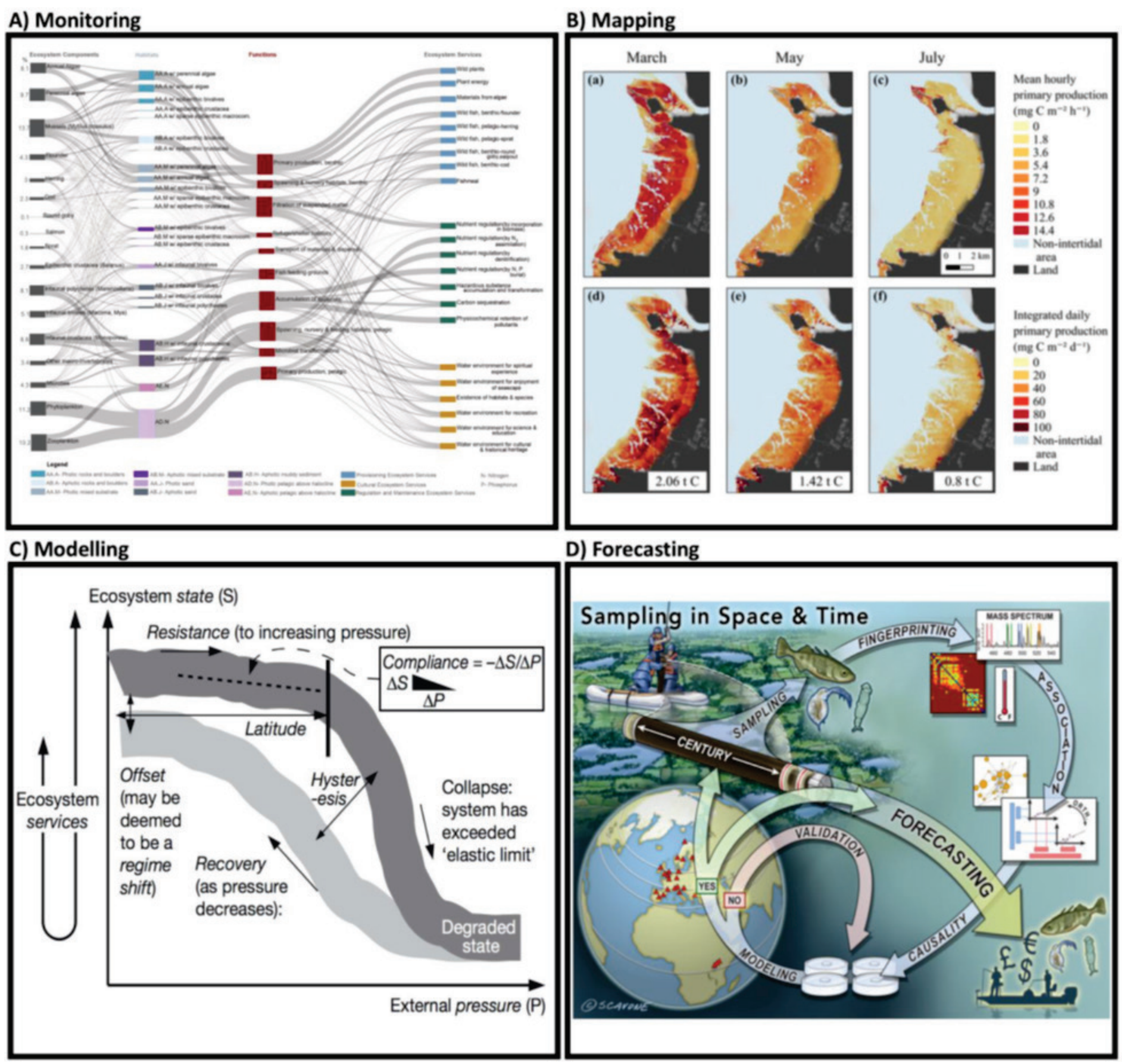

Figure. Ecological assessment methods in general.

The aquaculture case study section is composed of literature review contributions by the U.S., Japan, China, and Canada. These reviews summarize the literature on aquaculture-related MES research in member countries. Dr. Ray provided an update on the U.S. case study, recapping the approach taken (that was adopted by most of the other countries), results, and an evaluation of the results. Similar updates were provided by Dr. Hiroki Wakamatsu for Japan, by Dr. Meng Su for China, and by

Dr. Gisele Magnusson for Canada. All four case studies indicate a paucity of aquaculture-related MES research in terms of numbers of studies, coverage of aquaculture species, coverage of specific MES, and spatial coverage. Dr. Wakamatsu importantly discovered that ES are frequently referred to as "multifunctional services" in the literature in Japan, though the aquaculture literature nevertheless was thin in Japan too.

Project 2. Country-specific surveys of agencies and decision makers

The second project is a survey project involving the development of country-specific surveys that will be administered to decision makers, analysts, and scientists involved in ocean and coastal management and research in each country. The goal of the study is to collect information necessary to understand how they view and use MES information, as well as the prospects and challenges currently facing each country for advancing its usage in policy and management and its integration into more integrative management frameworks (like ecosystem-based management). China, Canada, and the U.S. have versions of this web-based MES valuation survey either completed or in progress.

Jingzhu Shen provided an update of China's MES valuation survey, which had been completed in 2020 and basic results were reported in previous meetings. Since then, it has been written up into a manuscript.

The Canadian and U.S. MES valuation surveys are both still in preparation but are both moving toward implementation. Dr. Magnusson provided an update of Canada's MES valuation survey, which is undergoing final checks before being implemented in mid-September in 3 waves. They expect to begin analysis of the data in October. Dr. Lew provided an update on the U.S. survey, indicating that it is still undergoing some internal review and approvals, but that a final version should be ready for implementation later in the fall after final edits and programming are completed and the sampling frame is updated and finalized.

AGENDA ITEM 3

Discussion on project next steps and other Working Group goals

The team briefly had a discussion about finishing the MES review report sections and the MES valuation surveys. Dr. Lew made clear that although the WG is officially ending, the work done in the WG will continue until the products (discussed on Day 2) are completed.

The discussion of "Other Working Group goals" was moved to Day 2 due to running out of time.

Day 2: September 9, 2021

AGENDA ITEM 1

Introduction

Dr. Lew welcomed everyone back and brief introductions were made again because of some new faces (individuals who were not there on the first day). Dr. Lew then provided a recap of Day 1 and the meeting goals. Since it was not completed on Day 1, the "other Working Group goals" item was discussed next. In short, he provided information about the new proposed expert group on Climate Extremes and indicated to the WG members that there is a particular lack of expertise in social sciences in the initial WG membership. He encouraged those interested in the topic (social and natural scientists alike) to let him know so they can be put in contact with the climate extremes WG organizers.

AGENDA ITEM 2

Discuss Working Group products/outputs

Dr. Lew led a discussion of the Working Group products. The "required" product for this WG is a PICES Press article. Dr. Lew indicated that he would take the lead in writing it and Dr. Dudas indicated a willingness to help with it. The article is expected to summarize WG 41's activities over its lifespan and provide a summary of the projects and findings.

Dr. Lew then informed the group about PICES' policies about publications from its expert groups (see figure below). He asked the individual project contributors to consider that process when putting together manuscripts.

- PICES requires manuscripts produced by its expert groups to be approved by parent committees, SB, and GC.
  - https://meetings.pices.int/publications/ApprovedPub
  - "All PICES publications generated by PICES activities require review by their parent committees. Then they can be recommended by Science Board to Governing Council for approval, before they can be posted on the PICES website. And, when a scientific paper is published that was a product of a PICES supported event (such as a capacity-building event, workshop or working group), it is important that PICES be acknowledged within the publication."

Figure. PICES publication procedures

Dr. Lew then led a discussion of other Working Group products. First was a PICES Scientific Report, which Dr. Lew suggested would be an appropriate outlet for the MES review report. A discussion about whether to organize it as an edited volume of individual contributions (with authors specific to their contribution) or as an integrated report (with all contributors as co-authors). The group agreed that the edited volume of individual contributions is more appropriate. Dr. Lew will edit the contributions to the PICES Scientific Report.

Next, a brief discussion about potential other products (journal articles) took place. Dr. Lew laid out several potential ideas, with the group gravitating towards the MES valuation surveys (cross-country comparison) as the principal one (Drs. Wallmo and Dudas indicated willingness to participate).

AGENDA ITEM 3

Group discussion of Working Group experience and its future

The group then had a discussion about the WG as a whole, their experience with it, and its future. In general, people noted that the MES valuation survey, once completed in Canada and U.S., may provide additional insights about the need and desire for MES information and MES values in general. That would help identify potential directions for any future working group. People also generally agreed the WG was useful to themselves and to their governments. The MES review is viewed as a good first step to better understanding MES. Dr. Magnusson also noted that the view we have brought into this group is primarily a federal/national government view, given the composition of the group. Dr. Dudas suggested marine spatial planning might be a good outlet for MES information and could be a focus for a future working group.

Bottom line: We will not be suggesting another MES-related expert group until we have results from the MES valuation surveys and have determined whether the results indicate a particular need. There was also some desire to get feedback/input from the HD committee about what further questions about MES could and should be explored.

However, the group decided to resubmit the topic session approved for PICES-2020 that had been cancelled due to COVID-19 (*WG 41 Endnote 3*). Drs. Dudas and Li will remain as the co-convenors.

In terms of reflecting back on the WG experience, Dr. Lew noted a number of challenges and positives associated with the group. The positives included:

- learning more about MES and different countries' perspectives and experiences,
- the effort some of the WG members and contributors made to make progress on the WG projects, and
- the relationships that were developed that will hopefully be ones that lead to future collaborations.

Some of the identified challenges included:

- the difficulties in getting the group organized and its membership filled by appropriate and willing members from the PICES nations,
- the often-slow progress made even more difficult by the pandemic and unforeseen setbacks, and
- some persistent challenges due to language differences that made communicating sometimes difficult.

Several other WG members echoed these, and added that working with experts in other disciplines was a real benefit of the group. A common communication platform for sharing documents and communicating was something several members indicated would be great to have and would have helped this group function better.

AGENDA ITEMS 4–5

Wrap up and meeting adjournment

Dr. Lew thanked the members and attendees for their valuable contributions and indicated he was looking forward to finishing up the projects with all the contributors. The meeting then adjourned as per the agenda.

WG 41 Endnote 1

WG 41 participation list

Members

Shang Sunny Chen (China, Co-Chair)
Dan Lew (USA, Co-Chair)
Sarah Dudas (Canada)
Gisele Magnusson (Canada)
Wei Liu (China)
Hiroki Wakamatsu (Japan)
Changsu Lee (Korea)
Jungho Nam (Korea)
Kirsten Leong (USA)
Kristy Wallmo (USA)

Members unable to attend

China:, Jingmei Li, Benrong Peng
Japan: Aoi Sugimoto
Korea: Hye Seon Kim, Seung-Hoon Yoo

Observers

Rosemary Kosaka (USA)
Alohi Nakachi (USA)
Kevin Ray (USA)
Jingzhu Shen (China)
Meng Su (China)
Julia Yazvenko (PICES)

WG 41 Endnote 2

WG 41 meeting agenda

Day 1: September 8, 17:00–19:00 Pacific Time

1. Welcome
    a. Meeting goals and organization
    b. Introductions
    c. Adoption of agenda
    d. Brief review of working group Terms of Reference and activities/projects
2. Brief updates/reports on projects
    a. Project 1: Review of MES report
        i. Sections 1-3 (Lew)
        ii. Section 4
        iii. Introduction and Economic subsection (Lew)
        iv. Sociocultural subsection (Leong/Nakachi)
        v. Ecological subsection (Dudas)
        vi. Section 5 (aquaculture case studies)
            1. U.S. (Ray)
            2. Japan (Wakamatsu)
            3. China (Su)
            4. Canada (Magnusson)
    b. Project 2: MES valuation survey
        i. China (Li)
        ii. Canada (Magnusson)
        iii. USA (Lew)
3. Discussion
    a. Project next steps
    b. Other Working Group goals
4. End of Day 1

Day 2: September 9, 17:00–19:00 Pacific Time

1. Introduction
   a. Recap of Day 1 and meeting goals for Day 2
   b. Finish incomplete items from Day 1 agenda
2. Discuss Working Group products/outputs
   a. “Required” products
      i. PICES Press article
   b. Other products
      i. PICES Scientific Report (an “edited” volume of individual contributions or an integrated report)
      ii. Potential journal articles
3. Group discussion of Working Group experience and its future (if any)
   a. Positives and negatives
   b. Should it continue in some way as a group within PICES?
   c. Future topic sessions or workshops to propose for PICES-2022?
4. Wrap-up and final thoughts
5. End of Day 2/Meeting adjourns

WG 41 Endnote 3

Proposal for a Topic Session on
“*Marine Ecosystem Services – Connecting science to decision making*”
resubmitted for PICES-2022

Convenors: Sarah Dudas (Canada) and Jingmei Li (China)

Duration: ½ day

Marine Ecosystem Services provide a conceptual framework to understand and communicate the value our coastal and marine ecosystems have from ecological, economic, and socio-cultural perspectives. All species and habitats provide ecosystem functions and produce ‘services’. This session seeks to bring together natural scientists (ecologists, biologists, oceanographers, *etc*.) studying species and habitats that provide these services with the social scientists (economists, anthropologists, sociologists, *etc*.), policy makers, managers, and others that use the concept of MES to affect decision making. The session will include discussions on ecological, economic, and socio-cultural metrics to identify synergies between them. An objective of this session will be to help bridge the gaps in communication and understanding about ecosystem services between natural and social scientists in PICES nations and to illustrate the range of applications studying marine ecosystem services.

PICES-2022
September 23–October 2, Busan, Korea

Excerpted from:

Summary of Scientific Sessions and Workshops at PICES-2022

FUTURE/HD/MEQ Topic Session (S2
Marine Ecosystem Services – Connecting Science to Decision Making

Convenors: Sarah Dudas (Canada) and Jingmei Li (China)

Background

Marine Ecosystem Services provide a conceptual framework to understand and communicate the value our coastal and marine ecosystems have from ecological, economic, and socio-cultural perspectives. All species and habitats provide ecosystem functions and produce 'services'. This session seeks to bring together natural scientists (ecologists, biologists, oceanographers, *etc*.) studying species and habitats that provide these services with the social scientists (economists, anthropologists, sociologists, *etc*.), policy makers, managers, and others that use the concept of MES to affect decision making. The session will include discussions on ecological, economic, and socio-cultural metrics to identify synergies between them. An objective of this session will be to help bridge the gaps in communication and understanding about ecosystem services between natural and social scientists in PICES nations and to illustrate the range of applications studying marine ecosystem services.

List of papers

Invited talk

1. **Integrating human wellbeing indicators in Puget Sound ecosystem restoration.** Kelly Biedenweg
2. **Implementing the marine ecosystem service concept.** Michael Townsend, Andrew M. Lohrer, Vera Rullens, Fabrice Stephenson, Conrad A. Pilditch, Judi E. Hewitt and Simon F. Thrush

Oral presentations

1. **Toward the inter-regional cooperation for high seas resource conservation: Implications from the Asia-Pacific region.** Iwao Fujii, Yumi Okochi, Hajime Kawamura and Mitsutaku Makino
2. **Floating marine debris in Shiretoko, Japan: Relationship between debris density, type and local human activities.** Monica Ogawa and Yoko Mitani
3. **Evaluation of ecosystem services provided by Pacific oyster, *Crassostrea gigas*, farms in Hansan bay, South Korea.** Jongyoon Baek and Sukgeun Jung
4. **Climate attribution time series to support decision making by fisheries stakeholders.** Michael Litzow, Brendan Connors, Erin Fedewa1 Trond Kristiansen, and Michael Malick.
5. **Blue carbon in South Korea: Knowledge gaps, critical issues, and novel approaches.** Yeajin Jung