2023 Science Board Meeting

Report

Prepared by Science Board Chair, Dr. Sukyung Kang, and the PICES Secretariat

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Agenda Item 1 Welcome, adoption of agenda

Science Board Chair, Dr. Sukyung Kang, called the meeting to order, welcomed participants, and made introductions.

List of Participant

Science Board	
Sukyung Kang	Science Board Chair
Jeanette Gann	Science Board Vice-Chair, TCODE Chair
Steven Bograd	FUTURE SSC Co-Chair
Hanna Na	FUTURE SSC Co-Chair
Akash Sastri	BIO Chair
Jackie King	FIS Vice Chair
Mitsutaku Makino	HD Chair
Andrew Ross	MEQ Acting Chair
Lei Zhou/Jennifer Jackson (online)	POC Chair/Vice Chair
Sung Yong Kim	MONITOR Chair
Yury Zuenko (online)	Russian representative
Governing Council & F&A Committee	
Tetsuo Fujii	PICES Vice-Chair
Tatsuki Oshima	F&A
Yutaka Hiroe	F&A
Guests from Strategic Partners	
Lee Cooper	IASC
Bill Karp	ICES
Alan Haynie	ICES
Maciej Telszewski	IOCCP
Janelle Curtis	NPFC, WG47 Chair
Aleksander Zavolokin (online, cancelled)	NPFC
Matthew Baker (Cancelled)	NPRB
Emily Twigg (online)	SCOR
Guests from PICES EGs and Projects	
Hannah Lachance	AP-ECOP
Hana Matsubara	AP-ECOP
Raphael Roman	AP-ECOP
Taewon Kim	Project SEATurtle
PICES Secretariat	
Sanae Chiba	Deputy Executive Secretary
Alex Bychkov	Ex Officio
Review Panel Members	
Eileen Hofmann	Panel Chair
David Checkley	
Fangli Qiao	Also GC
Jörn Schdmit	Also rep. ICES
Sinjae Yoo	Also rep. SCOR

Agenda Item 2 Reports of PICES Partner Organizations

Representatives of PICES partner organizations participated in the SB meeting either in-person or remotely to update their recent activities and collaboration with PICES.

2.1. International Council for the Exploration of the Sea (ICES)

Presenters ICES Executive Secretary Alan Haynie and SCICOM Chair Jörn Schmidt (in-person)

ICES and PICES currently share several joint Expert Groups; Section on Climate Change and Marine Ecosystems (S-CCME), WG43 on Small Pelagic Fish, WG44 on Integrated Ecosystem Assessment for the Northern Bering Sea – Chukchi Sea (WGIEANBS-CS), WG45 on Impacts of Warming on Growth Rates and Fisheries Yields (WG-GRAFY), WG46 on Ocean Negative Carbon Emissions (WG-ONCE) and Advisory Panel on United Nations Decade of Ocean Science (AP-UNDOS). WG39 (disbanded at PICES-2022) and WGICA on an Integrated Ecosystem Assessment for the Central Arctic Ocean held the 4-day workshop during PICES-2023. ICES-PICES MoU (1998). The IOC endorsed the joint ICES/PICES UNDOS program SmartNet in 2021 which will also ensure close cooperation of the organizations over the next decade (see Agenda 5 for SmartNet activity update).

2.2. North Pacific Fisheries Commission (NPFC)

Presenter NPFC Science Committee Chair Janelle Curtis (in-person)

NPFC and PICES endorsed the NPFC–PICES Framework for Enhanced Scientific Collaboration in the North Pacific (link) in 2019. The Framework identified three broad areas of joint interest to PICES and the NPFC (i) support for stock assessment for priority species; (ii) vulnerable marine ecosystems; and (iii) ecosystem approach to fisheries. At PICES-2023, NPFC sponsored Session 14 Seamount biodiversity vulnerable marine ecosystems (VMEs) and species associated with seamounts in the North Pacific Ocean.

2.3. North Pacific Research Board (NPRB)

The planned presenter, NPRB Science Director, Matthew Baker cancelled his attendance.

NPRB directs research towards species, processes, and dynamics in the marine ecosystems of Alaska, including the Gulf of Alaska, the Bering Sea, the Aleutian Islands, and the Chukchi and Beaufort Seas in the Arctic, to improve the understanding of Alaska marine systems and inform effective fishery management. NPRB has sponsored the PICES Project The Continuous Plankton Recorder Survey of the North Pacific since the early 2000s and contributed to the completion of the multiple Reginal Reports on NPESR III in 2022/23.

2.4. Scientific Committee on Ocean Research (SCOR)

Presenter SCOR Executive Director, Emily Twigg (virtual)

SCOR and PICES have developed a cooperative model for an international non-governmental organization and a regional intergovernmental organization to share their strengths in championing ocean science. Collaboration between PICES and SCOR is based on the recognition that PICES can play an important role in bringing a North Pacific perspective to the global activities of SCOR. The collaboration is implemented through activities in the following areas

- Contribution of scientific expertise to relevant international scientific projects of SCOR e.g., Harmful Algal Blooms (GlobalHAB), IMBeR, SOLAS, GACS (Global Alliance of Continuous Plankton Recorder Surveys), and to SCOR-supported projects e.g. (IOCCP, International Ocean Carbon Coordination Project). PICES also has supported several SCOR Working Groups.
- Reciprocal representation of the SCOR and PICES Executives at annual meetings of the organizations including the PICES Deputy Executive Secretary as a member of SCOR's Capacity Development Committee.

At PICES-2023, SCOR sponsored Workshop 3 GlobalHAB International Workshop on Solutions to Control HABs in Marine and Estuarine Waters and Session 4 The Oceanographic, Ecological and Societal Impacts

Arising from Extreme Weather and Climatic Events in Coastal Regions.

2.5. International Ocean Carbon Coordination Project (IOCCP)

Presenter IOCCP Director Maciej Telszewski (in-person)

IOCCP is co-sponsored by the Scientific Committee on Oceanic Research and the Intergovernmental Oceanographic Commission of UNESCO. IOCCP promotes the development of a global network of ocean carbon observations for research through technical coordination and communication services, international agreements on standards and methods, and advocacy and links to the global observing systems. Dr. Telszewski pointed out the recent decline in participants from PICES countries to the IOCCP-organized training sessions/events for carbon observation. He urged PICES to promote the participation of young scientists and students in their events.

2.6. International Arctic Science Committee (IASC)

Presenter IASC Marine Working Group, Lee Cooper (in-person)

IASC is a non-governmental, international scientific organization, committed to pursuing a mission of encouraging and facilitating cooperation in all aspects of Arctic research, in all countries engaged in Arctic research and all areas of the Arctic region. Overall, IASC promotes and supports leading-edge interdisciplinary research in order to foster a greater scientific understanding of the Arctic region and its role in the Earth system. Dr. Cooper is a member of WG44 Joint PICES/ICES Working Group on Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea (NBS-CS). He noted that he would continuously work to liaise between IACS and PICES in the area of Arctic research.

2.7. Recent activity on collaboration with other partners

PICES Deputy Executive Secretary, Dr. Chiba, updated collaboration with and recent activities of other PICES partners.

2.7.1. Asia-Pacific Network for Global Change Research (APN)

APN and PICES are Intergovernmental Organizations with shared goals, particularly in terms of supporting international cooperation in research and capacity development, and partially overlapping geographic regions of focus. Through reciprocal participation at recent Annual Meetings both organizations had identified the need to strengthen this partnership and a Collaborative Framework for scientific cooperation was signed by both organizations in February 2023. PICES received potential PICES-APN collaboration opportunities on their events scheduled for 4-8 March 2024 at the University of the South Pacific in Fiji (TBD), which includes a 3-day Proposal Development Training Workshop (see Agenda item 17 Capacity Development).

**Note The APN training workshop was postponed to summer 2024.*

2.7.2. Pacific Salmon Commission (PSC)

PSC is a bilateral treaty organization between the USA and Canada with the responsibility to prevent over-fishing, provide for optimum production, ensure that both countries receive benefits equal to the production of salmon originating in their waters, and conduct research to investigate the migratory and exploitation patterns, the productivity, and the status of stocks of common concern. The PICES-Pacific Salmon Commission MoU was signed in November 2022. At PICES-2023, PSC sponsored Workshop 9 *Indigenous and Community-Led Approaches to support climate change adaptation and Ecosystem Resilience in the North Pacific and Arctic* to support travel of the invited local indigenous leaders to attend the workshop.

2.7.3. The International Pacific Halibut Commission (IPHC)

IHPC is an international organization that has been managing the Pacific halibut fishery and conducting research on Pacific halibut population biology and its environment in the Convention waters of Canada and the USA. The IPHC-PICES MoU was signed in 2000 (superseded in 1999) from 2019 to 2024 to promote mutual collaboration and to engage in multinational efforts to promote data exchange and research collaborations in topics relevant to the North Pacific Ocean ecosystem. IHPC celebrates its 100th anniversary in 2023 and PICES hosted the IPHC Special Session *The International Pacific Halibut Commission 100 years of science-based fishery managemen*t during the PICES-2023.

2.7.4. North Pacific Anadromous Fish Commission (NPAFC)

The PICES-NPAFC MoU was signed in 1998 and revisited in the 2013-2014 Joint NPAFC-PICES Study Group on Scientific Cooperation in the North Pacific Ocean which set out guidelines and targets for enhanced collaboration. Some scientists are active in both organizations and recent interactions have focussed on the International Year of the Salmon (IYS) Program and the follow-on UNDOS-endorsed project "Basin-scale Events to Coastal Impacts An ocean intelligence system for fish and people (BECI)". See Agenda 3 for BECI update. The NPAFC's New Executive Director, Yoshikiyo Kondo attended PICES-2023.

Agenda Item 3 Basin-scale Events to Coastal Impacts An ocean intelligence system for fish and people (BECI) Updates

Dr. Chiba briefly reviewed and updated the progress of the BECI Project in 2023. SB members.

Background (2021-2022)

PICES and NPAFC were partners in developing the "Basin-scale Events to Coastal Impacts An ocean intelligence system for fish and people (BECI)" proposal which was endorsed as a UNDOS project in early October 2021. At PICES-2021 GC encouraged the development of BECI as a potential PICES Special Project. A series of virtual workshops held during 2022 which encompassed a review of down-scaled modelling and experience linking these models with ocean processes, a review of technologies and innovations applicable to studies of the North Pacific Ocean and its biological characteristics, and a discussion of data management and sharing amongst agencies and between nations. GC approved the creation of an encumbered fund (when monies became available) to support the development of BECI at PICES-2022

Updates (2023)

With in-kind and financial support from DFO, NOAA, NPAFC, the Tula Foundation and others, the BECI coordinating team convened a science plan development workshop in March 2023 with over 25 people from both sides of the North Pacific participating in-person and online to collaborate on drafting the components of a science plan that will connect state of the art climate and oceanographic models to fisheries management, with special reference to Salmon, in the NE Pacific to seek funding support for BECI. A funding announcement to set up an initial BECI project office is expected very shortly. A Science Director position to lead the development and implementation is expected to be filled shortly. Additionally, there has been communication with the Decade Collaborative Centre on Ocean-Climate Nexus and Coordination Amongst Decade Implementing Partners in China (DCC-OCC), and with the Decade Collaborative Centre for the Northeast Pacific Ocean (DCC NEPO) to improve awareness and coordination of activities on both sides of the Pacific.

BECI and SmartNet

SmartNet agreed to endorse BECI to become a project under the umbrella of SmartNet. As the PICES group with responsibility for SmartNet, AP-UNDOS proposes to be the reporting body of BECI by which BECI provide their activity update to the Science Board through AP-UNDOS. However, some members questioned the suggested role of AP-UNDOS as the reporting body of BECI to SB and the PICES community. SB pointed out that, though they acknowledge BECI has made progress in the past year, its plan is still developing and its future as a PICES Special Project is not clear without a solid implementation plan. SB agreed that they should wait for the establishment of the BECI project office and completion of its implementation plan before clarifying its reporting procedure among the PICES community.

Agenda Item 4 FUTURE Update

FUTURE SSC co-chairs, Drs. Bograd and Na presented an update of FUTURE activities and its planning in 2024 as discussed at the FUTURE SSC Business meeting held on October 26th.

SSC updates and general business

- Review of 2023 Action Items
- Review of 2023 ECOP FUTURE SSC Award
  Awardee Vivitskaia J.D. Tulloch, Conservation decision scientist, U British Columbia
  Presentation title (S1) Application of a Social-Ecological-Environmental system Framework to address and manage future climate change impacts on threatened killer whales and their Pacific salmon prey.
- Update/revision of Liaison Table & FUTURE Schematic

Writing progress and timeline

- FUTURE Phase II Final Report
- FUTURE Product Matrix paper
- FUTURE Review paper "Climate Variability and Ecosystem Resilience in the North Pacific Lessons Learned from the PICES FUTURE Program" by Takemura, Makino et al. (to be submitted)

Develop 2023-2024 Action Plan & Timeline
FUTURE Phase III Priorities

1. Retain a Flagship Science Program to integrate PICES science.
2. Maintain the momentum of FUTURE and proceed with *Phase III* tasks.
3. Bring ECOPs into SSC membership for new ideas, and enthusiasm.
4. Facilitate cross-pollination across FUTURE, AP-UNDOS, AP-ECOP, AP-SciComm [FUTURE recommendation Joint AP meeting at Annual Meeting]
5. Renewed focus on science-based solutions & operational products
6. Around 2025-2027, rethink a new Science Program for PICES, informed by emergent themes identified in UNDOS.

Planning for 2024 FUTURE Open Science Meeting

- **FUTURE** has helped PICES develop a better understanding of the combined consequences of climate change and anthropogenic pressures on marine ecosystems, ecosystem services, and marine-dependent social systems. We now embark on the "FUTURE" of PICES that will lead to better observations, improved awareness of mechanisms of change, and ultimately science for sustainability by 2030.

Agenda Item 5 SmartNet/IPOD Report

SmartNet co-chair, Dr. Bograd, updated SmartNet activities and planning for 2023~24 as discussed in its business meeting held on October 22nd.

Major activities after PICES-2022

- Participated in Ocean KAN 'network weaving' training session (**Oct 2022**)
- Reviewed proposed Projects for UNDOS endorsement (**Oct 2022**)
    a. Recommended endorsement of *The Ocean Matter; COST Action - Marine Animal Forest of the World; sustainMare*
    b. Need more information for *Monitoramento Mirim Costeiro; Frames; Conserve, Restore and Manage C&M Habitats*
- Conference call to discuss SmartNet-SIDS engagement with Khush Jhugroo and Daniel Marie of Mauritius Oceanographic Institute (**Nov 2022**)
- Chairs coordination discussion with Ocean Visions Decade Coordination Centre (DCC) (**Dec 2022**)
- IPOD members' virtual meeting (**Feb 2023**)
- Participated and presented on SmartNet at Ocean Visions Summit in Atlanta (**Apr 2023**)
- Co-hosted ECCWO UNDOS co-design workshop in Bergen, Norway (**Apr 2023**)
- Submitted SmartNet Annual Report to Decade Coordination Unit (**May 2023**)
- Published *PICES Press* article on ECCWO workshop & SUPREME (**July 2023**)
- Endorsed the Global Plastic Ingestion Bioindicators Project (GPIB) chaired by Dr. Mathew Savoca of MEQ under the SmartNet umbrella (**Jun 2023**)
- Represented SmartNet on Ocean Visions DCC planning call (**Jul 2023**)
- Contributed to PICES/SmartNet abstract for DITTO meeting (**Jul 2023**)
- Check-in call (with SUPREME) with Northeast Pacific DCC (**Aug 2023**)
- Organized PICES-2023 Workshop 2 (**Oct 2023**)

Planning for 2024~

<u>Writing task</u>

- Prepare SmartNet Implementation Plan (including Phase I action plan, products & deliverables)
- Prepare contribution to 'Food for Thought' article based on the outcome of the co-design Workshop at ECCWO for *ICES Journal of Marine Science*.
- Contribution to UNDOS Ocean Visions 2030 white paper (see below A)
- Contribute to the paper on the UNDOS National Surveys (Makino-san et al)
- Contribute to the TOC journal special issue on Capacity Development

<u>Project coordination</u>

- Review and mobilize the role and progress of IPOD task teams (see below B)
- Develop partnerships with multiple DCCs to review suggested umbrella Projects, and facilitate collaborative activities with SmartNet-endorsed projects with DCC's support
- Follow up on SmartNet-SIDS engagement (Khush Jhugroo and Daniel Marie of Mauritius Oceanographic Institute)
- Facilitate collaborative activities with Empowering Women for the UN Decade of Ocean Science for Sustainable Development (WMU)
- Planning and organization of Workshops on community engagement (ITK; community-supported observation), with DCCs' support

A. Participation in UNDOS Ocean Visions 2030 Process

In recent months PICES has participated in a workshop to set out a roadmap for the UN Oceans Conference in 2025 that took place aboard a tall ship (Erin Satterthwaite, PICES ECOP, participated) and in Working Groups for the Vision 2030 process. Ten WG are being implemented within the framework of the UNDOS, as a global initiative aimed at mobilizing actors to generate and apply the knowledge needed to achieve a sustainably managed ocean by 2030. PICES members invited as WG members include Fangli Qiao, Steven Bograd, Toru Suzuki, and Sonia Batten, and they will contribute to white papers developed during 2023/24 that will be presented at the UN Ocean Decade Conference in 2024.

B. IPOD task teams.

1. **Writing Team** (a) Co-design review paper; (b) SmartNet Phase I Implementation Plan
2. **Survey Team** (a) Execute national UNDOS surveys; (b) Interpret & disseminate results
3. **Outreach Team** (a) Plan & execute workshops; (b) Prepare SmartNet/IPOD reports and meeting materials
4. **Network Team** (a) Facilitate engagement with Decade Collaborative Center; (b) Facilitate engagement with UNDOS partners (Empowering Women, ECOPs, SmartNet-umbrella projects)
5. **Capacity-Sharing Team** Facilitate engagement with SIDS and international partners

C. SmartNet Coordinator Proposal (see Agenda 14)

Agenda Item 6 Special Project Updates

6.1. SEAturtle Sea turtle ecology in relation to environmental stressors in the North Pacific region

SEAturtle has completed its term at the PICES-2023. The project leader Dr. Kim presented the summary of the accomplishments of the project and acknowledged PICES's support of their project throughout the term. SB praised the success of SEAturtle not only in scientific achievement but also in capacity building and marine conservation literacy among the local communities. Dr. Kim brought many young scientists to PICES-2023 to present SEAturtle outcomes to the PICES-2023 audience. SB members encouraged Dr. Kim to seek research funds to continue the efforts as a post-SEAturtle project.

https //meetings.pices.int/projects/SEAturtle

Term December 2018 – October 2023 (term extended from initial 4 years with additional funds)

Project Science Team Co-Chairs

Taewon Kim (Inha University, Korea)

George Balazs (Golden Honu Services of Oceania, USA)

Funder the Ministry of Oceans and Fisheries of Korea

Parent PICES Committee Biological Oceanography Committee (BIO)

Project Goal

The overall project goal is to research the sea turtle population found in the North Pacific regions centering on Jeju Island of Korea to enhance the understanding of their habitat use and ecology related to anthropogenic activities. The project key questions are (a) How the sea turtles found in Jeju Island, Korea, Kyushu Island, Japan, and Hong Kong, China are connected to the other identified populations in the North Pacific areas and (b) What are the major environmental stressors to the sea turtles in the North Pacific regions.

6.2. FishPhytO Creating a phytoplankton-fishery observing program for sustaining local communities in Indonesian coastal waters

FishPhytO was launched in June 2023 as the third in a series of collaborative projects with Indonesia following the previous PICES-MAFF projects FishGIS (2017–2020) and Ciguatera (2020–2023). Project Science Team co-chair, Dr. Makino, introduced the objectives and planning of FishPhytO, and reported the project kick-off meeting, the PICES/MAFF Indonesian workshop, held on July 2-8, 2023 in Banten and Lombok. The report will be posted on the PICES project website (See Agenda 19)

Term June 2023 – March 2026 (approved at IGC-2023)
Project partners in Indonesia
The National Research and Innovation Agency of Indonesia (BRIN)
The Indonesian Agency for the Assessment and Application of Technology (BPPT)
*PICES and the Institute of Technology of Indonesia (ITI) signed MoU in March 2022
Project Science Team Co-Chairs
Mitsutaku Makino (The University of Tokyo, Japan)
Mark Wells (University of Maine, USA)
Project Coordinator Alexander Bychkov (PICES)
Funder Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan, through the Fisheries Agency of Japan (JFA) from the Official Development Assistance (ODA) Fund.
Parent PICES Committee Human Dimensions Committee (HD)

Objectives

- To establish, in collaboration with local fishers, research institutes and universities, a phytoplankton-fishery observing program in the Lombok Island region (Indonesia) using tools developed and modified/refined during the previous two PICES-MAFF projects FishGIS (2017–2020) and Ciguatera (2020–2023)
- To enable the detection of toxic benthic Harmful Algal Bloom (HAB) species that can threaten tropical reef fisheries
- To record images of the fishery catches for enumeration of fish species and sizes.

Long-term Objectives

- To provide local communities with the capacity and knowledge to sustainably manage their fisheries resources and ensure seafood safety,
- To identify research needs for deploying these tools in PICES member countries.

Agenda Item 7 Science and Technology Annual Report

SB, FUTURE and Committee chairs reported scientific achievements and progress of TOR of their respective Children Expert Groups since ISB-2023 (~5 min for each EG). Committees also updated their specific achievements whenever applicable.

Agenda Item 8 SB chair and membership

8.1. Election of SB Vice-Chair

A term of the SB Vice-chair is one year and they shall be eligible for re-election for a successive term. Jeanette Gann was elected to be the SB Vice Chair from PICES-2022 to PICES-2023. Science Board re-elected Gann as the SB Vice-Chair for the additional 1-year term to PICES-2024 and recommended GC approve her appointment.

8.2. Request for appointment of a Russian SB member

Russia currently has no representation on the Science Board via committee or program chairpersonship. According to PICES Rules of Procedure Rule 12, Russia may appoint a suitably qualified member. Science Board discussed the need for having a Russian representative among SB members. SB requested that Russian national delegates appoint a member at an appropriate time.

PICES Rules of Procedure 12 Science Board

ii. the Vice-Chair of the Science Board shall be elected from amongst the members of the Science Board for a term of one year and shall be eligible for re-election for a successive term. The Vice-Chair will normally reside on the opposite side of the Pacific to the Science Board Chair. The Vice-Chair shall act as Chair whenever the Chair is unable to act;

iii. should a Contracting Party have no representation on the Science Board via committee or program Chairship, it may appoint a suitably qualified member;

Agenda Item 9 Committee Chair Election Results

Dr. Chiba reported the election of the new Committee Chairs and Vice-chairs of BIO, FIS and MEQ committees. SB recommended GC approve the appointment of the new chairs as listed.

**GC requested at IGC-2023 to consider developing a scheme for ECOP involvement in Committee leadership, e.g. setting a shadow ECOP members for each Committee from each member country. To be discussed at ISB-2024*

PICES Rules of Procedure Rule 17 ii (Link)

The Chair of a Scientific Committee or Technical Committee shall be elected by its members from among its members for a term of three years, shall assume office at the conclusion of the Annual Meeting at which elected, and shall be eligible for re-election for one consecutive term.

	Date of Election	New Chairs
BIO	04 Oct.	Dr. Toru Kobari (Japan) was elected as the new Vice Chair of BIO Committee
FIS	09 Oct	Dr. Jackie King (Canada) was elected as the new Chair of FIS Committee Dr. Naoki Tojo (Japan) was elected as the new Vice Chair of FIS Committee
MEQ	22 Oct	Dr. Thomas Therriault (Canada) was elected as the new Chair of MEQ Committee Dr. Takafumi Yoshida (Japan) was elected as the new Vice Chair of MEQ Committee

Agenda Item 10 Proposals from TCODE/SG-DATA

10.1. PICES Open Data Excellence Award

TCODE Chair Ms. Gann proposed the establishment of PICES new award "Open Data Excellence Award". Motivated by the fact that projects with excellent data management and sharing standards have been often ranked low in the POMA award selection process, the idea was raised and discussed by SG-DATA and TCODE members in advance of SB-2023 (see the proposal on the following page). Ms. Gann explained the difference in the criteria of POMA and the new Data award (see **A** below), and the rationale why the new award focusing on data in addition to POMA should be needed.

Although finding the motivation understandable, SB members agreed that the current proposal did not fully clarify the overlap of the criteria of these two awards and the selection protocol of the new award which would likely require modification of the current POMA award selection protocol (see **B** below). SB members suggested that TCODE and MONITOR discuss the rationales and new selection protocols of POMA and the new Data award, and if agreed, submit the revised proposal at ISB-2024 or later.

A. Clarification of difference from PICES Ocean Monitoring Award (POMA)
TCODE discussed the criteria of this award as clearly distinguishable from that of POMA which states

" (POMA Eligibility)*The award is given for significant contributions to the progress of marine science in the North Pacific through long-term monitoring operations, management of data associated with ocean conditions and marine bio-resources in the region, development of advanced and innovative technologies for ocean monitoring or all categories. Recipients may include, for example, research vessels, research or administrative institutes or portions thereof, or technical groups involved in monitoring, data management and dissemination, or the development of tools or technologies that have been shown to enhance ocean monitoring, or a combination of these activities. Outstanding individual efforts may also be recognized*."

For POMA, long-term monitoring programs are often more highly regarded by those ranking the proposed recipients, over databases and data dissemination groups.

POMA keep the requirement for a monitoring program to freely share their data but restrict the award to monitoring programs and utilization of new innovative technology/tools only (i.e. eliminate awards to technical groups solely involved in data management and dissemination.)

Doing these would help clearly separate the POMA vs the Open Data Excellence Awards, and help to achieve SG-DATA's goal of providing incentives for data sharing.

B. POMA Nomination and Selection
Nominations from individuals or groups from PICES member countries should be sent with supporting documentation to the Executive Secretary (Sonia.Batten@pices.int) by the deadline specified in the Call for Nominations. The Technical Committee on Monitoring (MONITOR) and the Technical Committee on Data Exchange (TCODE) will evaluate independently the documents submitted with each nomination, and recommend some or all of the nominations for consideration by Science Board. Evaluations will include the relevance, duration and balance of activities (ocean observation, resource monitoring, data management, etc.). If more than one nomination is considered worthy of recognition by MONITOR or TCODE, rank preferences will be provided to Science Board by each Technical Committee. A maximum of one award will be given each year. To keep a large pool of potential candidates, Science Board will reserve any surplus of recommendations for review in two consecutive years and will be reactivated if nominator gives approval"

Proposal for the PICES Open Data Excellence Award

in honor of Igor Shevchenko

Overview

The **PICES Open Data Excellence Award** is an annual award presented to individuals, groups, or organizations who have demonstrated exceptional innovation in the field of open science, data sharing, and FAIR data principles (Findable, Accessible, Interoperable, Reusable; Wilkinson et al., 2016) in support of the PICES community. This prestigious award recognizes individuals or groups who have made outstanding contributions to the advancement of open data science, with a particular focus on its applications in marine research and oceanography, and as relevant to the PICES mission, data policies, as outlined in the organization's Convention.

The Data Science Excellence Award is bestowed in honor of the respected Dr. Igor Shevchenko, who for many years was deeply involved in national and international data-sharing activities. Dr. Shevchenko's pioneering work in differential games and artificial intelligence, along with his extensive involvement in data sharing and metadata initiatives, has left an indelible mark on the PICES community in the field of marine science. In particular, his tireless work in helping to create and maintain an extensive resource for metadata and data records via the technical committee on data exchange (TCODE) metadata catalog, will be a PICES legacy upon which we continue to build. As an Advisor to the Head of the Pacific branch of the Russian Institute of Fisheries and Oceanography, his leadership and expertise have played a pivotal role in advancing scientific knowledge and promoting international collaborative approaches. Additionally, his dedication to teaching and mentoring students majoring in mathematics and programming has inspired countless young minds to pursue careers in data science and its applications. In recognition of his remarkable achievements and contributions, the PICES Open Data Excellence Award stands as a testament to Dr. Igor Shevchenko's legacy and the enduring impact of his work.

This award honors an individual or group within PICES who exemplifies the spirit of excellence in open data science and data sharing and continues to push the boundaries of knowledge, just as Dr. Shevchenko has done throughout his distinguished career. The award celebrates the spirit of collaboration, transparency, and progress in marine science research through open data sharing and access equity. By recognizing outstanding individuals or groups who embrace these principles, the award aims to inspire further advancements in the field and foster a community committed to innovation in open data and sharing for the betterment of our marine ecosystems and the greatest societal good.

Rationale/Purpose of the Award

The main purpose of the PICES Open Data Excellence Award is to honor those who have excelled in promoting and coordinating marine scientific research by actively and openly sharing and exchanging information and data originating within the PICES region or relevant to the PICES community. The award highlights the importance of open data and its role in driving scientific progress and addressing global challenges, including weather and climate change impacts on marine ecosystems and human activities.

Nomination and Selection Process

The PICES Open Data Excellence Award invites annual nominations from the PICES community, aiming to acknowledge significant contributors to advancing open data, data sharing, and data management in marine-related disciplines. While the award may not be granted annually, its purpose is to honor individuals or groups who have made substantial strides in promoting and advancing a culture of open data principles and practices in alignment with PICES' mission and objectives. This includes advancing open data principles from research to application and particularly within the realm of marine and ocean related work. Priority will be granted to nominees who have demonstrated exceptional dedication to integrating diverse marine science disciplines within their open data initiatives.

Criteria for selection include contributions such as developing or implementing open data tools, infrastructure, databases; publishing reusable and interoperable data/metadata; building open data communities, networks, practices; developing novel training material and mentoring colleagues to enhance open data practices; sharing data, algorithms, code, data management capacity building, and protocols; and substantial contributions to progressing marine science towards data intensive research. Only one award will be conferred each year.

Nominations from individuals or groups residing in PICES member countries should be submitted, along with the requested supporting documentation, to the Executive Secretary (Sonia.Batten@pices.int) by the deadline specified in the Call for Nominations. Nominees who have actively participated in PICES activities or research projects within the organization's purview will receive preferential consideration. The Technical Committee on Data Exchange (TCODE) will independently assess the documents accompanying each nomination and recommend some or all of the nominations for consideration by the Science Board. The Selection Committee, represented by the PICES Science Board, will evaluate all nominations and identify the most deserving recipient. Those who have been nominated but not selected for the PICES Open Data Excellence Award will remain eligible for re-nomination in subsequent years. If re-nominating, please provide updated nomination documents to ensure an accurate representation of the candidate's open data accomplishments. To maintain a substantial pool of potential candidates, the Science Board will retain any excess recommendations for review over two consecutive years, and these recommendations will be reactivated with the nominator's approval.

Award Presentation and Benefits

The Award Presentation Ceremony takes place during the Opening Session of the PICES Annual Meeting. The successful nominee will be provided with a certificate of recognition to attend the ceremony. No financial support from PICES will be provided to the recipient to attend the Annual Meeting where the award is given. Should any representative be unable to attend the Annual Meeting, a Delegate of the recipient's country will be asked to accept the award on behalf of the recipient. The award itself symbolizes recognition of the recipient's commitment to open data principles and their contributions to advancing marine scientific research through data sharing.

10.2. Revision of PICES Data Policy

Ms. Gann presented the draft PICES data policy developed and submitted by SG-DATA to TCODE as a part of the final recommendation of SG-DATA. However, TCODE recognized some paragraphs of the data policy update included vague recommendations and some decisions needed further consideration. TCODE plans to submit a final draft to SB at the ISB-2024 or later.

See **Appendix 1** PICES Draft Data Policy

Agenda Item 11 New Expert Group Proposals

SB members who were the chairs of the proposed parent committees presented the proposals or ideas of new expert groups (see the following pages for full proposals).

AP-ARC. SB Chair Dr. Kang presented the AP-ARC proposal. The proposal of this AP was initially submitted at PICES-2023 but SB recommended it start as a Study Group to develop the TOR and clarify the function of the new group and GC approved the establishment of SG-ARC. SG-ARC summarized the recommendation on the function and objectives of the new expert group in its final report (**Appendix 2**) and submitted the proposal for the new expert group AP-ARC. SB recommended GC approve the establishment of AP-ARC.
**GC did not support the recommendation and suggested a half-year extension of SG-ARC. GC suggested SG members discuss with the GC members (delegates of all member countries) to clarify the functions of the new EG and submit the revised proposal at ISB-2024.*

WG-Global ONCE-CN. POC Chair, Dr. Zhou presented the WG Global ONCE-CN proposal. Although the proposed parent committees, POC and BIO recommended the proposal at their pre-PICES-2023 business meetings, SB agreed that the proposal needed revision to clarify the difference and progress from its predecessor WG46 ONCE. SB recommended the group submit the revised proposal at ISB-2024.

WG-DATA. TCODE Chair Ms. Gann presented the WG-DATA proposal which was developed through the activities of SG-DATA (see SG-DATA final report (**Appendix 3**). SB recommended GC approve the establishment of the new group. While acknowledging the achievement including its final report of SG-DATA, SB noticed that many active SG-DATA members had not officially been appointed throughout its term. SB decided to send another message to GC to urge the swift appointment of EG members including WG-DATA.

AP on Plastic Pollution (planning only). MEQ Acting Chair, Dr. Ross presented the plan of the new expert group to address plastic pollution. SB members questioned the relational why the new EG would be proposed as an AP, not a Section or Working Group. Dr. Chiba explained the criteria of AP and Section which are defined in the PICES Rules of Procedure 13, and SB members agreed that the objectives and function of the new group defined in its draft proposal would fit into Section rather than AP. Dr. Ross confirmed that the group would revise the proposal and submit it at ISB-2024 or PICES-2024 in respect of the discussion at SB-2023.

WG of Post-WG43 (planning only). FIS Vice-Chair, Dr. King reported that the members of WG43 were developing the idea of a new working group with a focus on Small Pelagic Fish. The group will submit the proposal for a new working group at ISB-2024 or PICES-2024.

List of new Expert Groups proposed or under development.

Name	Proposed Parent Committee	Linkages to other PICES EGs and/or other organizations/programmes.	SB Decision
AP-ARC (**Full Proposal**)	SB, FIS, HD, MONITOR	• Coordination of the joint scientific activities of PICES and strategic partners to advance understanding of the Arctic Ocean and its linkage with NP • Contribution to the implementation of SmartNet (with AP-UNDOS, FUTURE, WG49) in Human Dimension aspects. Collaborator UNDOS Regional Collaborative Center for NE Pacific. See **Appendix 2** SG-ARC Final Report	recommended
WG-Global ONCE-CN (**Full Proposal**)	POC, BIO	• Built upon the achievements of the previous PICES/ICES joint WG 33 on "Climate Change and Biologically-driven Ocean Carbon Sequestration" and the PICES/ICES joint WG 46 on "Ocean Carbon Negative Emissions (ONCE)" • ONCE is a UNDOS-endorsed programme	NOT recommended
WG-DATA (**Full Proposal**)	TCODE	• Built upon the recommendation of SG-DATA • Provide a comprehensive strategy for modernizing and streamlining data and information management and sharing practices within PICES. See **Appendix 3** SG-DATA Final Report	recommended
AP on Plastic Pollution and Associated Contaminants (**Full Proposal**)	MEQ	• Promote collaboration of PICES countries on marine plastic pollution research. • Liaise activities in the PICES to Global initiatives of monitoring and policy-making on marine plastic pollution.	To be submitted at ISB-2024 or PICES-2024
Post WG43 Under planning	FIS	WG43 considers the idea of a new Expert Group on Small Pelagic Fish to propose ISB-2024 or PICES 2024	To be submitted at ISB-2024 or PICES-2024

Proposal for

PICES Advisory Panel on the Arctic Ocean and the Pacific Gateways

（AP-ARC）

Acronym AP-ARC
Potential Parent Committee Science Board (SB), FIS, MONITOR, HD
Term Nov. 2023/2024? - TBD

Background

The Central Arctic Ocean (CAO), that is in between the North Pacific and North Atlantic, is in rapid transition, in interaction with and impacting these waters. It has become more accessible to a range of activities. For example, rapid loss of sea ice cover has opened up the CAO for potential fishing opportunities. In this context, the agreement to Prevent Unregulated High Seas Fisheries in the CAO has been signed and entered into force which will necessitate joint research and monitoring. The Pacific gateway to the CAO, i.e., the Northern Bering Sea-Chukchi Sea (NBS-CS) is also experiencing unprecedented warming and loss of sea ice as a result of climate change. Declines of seasonal sea ice and warming temperatures have been more prominent in the northern Bering and Chukchi seas than in the European Arctic. Chronic and sudden changes in climate conditions in this Arctic gateway are clearly reshaping the system and its food-webs, and enlarging opportunities for commercial activities (shipping, oil and gas development and fishing), with uncertain and potentially wide-spread cumulative impacts.

PICES took upon responsibilities in the CAO issues when it joined the WGICA (Joint PICES/ICES/PAME Working Group on an Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (CAO)) by establishing WG39 in 2017. In 2019, PICES also established WG44 (Joint PICES/ICES Working Group on Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea) in efforts to understand the Arctic system and its impacts to the sub-Arctic and mid-latitude North Pacific. An integrated ecosystem assessment (IEA) is a useful approach that is shared by these two Working Groups, particularly relevant with substantial science and policy needs emerging for the sustainable Arctic. This renders a coordinated IEA of the CAO and NBS-CS as a priority task. In addition, it is of particular significance to developing future approaches for The United Nations Decade of Ocean Science for Sustainable Development in the Arctic Ocean (UNDOS-Arctic), where science for resilience and sustainability is more important than anywhere else in the world oceans. Despite this continuing significance and unfinished commitment to WGICA and also WGIEANBS-CS, WG 39 ended the term with the closure of PICES 2022 and WG 44 will end the term with the closure of PICES 2023 Annual Meeting. In this context, we propose PICES establish AP-ARC to coordinate and integrate PICES scientific activities on the Arctic issues and to further advance the understanding of the Arctic system and linkages and impacts to the North Pacific.

Proposed Terms of Reference (ToRs)

1. Coordinate and promote the joint scientific activities of PICES to further advance the understanding of the Central Arctic Ocean and its interaction and linkage with its Pacific Gateways;
2. Convene workshops/sessions to engage those involved in IEA and monitoring of the Arctic Ocean and its Gateways;
3. Represent and coordinate responses of PICES concerning the Arctic Ocean and the connected waters in cooperation with partners and other international organizations, including WGICA (Joint PICES/ICES/PAME Working Group on an Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (CAO)), and WGIEANBS-CS (Joint PICES/ICES Working Group on Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea)；
4. Develop recommendations for PICES to better collaborate within PICES and with larger international

initiatives relevant to the Arctic Ocean including the UN Decade of Ocean Science;

Proposed Co-chairs (two west and two east)
Sei-Ichi Saitoh (WG39) (Japan) - ssaitoh@arc.hokudai.ac.jp
Hyoung Chul Shin (WG39) (Korea) - hcshin@kopri.re.kr
Nadja Stefanie Steiner (Canada) - nadja.steiner@dfo-mpo.gc.ca
Sarah Wise (WG44) (USA) - Sarah.Wise@noaa.gov

Proposed Membership
Andrea Niemi (WG-44) (Canada)
Nadja Stefanie Steiner (WG-44) (Canada)

Zhongyong Gao (CC-S, WG-39, WG-44) (China)
Guangshui Na (FUTURE-SSC, MEQ, SB, WG-35, WG-39) (China)
Fang Zhang (WG39) (China)

Hyoung Chul Shin (WG39) (Korea)
Hyoung Sul La (WG-44) (Korea)

Sei-Ichi Saitoh (WG39) (Japan)
Fujio Ohnishi (WG39) (Japan)
Takafumi Hirata (WG-44) (Japan)
Shigeto Nishino (WG-44) (Japan)

Yury I. Zuenko (CREAMS-AP, POC, S-CCME, SG-UNDOS, WG-35, WG-40, WG-44) (Russia)
Kirill Kivva (WG-44) (Russia)

Zack Oyafuso (USA)
Sarah Wise (WG44) (USA)
Elizabeth A. Logerwell (FIS, WG-44) (USA)
Lisa B. Eisner (MONITOR, WG-44) (USA)
David L. Fluharty (WG-39) (USA)

*This is a tentative membership, in future, almost all WG44 members will join this AP.

References
Skjoldal, H. R. (Ed.). 2022. Ecosystem assessment of the Central Arctic Ocean Description of the ecosystem. ICES Cooperative Research Reports Vol. 355. 341 pp. https //doi.org/10.17895/ices.pub.20191787

Proposal for a new PICES/ICES joint Working Group on Global Ocean Carbon Negative Emissions for Carbon Neutralization (WG Global ONCE-CN)

Group type **Working Group**
PICES Acronym WG Global ONCE-CN
Parent Committees POC, BIO
Term 2024-2027

PICES Chair
Nianzhi Jiao /China
Co-Chair from ICES
Carol Robinson /UK (to be finalized)

Background, Goals and Motivations

Facing the upcoming climate crisis, to achieve the goal of global carbon neutralization and the Paris Agreement to limit global warming, actions were taken in the past decade. The previous PICES/ICES joint WG 33 on "Climate Change and Biologically-driven Ocean Carbon Sequestration" and the PICES/ICES joint WG 46 on "Ocean Carbon Negative Emissions (ONCE)" have finished its missions on identifying the knowledge gaps, developing innovations of new technology and integrating ONCE approaches. The ocean has been and is being under great impacts from anthropologic activities. The working groups have discussed about the theoretical effects of climate change on the carbon cycle in the ocean (WG-33), as well as the showcases of innovative technologies, methodologies, and best practices that leverage the potential of the world's oceans to carbon negative emissions (WG-46).
Global Ocean Negative Carbon Emissions (Global ONCE) has been a newly endorsed UN decade program, which requires international cooperation and putting scientific efforts into practical actions on carbon negative emissions. Based on the previous WG-33 and WG-46, the newly proposed PICES/ICES joint Working Group on "Global Ocean Carbon Negative Emissions for Carbon Neutralization (Global ONCE-CN)" will promote collaborations and communications among the ONCE science community to achieve ONCE approaches consensuses regarding research strategy, technical protocols, and MVR assessment framework moving forward to the goal of the global carbon neutralization for mitigating climate change and a sustainable future ocean. The activities of the proposed WG will be supported by the Global-ONCE UN decade program, MOST-ONCE and Xiamen University, China.

Tentative Terms of Reference

The main objective of this WG is to link scientific theories with techniques, engineering and policies.
The key scientific topics will be

- Integration of the theoretical framework of carbon cycle in the ocean, including the physical, chemical and biological processes ;
- Synergistic effects on climate change of the oceanic carbon pumps under anthropologic impacts;
- Innovative technologies for oceanic eco-engineering;
- Sustainable coastal aquaculture and carbon negative emissions;
- Feasibility of ocean carbon negative emissions (ONCE) approaches;

Based on the scientific agreements of the key scientific topics, the WG aims to improve the communications between scientific community, managers, policymakers and the general public on the theme of oceanic carbon neutralization.

Expected Deliverables

1) Develop an international network of communication and collaboration for ONCE science and technology;
2) Co-design research strategy and technical protocols;
3) Develop an assessment framework for ONCE approaches;

4) Facilitate capacity building, equitable policy, governance and societal understanding.

Tentative Members (A-Z)

- **PICES member**

Curtis Suttle /Canada (Marine Viruses and Ecology)
Hongsheng Bi /USA (Fisheries Oceanography and Imaging systems)
Jeremy Testa /USA (Eutrophication and Ocean Acidification)
Jung-Ho Hyun /Korea (Sediment Biogeochemistry and Microbial Oceanography)
Yanli Lei /China (Foraminifera Diversity and Global Change)
Zhao Zhao /China (Complex Interactions of Marine Microbes and Organic Matters, WG Secretary)

- **ICES members**

Carol Robinson /UK (Co-Chair from ICES to be finalized)
Wei-Jun Cai /USA (Air-sea CO_2 flux; Carbon Cycling Acid-base and Redox Chemistry)
Buki Rinkevich /Israel (Oceanographic & Limnological Research)
Celeste López-Abbate /Argentina (Biological Oceanography, Marine Ecology)
Gerhard J. Herndl /Austria (Marine Microbial and Molecular Ecology)
Helmuth Thomas/Germany (Marine Chemistry in Marginal Seas)
Maria Triantaphyllou /Greece (Micropaleontology Paleoenvironment Stratigraphy)
Michael Gonsior /USA (Photochemistry, Dissolved Organic Matter Diversity)
Philip Renforth /UK (Carbon Dioxide Removal)
Ramaiah Nagappa /India (Microbes and Ocean Productivity

Terms of Reference for the proposed PICES DATA Working Group

Acronym WG-DATA

Parent Committee(s) TCODE

Rationale & Goals of WG-DATA

The PICES Data Management Working Group (WG-DATA) is established to address the need for an enhanced data, metadata, and information management and data sharing plan within the North Pacific Marine Science Organization (PICES). The WG-DATA will build upon the recommendations of the Study Group on Encouraging Data Awareness and Increased Transmission and Accessibility (SG-DATA) and provide a comprehensive strategy for modernizing and streamlining data and information management and sharing practices within PICES. By aligning with international standards and promoting a culture of data sharing, PICES aims to enhance the accessibility, reach, and utility of its scientific data, fostering collaboration and advancing marine science in the North Pacific region.

Terms of Reference

1. **Revise and update the PICES Data Policy.** Revise and update the PICES Data Policy to align with international standards (UNESCO IOC and UN Decade of Ocean Science), incorporate FAIR and CARE principles, promote data sharing culture, and recommend data repositories and open data licensing options.
2. **Promote a culture of data sharing within PICES.** Promote a culture of data sharing within PICES such as by identifying and addressing data sharing barriers through an annual survey to PICES members and other related organizations, offering education and training resources, developing a data management road map, creating an inventory of data assets, identifying novel ways to incentivize data sharing, and encouraging 'data publications' adhering to open data licensing and DOI citation standards.
3. **Recommend data management platforms, standards, and technologies.** Identify, recommend and support data management platforms, standards, and technologies aligned with open data principles and internationally supported ocean data standards. Modernize PICES data management by developing accessible data management templates, facilitating report publication to repositories, evaluating the TCODE Catalog, promoting DOIs and data licensing, identifying collaborative word-processing tools, and establishing a PICES Data Stewardship Officer (DSO) for coordinated data management.
4. **Develop a data, metadata, and information (reports/pubs) flow diagram** from expert groups, PICES members, summer schools, and other associated initiatives across the PICES network to a final repository (e.g. recommended databases, searchable catalogs, and metadata catalogs).

Proposed/recommended chair(s)
We would like to propose 2 chairs (ideally one from West and East Pacific).
Please include your name here if you would like to be considered to be chair for WG-DATA if it is approved.

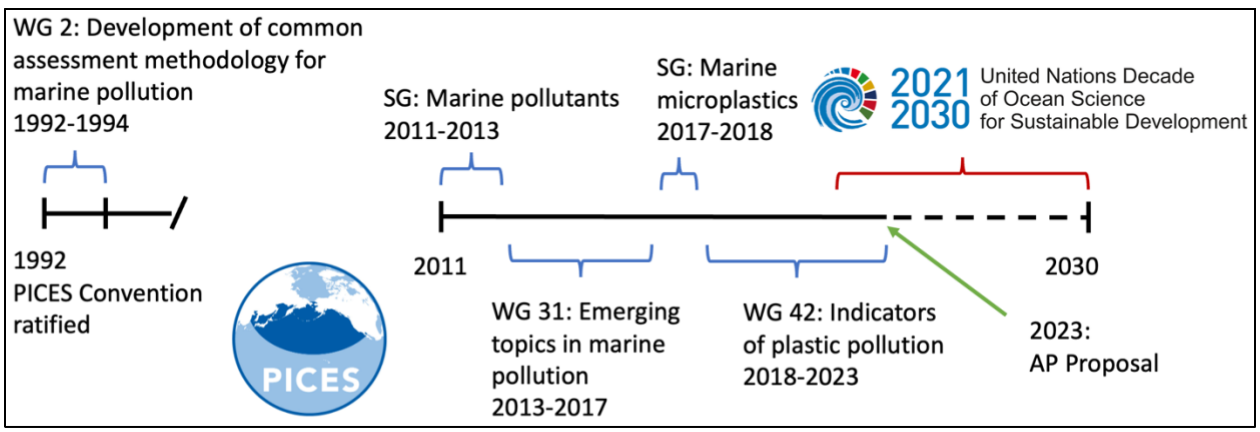
- Brett Johnson

Proposed/recommended full members
Please include your name here if you would like to be considered to be involved in WG-DATA if it is approved

- Brett Johnson
- Jeanette Gann
- Erin Satterthwaite
- Hernan Garcia

Proposal for an Advisory Panel on Plastic Pollution and Associated Contaminants

Rationale
The countries surrounding the North Pacific Ocean contain some of the most densely populated regions on the planet. The North Pacific absorbs the burden of this footprint by being the final sink of many pollutants. In terms of plastic pollution, no large open ocean region is more affected than the North Pacific. Despite this, PICES has not had a stable expert group to specifically keep pace with plastic debris and pollutants. The first expert group on marine pollution dates back to the beginning of PICES, with Working Group 2 (see timeline below). In 2017, the Study Group on Marine Microplastics (SG-MMP) was formed and led by Won Joon Shim. Working Group-42 Indicators of Marine Plastic Pollution (https //meetings.pices.int/members/working-groups/wg42) took over where SG-MMP left off. Co-led by Jennifer Lynch and ChengJun Sun, WG-42 was especially productive, with members convening scientific sessions at multiple PICES conferences, co-leading a session at the 2021 ICES annual meeting, and participating and co-leading several sessions at the 7th International Marine Debris Conference in Busan, Korea in 2022. Also in 2022, members of WG-42 published three peer-reviewed papers summarizing their work identifying indicators of plastic pollution in the North Pacific, which also outlined monitoring guidelines for seawater, beaches, and biota. WG-42 is concluding its five-year term in 2023 (see timeline below).



PICES Timeline of pollution related expert groups. Despite interest in marine pollution from the advent of PICES, there has not been an Advisory Panel or Section to address this pervasive issue in the long term.

The bioindicators work that came out of WG-42 (Savoca et al. 2022, *Environ Pollut*) began an international collaboration, The Global Plastic Bioindicators Project, which was recently endorsed as a Project for the UN Decade of Ocean Science under the program SmartNet (an ICES-PICES collaboration). As such, we expect this proposed Advisory Panel to interact closely with the Advisory Panel on the United Nations Decade of Ocean Science, the Section on Marine Birds and Mammals, as well as our PICES parent Committee, Marine Environmental Quality.

Unfortunately, marine plastic pollution is here to stay. In this world, PICES should have a standing expert group that member nations can consult for longstanding, as well as novel unexpected pollutant pulses, discoveries, and concerns. In concert with other stressors like climate change, pollution may affect living marine resources and human welfare in the PICES region and is thus well aligned with the PICES mission. It is important that PICES keeps pace with plastic pollution research and collaboration on the world stage with other intergovernmental science working groups (e.g., ICES Working Group on Marine Litter https //www.ices.dk/community/groups/Pages/WGML.aspx; GESAMP Working Group 40 http //www.gesamp.org/work/groups/40). To do so, PICES needs to have an expert group that can directly interface with these sister groups in other regions as well as with representatives in PICES member nations.

Terms of Reference

1. Work collaboratively to characterize and understand the flow and impacts of plastic pollutants within the PICES region (i.e., sources and sinks), including, but not limited to, the Great Pacific Garbage Patch.
2. Continue to develop abiotic and biotic indicators of plastic debris and pollutants in the PICES region and develop monitoring plans to assess temporal trends in plastic pollutants as new legislation takes effect (e.g., High Seas Treaty, UN Plastics Treaty). Provide scientific guidance towards the international harmonization of plastics monitoring data within and beyond the PICES region.
3. Plan workshops/sessions/symposia related to plastic pollution and maintain a community of scientists within PICES that will work together to evaluate and recommend strategies for PICES member nations to engage on plastic pollution issues.
4. Engage professionally with other intergovernmental science organizations (e.g., ICES for the North Atlantic, AMAP in the Arctic, APN in the western and subtropical Pacific, SCAR in the Southern Ocean etc.) and entities (e.g., SCOR, GESAMP) to accomplish these Terms of Reference.
5. Publish reports on Advisory Panel accomplishments.

Proposed Chairs

Dr. Matthew Savoca (Co-Chair) USA (ECOP)
Hopkins Marine Station of Stanford University
msavoca13@gmail.com

Dr. ChengJun Sun (Co-Chair) People's Republic of China
First Institute of Oceanography, Ministry of Natural Resources
csun@fio.org.cn

Potential membership

People's Republic of China
Dr. Connie Ka-yan NG (ECOP)
City University of Hong Kong
kayan.ng.connie@gmail.com

Prof. Huahong Shi
East China Normal University
hhshi@des.ecnu.edu.cn

Republic of Korea
Dr. Miran Kim **(ECOP)**
Seabirds Lab. of Korea
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Dr. Sang Hee Hong
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Dr. Shiye Zhao **(ECOP)**
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Dr. Sarah Dudas
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Dr. Jennifer Provencher
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Dr. Susanne Brander
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anela@ucsd.edu

Dr. Amy V. Uhrin (Co-Chair) USA
NOAA Marine Debris Program
amy.uhrin@noaa.gov

Agenda Item 12 EG Proposals for SB Recommendation
- with the implication of funding support

Science Boards reviewed an intersessional workshop proposal (12.1) and four travel fund requests (12.2). SB ranked and adjusted the requested budget based on the ranking. SB recommended GC approve the funding for the workshop and travel support listed below.

12.1. Intersessional Workshop Proposal

AP-CREAMS (MONITOR)			
Workshop Title / Date	**Location/Host**	**Amount and rationale of fund request**	**SB Ranking**
International studies of North East Asian Marginal Seas from circulation and biogeochemistry to socio-economic research. 30th Anniversary of the CREAMS program. 2~3 days in July 2024 Expected participants No 80	Seoul National University, Korea (Prof. SungHyun Nam) *Local support to be secured	CA$ 7,000 Partial travel support for 4 participants (3 students or ECOPs and 1 invited speaker) **proposed as CA$ 10,000 for 6 participants (4 students/ECOPs and 2 invited speakers) and adjusted as above.*	Rank 4

Proposal for the Intersessional Workshop in Summer 2024

International studies of North East Asian Marginal Seas from circulation and biogeochemistry to socio-economic research. 30th Anniversary of the CREAMS program

SungHyun Nam, namsh@snu.as.kr; Vyacheslav Lobanov, lobanov@poi.dvo.ru; Fei Yu, yuf@qdio.ac.cn
Date July 2024, Korea

An international program on Circulation Research of East Asian Marginal Seas (CREAMS) started in 1993. It was the first international program in this area and it significantly promoted collaboration between marine scientists of border countries as well as their colleagues from other parts of the world. East Asian Marginal Seas are one of the most affected areas in the global ocean by climate changes and anthropogenic impacts. There have been considerable advances in exploring these seas over the 30 years. Being initially focused on the research of water circulation and ventilation, the CREAMS program evolved into biogeochemical and ecosystem research and now is seeking a way to be a more socio-economic oriented program. This workshop would summarize and share the knowledge and experience in water dynamics, biogeochemistry, ecosystem and their variability at multi-scales, and discuss the future directions of research in the area moving toward a multidisciplinary science. It is especially important to identify links between marine sciences and socio-economic requirements in the area to develop an integrative program for future research in this region to correspond to the UN Decade targets. Participation of young scientists and students is especially welcomed to involve them in the CREAMS activity. The workshop outcome should clarify a vision of international comprehensive marine research in the North East Asian region that meets the current needs of society. It is expected to prepare a special issue of a journal based on the workshop presentations.

Motivation
Acknowledge the CREAMS founders, involve young scientists, discuss the future of CREAMS, and move closer to SEES.

12.2. Travel Support

Requests of travel support for PICES scientist(s) who convene or be invited to the Sessions/Workshops relevant to EG's activities at the international meeting(s) etc. other than the PICES Annual Meeting.

AP-UNDOS (SB)			
Conference title / Date / Location	**Recipient name/ organization/ country/contact**	**Amount and rationale of fund request**	**SB Ranking**
UN Ocean Decade Conference April 2024, Barcelonan, Spain	AP-UNDOS Chair (1) ECOP (1)	CA$ 6000 *Invited by IOC to host the side event on AP-UNDOS related project (IP M. Makino covers his travel at his own cost)	Rank 2
AP-ECOP (SB)			
Conference title / Date / Location	**Recipient name/ organization/ country/contact**	**Amount and rationale of fund request**	**SB Ranking**
UN Ocean Decade Conference April 2024, Barcelonan, Spain	ECOP (2) one from WNP one from ENP	CA$ 6000-7000 *to participate in two joint ECOP-SmartNet side-events, a. Wave of Wisdom Bridging Generations for Ocean Conservation (intergenerational dialogue and networking session),b. The inclusivity we need for the ocean we want.)	Rank 1
BIO (also S-CCME, S-MBM, AP-NPCOOS)			
Conference title / Date / Location	**Recipient name/ organization/ country/contact**	**Amount and rationale of fund request**	**SB Ranking**
ICES ASC 2024, PICES-cosponsored theme session "Evaluating ecosystem-based management performance examples of success" Gateshead UK, Sept 9-12	BIO member Xuelei Zhang ECOP (1)	Up to CA$ 6000 *ICES Science Committee notes that the cost of PICES convenor should be supported by PICES **proposed as CA$ 9000 for Zang and 1-2 ECOPs and adjusted as above.*	Rank 3
H-HAB (MEQ)			
Conference title / Date / Location	**Recipient name/ organization/ country/contact**	**Amount and rationale of fund request**	**SB Ranking**
S-HAB intersessional meeting, Seattle, mid-Feb (3 days), 2024	Member from Western NP (1) or ECOP (1)	CA$ 3500 *for writing 2 journal papers (planned to submit to *Nature Commentary* and *Journal Harmful Algae*)" **proposed as CA$ 7500 for 1 WNP member and 1 ECOP and adjusted as above.*	Rank 5

Agenda Item 13 EG Proposals for SB Recommendation - without funding request

13.1. Membership Needs/Change

SB acknowledged the membership requests of each EG and asked the national delegates to consider accelerating the membership appointment process. SB requested GC appoint EG members ***within one month*** of this request if possible to avoid the delays of EG progress.

Request for the acceleration of the membership appointment process.
When SB recommends the establishment of new EGs with a suggested list of members, the official appointment of the members by member countries often takes a long time, sometimes even more than 6 months despite repetitive requests for a membership decision by the Executive Secretary. This has caused serious delays in the launch of EG activities and stagnation in their implementation plan. SB request the GC and national delegates to consider this situation seriously and accelerate the decision-making process of the submitted membership requests.

Requested SB/GC2022, Requested ISB/IGC2023

EG	Country	Name/Organizations if identified	email
SG-GREEN	Secretariat China Russia	1 liaison (Replacement of Lori Water) Dr. Ruoyu Guo (Second Institute of Oceanography) 1 – 2 members	dinoflagellate@sio.org.cn
AP-NIS	Japan USA	Keiji Iwasaki, Nara University John Darling, US Environmental Protection Agency	iwasaki@daibutsu.nara-u.ac.jp darling.john@epa.gov
AP-SciCom	Russia	1 – 2 members	
AP-UNDOS	Canada Russia	Raphael Roman (IOC) UNDOS ECOP leaders Khush Jhugroo, SmartNet outreach to SIDS Evgenia Kostianaia (IOC), ECOP leader in UNDOS	rk.roman@unesco.org khushboo.jhugroo@hatch.com e.kostianaia@unesco.org
AP-NPCOOS	Canada	Jennifer Jackson (DFO)	Jennifer.Jackson@dfo-mpo.gc.ca
WG-48	USA China	~~Sabrina Groves (U Maryland) ECOP~~ (stay as an observer confirmed by Hongsheng Junbai Yue (Tsinghua U) ECOP	sgroves@umces.edu. yuejb21@mails.tsinghua.edu.cn.
WG-49	Canada	Jennifer Jackson (DFO) => approved by Canada at GC-2023	Jennifer.Jackson@dfo-mpo.gc.ca
WG-50	Russia Canada	Nikita Aleksandrovich Chikanov (St. Petersburg State University) Sergey Prants (Pacific Oceanological Institute, Department of the Ocean and Atmosphere Physics) Jody Klymak (Unv Victoria)	erjey_nik@mail.ru prants@poi.dvo.ru jklymak@uvic.ca
WG51 (HD)	Canada Korea USA	Raphael Roman (IOC) ECOP Karen Hunter (DFO) (also co-chair) Rebecca Martone (Tula, DCC NEP) Jongseong Ryu (Anyang U) Rachel Seary (NOAA) ECOP	rk.roman@unesco.org karen.hunter@dfo-mpo.gc.ca rebecca.martone@tula.org jsryu90@gmail.com Rachel.seary@noaa.gov
S-CCME (FIS)	Canada Korea	Philina English (DFO) (ECOP) Dongwha Shon, Minje Choi, Seokjin Yoon	philina.english@dfo-mpo.go.ca
S-HAB	Canada	Svetlana Esenkulova (PSF)	sesenkulova@psf.ca
FUTURE	Canada Japan Korea USA	Mackenzie Mazur (DFO)(ECOP) Daiki Ito (FRA)(ECOP) Seongbong Seo (KIOST)(ECOP) Erin Satterthwaite (UCSD)(ECOP)	mackenzie.mazur@dfo-mpo.gc.ca ito_daiki41@fra.go.jp sbseo@kiost.ac.kr esatterthwaite@ucsd.edu
HD	USA	Sarah Wise to replace Ron Felberton	sarah.wise@noaa.gov
MONITOR	USA	Mariela K. Brooks (NMFS, NOAA)	mariela.brooks@noaa.gov
TCODE	Russia	1-2 members	

13.2. Change of EG Chairs

SB recommended GC approve the appointment of new chairs as listed.
*Canada committed to appointing Jackson's membership within a week after the GC meeting.

EG (Reporting Committee)	Current Chair to replace	New Chair Name/Country/Organization
AP-NPCOOS (MONITOR)	Kim Juniper (Canada)	Jennifer Jackson, DFO (Canada) **upon her membership approval*

13.3. Extension of the WG Term

SB reviewed the proposals for the extension of these Working Group terms and recommended GC approve the extensions.

EG (Reporting Committee)	Duration	Rationale
WG48 (BIO)	1 year to PICES-2024	To complete the review paper "A primer on underwater plankton imaging systems" which the WG currently work on. *approved during the Covid pandemic.
SG-GREEN	6 months to PICES-2024	To work together to publish our survey findings in PICES Press and to formulate a presentation for PICES 2024 to present our survey results to the PICES membership. **GC deferred the decision to ISB-2024*

13.4. Change of TOR

SB recommended GC approve the change of TOR as listed.

EG	Description and Rationale of Changes
WG47	**1.** Omit the following items from Year 2 TOR • *Use available data to predict climate-induced changes in the distribution of seamount fauna* (rationale) It turned out WG-47 lacks the capacity to undertake this TOR although the members recognize the value and importance of such research. **2.** Change the focus of the following TOR from "pelagic, demersal, *and* benthic taxa/species/biodiversity" to "pelagic, demersal, *or* benthic taxa/species/biodiversity" (rationale) Current members of WG-47 focus their research activities on benthic taxa. The four specific TORs that require this change are • *Year 1 Gather data on the distribution and life history of pelagic, demersal,* ***OR*** *benthic taxa, including fish and invertebrate assemblages associated with seamounts in the North Pacific Ocean and facilitate their submission to appropriate biodiversity databases, e.g., Ocean Biogeographic Information System (OBIS).* • *Year 2 Identify environmental and ecological predictors of patterns in the distribution and biodiversity of pelagic, demersal,* ***OR*** *benthic taxa associated with seamounts in the North Pacific Ocean.* • *Year 2 Apply one or more modeling approaches (e.g. MaxEnt, Boosted Regression Trees, or high-resolution bathymetry-based models) to predict the distribution of pelagic, demersal,* ***OR*** *benthic biodiversity associated with seamounts in the North Pacific Ocean.* • *Year 3 Identify potential indicators for assessing and monitoring the biodiversity of pelagic demersal,* ***OR*** *benthic taxa associated with seamounts.*

**GC discussed the proposed changes to the Terms of Reference for WG47 but while they understood the issue GC did not think it appropriate to retroactively change these ToRs, instead recommending that it would be more transparent to include details in the final report indicating where goals could not be met, and identifying the reasons such as lack of capacity, or data. Such information will be useful in guiding the next steps.*

Agenda Item 14 Proposal for SmartNet Coordinator

SmartNet and AP-UNDOS co-chair, Dr. Bograd, presented the proposal for the SmartNet Coordinator to follow up on the scheme for an "UNDOS intern" which was proposed at SB-2022 and acknowledged at GC-2022. SB reviewed the proposal and recommended GC support the proposal and take the needed actions for having a SmartNet Coordinator.

Coordination Requirement
SmartNet was intended to be the flagship contribution of ICES and PICES to UNDOS; The motivation was to use the legacy, infrastructure, expertise, and networks in both organizations to provide leadership to the Decade. However, the increase in the number of UNDOS activities and the growing size of the community have correspondingly increased the challenge.

SB/GC Decision at PICES-2022
At PICES-2022, SB proposed the establishment of a new scheme for "UNDOS intern" to facilitate the coordination of UNDOS activities within PICES, and between PICES and the various UNDOS entities (national Committees, regional Coordination Centres, other global and regional UNDOS programs, projects and actions, and the IOC). Despite the interest expressed by GC, no individual has been subsequently identified by a member country. The AP-UNDOS co-chairs have reiterated their request to both PICES and ICES Secretariats.

The full proposal summarizes a request for additional coordination requirements, perhaps via a funded post-doc, presented to both ICES and PICES leadership

**GC reviewed and discussed the UNDOS Coordinator proposal. It was agreed that voluntary financial contributions, or in-kind contributions of staff time, would be equally useful in filling this role and members were encouraged to investigate possible options.*

Proposal for the SmartNet Coordinator – benefits and resources

Background
SmartNet (Sustainability of marine ecosystems through global knowledge networks) is a joint ICES-PICES activity and was announced by the IOC as a Program in the very first round of UNDOS activity endorsements. Momentum generated by the proposal's success was initially maintained with outreach, via websites and articles, and satellite activities as part of the IOC's suite of events, but is increasingly difficult to sustain without additional resources. As other UNDOS activities at the national, regional and global scale have been initiated there is an ever-increasing set of actors to coordinate with.

SmartNet is meant to be the flagship contribution of ICES and PICES to UNDOS; The motivation was to use our legacy, infrastructure, expertise, and networks to provide leadership to the Decade. But without the capacity to coordinate activities across, and outside, our organizations we are not really providing that leadership, or having as big an impact in the Decade as we hoped. Most UNDOS Programs have a full-time coordinator to build networks, interact with the Decade Coordination Unit at the IOC, liaise with regional and national Decade centres, programs and projects. While the SmartNet leadership has been trying to achieve the required coordination they are busy people for whom this is one role, competing with many others. A dedicated coordinator is needed. Now that we are in year three of the Decade it is time for ICES and PICES to make an investment in the program if it is to succeed.

Goal

A two to three-year dedicated position to coordinate SmartNet and other ICES/PICES UNDOS contributions. Coordination is required across both organizations, to connect our expert group activities with relevant UNDOS projects and programs, to organize workshops and meetings, to liaise with the Decade Coordinating Unit at IOC, regional Decade Collaborative Centres and national Decade committees for ICES and PICES member countries.

Resource Requirements

Costs would be on the order of $100,000 per year for salary and travel. The position could be primarily based at either Secretariat but would be shared. It could also be achieved by a secondment from a government agency active in ICES or PICES and perhaps might be of most interest to one active in both (such as DFO or NOAA).

The position could be a straightforward administration role, or it could be designed as a post-doc, for an individual interested less in research and more in international science organization. There would be opportunities to work with a large number of scientists from different countries, to build networks, to organize scientific meetings and products. It is also an intent to have SmartNet publications in the peer-reviewed literature, e.g. a vision for co-designing international science, so there could be opportunities to publish.

Benefits

Dedicated Smartnet coordination will result in a higher profile for ICES and PICES within the Decade and more visible leadership. It will result in more effective communication of our activities and outputs. A more rapid awareness of other relevant Decade activities will result in a more effective use of our limited resources and likely more tangible progress toward meeting the Decade Challenges than would occur without this coordination.

Member countries would benefit through a clearly defined connection from national efforts to international UNDOS activities. It would provide a mechanism to facilitate access to ICES/PICES infrastructure to deliver UNDOS activities. Supporting the SmartNet coordination would be a way for member countries to show commitment to the Decade.

Agenda Item 15 PICES-2024 Planning and PICES-2025 Session/Workshop Proposal Review Protocol

PICES-2024 Basic information

Conference Title The FUTURE of PICES Science for Sustainability in 2030
Date October 26-November 3, 2024, **Location** Honolulu, USA
Local Organizer N/A (hosted by PICES Secretariat)
Venue Honolulu Convention Center
Format in-person (hybrid option for business meetings is under consideration)
Including One-day FUTURE Open Science Meeting

Dr. Chiba presented the basic information and model structure of PICES-2024 during which a 1-day FUTURE Open Science Meeting would be held. With the lack of a host from among the member countries for 2024, she explained that PICES Secretariat would host the meeting and thus needed to be prepared to compromise on the meeting budget and duration. Considering the constraints, SB agreed to the model structure of PICES-2024 as follows.

SB recommendation for GC approval

- Hold a 1-day FUTURE Open Science Meeting on Friday **GC decided to have it on Monday.*
- Committee Paper Sessions will be set for poster-only
- Science Board holds its 1st meeting in person on October 25 at a separate venue (e.g. hotel room) **not Approved by GC*
- Committees/FUTURE holds one virtual pre-PICES-2024 business meeting and one in-person meeting (evening) during PICES-2024
- EGs are requested to virtually hold a business meeting before the Annual meeting. An additional in-person business meeting would be approved for each EG upon request at ISB-2024.

As for the selection of Session/Workshop proposals for PICES-2024, there was a variety of views on whether PICES should accept late submission of proposals. SB discussed the optimal protocol (timeline) for the selection of the proposals for the following PICES Annual Meeting. SB concluded that PICES should keep the current protocol with the deadline a few weeks in advance of the Annual Meeting, which allows Committee members to have enough time to review the proposals before the SB meeting. However, SB didn't exclude the case of late submissions if the proposals had significant scientific excellence.

GC Discussion on Annual meeting session and workshop planning.
GC reviewed the proposed workshops, sessions and draft schedule for PICES-2024. GC requested to hold the FUTURE Symposium on Monday after the Opening Session and a slot for a Panel to discuss future science priorities for PICES on Friday before the Closing Session. There was discussion on balancing the length of the annual meeting (and the associated travel burden for member countries) while allowing sufficient time for the discussion and development of emerging ideas. GC proposed a modified schedule of session/workshop proposals (for PICES-2025) to be trialed in 2024 and adjusted the schedule of PICES-2024 to reflect this.

(GC Decision 2023/S/14)
GC approved a new process for 2024 whereby the Session and Workshop proposal deadline be set two weeks after the end of the PICES annual meeting. Committees will work inter-sessionally/by correspondence to review, rank and report to Science Board by the end of November. Science Board will review and provide to GC in early December for approval before year end.

PICES-2024 Timeline (**modified version based on the GC decision*)

Pre-PICES-2024 Online Business Meetings		
late Sept ~ early Oct	EG online business meeting to develop the report to Parents CMT	
early Oct ~ mid Oct	Committees (& FUTURE) online business meeting to review Children EG Reports	
PICES-2024 in-person Meeting		
Date	**Session/WS**	**Business Meeting**
Oct 26 (Sat)	Parallel Workshops x 3	Day EG meetings Evening CMT meetings
Oct 27 (Sun)	Parallel Workshops x 3	Day EG meetings Evening CMT meetings
Oct 28 (Mon)	Opening Session (no keynote) FUTURE Symposium	
Oct 29 (Tue)	Parallel Topic Sessions x 3	EG meetings, F&A meetings?
Oct 30 (Wed)	Parallel Topic Sessions x 3	EG meetings F&A meetings?
Oct 31 (Thur)	Parallel Topic Session x 3 Evening Poster Session	EG meetings
Nov 1 (Fri)	AM Panel on the future of FUTURE and the next decade Noon Closing Session	PM SB Day 1
Nov 2 (Sat)		SB Day 2, GC Day 1
Nov 3 (Sun)		GC Day2

New Protocol of Session/Workshop Proposal (for PICES-2025) Review and Timeline

Date	Action
Nov 14, 2024	Session/Workshop proposal submission due
~ Nov 30, 2024	Committees review & rank proposals (via virtual meeting or email basis)
~ early Dec, 2024	Science Board reviews the Committees' proposal ranking, selects the workshops/sessions for PICES-2025, and recommends them for GC approval (via virtual meeting or email basis)

Agenda Item 16 PICES-2024 Session/Workshop selection

During the virtual business meetings held before PICES-2023, Committees and FUTURE SSC members reviewed and ranked the Session and Workshop proposals based on their relevance to the conference scope, the quality of the proposal, and each Committee's interest in sponsoring. Dr. Chiba provided SB members with the averaged Committee/FUTURE rankings in advance of the SB meeting and SB made the selection considering the evaluation of the Committees/FUTURE and other factors. SB declined to accept a proposal submitted during the PICES-2023 (two days before the SB meeting) in light of fairness and transparency in the selection procedure in which evaluation of Committee and FUTURE SSC members should be respected. SB recommended GC approve the following Workshop and Session proposals for PICES-2024.

List of the Workshop Proposals

	Title	Relevant PICES EG	Correspondin g convenor	Duration (day)	Sponser CMT	Potential Cosponsors
W1	North Pacific Plankton Time Series Data Analyses and Synthesis	AP-NPCOOS	Akash Sastri	1.0	FUTURE, BIO, MONITOR, TCODE	
W2	Applying social-ecological frameworks to explore actionable solutions for climate extreme events across the North Pacific => make clear the difference with Session proposal	WG49	Karen Hunter	0.5	FUTURE, HD, MONITOR	CLIVAR
W3	Exploring Human Networks to Power Sustainability in North Pacific Ocean	WG51, AP-UNDOS	Shion Takemura	1.0	FUTURE, HD, TCODE	
W4	Contrasting the occurrence of toxic Alexandrium blooms in the eastern and western north Pacific	S-HAB	Mark L. Wells	1.0	MEQ,	GlobalHAB, IOC UNESCO, ICES WGHABD, NOWPAP, ISSHA
W5	Exploring international knowledge co-production: Lessons learned from international marine science organizations at the science-policy interface	AP-UNDOS, AP-ECOP, AP-UNDOS	Erin Satterthwaite	1.0	FUTURE,	ICES, SmartNet
W6	Co-creating a shared framework for ocean data management: Finding common ground on terminology	SG-DATA, AP-ECOP, AP-UNDOS	Erin Satterthwaite	0.5	MONITOR, TCODE	DCC for the Northeast Pacific
W7	Integrating biological research, fisheries science and management of flatfish species in the North Pacific Ocean in the face of climate and environmental	(FIS)	Josep Planas	0.5	FIS, MONITOR	IPHC
W8	'Science Jam' - Bridging the gap between science and social media to communicate PICES accomplishments with the world	AP-SciCom	Natsuko Nakayama	3-days Lunchtime Events	FUTURE, TCODE	
W9	Puffin diet samples as indicators of forage nekton availability and community structure in the Aleutian marine ecosystem	S-MBM	William Sydeman	0.5	BIO	NPRB, Audubon, NFWF, Pew

List of the Session Proposals

	Title	Relevant PICES EG	Corresponding convenor	Duration (day)	Sponser	Potential Cosponsors
S2	Climate Extremes and Coastal Impacts in the Pacific	WG49	Chan Joo Jang, Antonietta Capotondi	1	FUTURE, HD, POC	CLIVAR
S3	S-CCME/SICCME session on innovation in using integrated approaches to detect and manage for the effects of climate change tipping points and critical thresholds in marine ecosystems.	S-CCME	Kirstin Holsman	1	FUTURE, BIO, FIS, HD, POC	ICES
S4	Advanced tools to monitor, observe, and assess small pelagic fish populations in support of ecosystem based fisheries management and maintaining ecosystem services	G43	Jennifer Boldt	1	FUTURE, FIS, HD, MONITOR	
S5	Observational frontier and new studies for understanding of ocean and ecosystem	AP-NPCOOS	Sung Yong Kim	1	FUTURE, BIO, MONITOR, TCODE	
S6	Ocean Negative Carbon Emissions: Blue Technology Innovation for Promoting Global Sustainable Development	WG46	Nianzhi Jiao	0.5	POC, TCODE	Global ONCE ICES, SOLAS IMBeR
S7	Past, Present and Future of CREAMS program: 30 years of international research in North East Asian Marginal Seas	AP-CREAMS	Vyacheslav Lobanov	1	FUTURE, MONITOR, TCODE	
S8	Social, economic and ecological implications of recoveries, range expansions and shifting distributions of marine birds, mammals and fish	S-MBM	Andrew Trites	1	BIO, HD	
S9	Changing ocean carbon cycle and its consequences for the ocean environment: Detection, prediction and mitigation	S-CC	Tsuneo Ono	0.5	BIO, POC	
S10	Recent advances in plastic pollution research in the North Pacific	WG42, AP-UNDOS	Matthew Savoca	0.5	MEQ	
S11	East Meets West and West Meets East: Past, Current and Future Implications of Non-indigenous Species (NIS) in the North Pacific	AP-NIS	Thomas Therriault	1	MEQ	NOWPAP ICES, US National Invasive Species Council etc.
S12	Impacts of warming-induced changes in body sizes on marine fish ecology and their consequences for ecosystems and associated fisheries	G45 (AP-ECOP, S-CCME)	Shinichi Ito	0.5	FIS	ICES
S13	The Changes in Distribution of Harmful Algal Blooms (HABs) in the North Pacific Region	S-HAB	Mark L. Wells	0.5	MEQ	GlobalHAB, IOC, ICES, NOWPAP ISSHA
S14	Rapid Plankton Assessment for Ecosystem Assessment	WG48	Hongsheng Bi	0.5	BIO	ICES

Agenda Item 17 Upcoming Capacity Development Events

17.1. Capacity Development events proposed by PICES EGs

Dr. Chiba and the respective reporting Committee chairs reported the proposals and planning for capacity development events (see the table) which would be held during 2024 and later.

AP-ECOP (FUTURE)		
Event Title / Date / Location	**Date/Location**	**Amounts and rationale of fund requested**
International Open Science Training Building effective international collaborations for ocean sustainability (some references [https //www.openscapes.org/resources/](https://www.openscapes.org/resources/)) co-sponsors (TBC) TCODE; AP-SciCom; ECOP Programme, HD (TBC), FUTURE (TBC)	Spring/Summer 2024 Virtual	CA$ 7000 support travel for 2 participants of this workshop to attend the PICES 2024 meeting to ensure that fruitful discussions and lessons learned can be shared and incorporated into other parts of PICES and that the training can continue through PICES 2024 *Approved to implement in 2023 (SB/GC-2022 decision), but deferred to 2024 due to bandwidth issues
PICES 101 - Similar to the PICES 101 provided during the AP-ECOP Workshop during PICES 2022. The goal is to provide a brief overview of PICES and its committees/EGs to help introduce new ECOPs/new PICES members to the organization.	PICES-2024 (Oct 29, 2024)	Funding N/A Propose the event every 2 years during the core Annual meeting days given many ECOPs prioritize the weekday schedule when travelling due to the funding constraints.
AP-NPCOOS (MONITOR)		
Event Title / Date / Location	**Date/Location**	**Amounts and rationale of fund requested**
Macro Coastal Oceanography summer school. 20 participants Analysis of coastal observing data ADCP, HF Radar, and other environmental variables	Autumn 2025 or Spring 2026 Hakodate, Japan	CA$) TBD travel, lodging, meals and administrative costs

17.2. Completed and Upcoming Partner Organizations' Capacity Development Events

Dr. Chiba reported the upcoming capacity development events organized by the PICES partner organizations.

17.2.1. SCOR Capacity Development (link)

Sanae Chiba, PICES Deputy Executive Secretary SCOR CD Committee member (July 2021~)
Core Programmes

- Visiting Scholars Programme
- Fellowship Programme (with POGO)
- Travel support for Conference (proposal must be submitted by Organizations)
  Funded US$ 6K for participants of 5th ECCWO (Apr. 2023)
  Proposal accepted US$ 6K for participants of ZPS7 (Mar. 2024)

17.2.2. SOLAS Summer School 2023

Date June 5-16, 2023 (in-person)
Venue OSCM (Ocean Science Centre Mindelo), Cape Verde, Senegal
Eligible applicants are post-graduate students and post-doc researchers with multidisciplinary air-sea interaction background
PICES funded up to CA$ 10,000 for travel support of participants from PICES countries

17.2.3. IMBeR ClimEco8 Summer School

Date July 24-28, 2023
Venue ZRS-Mediterranean Institute for Environmental Studies, Koper, Slovenia
Designed for 60-70 post-graduate students and early career researchers, and led by an interdisciplinary group of scientists which includes leaders in their respective fields.
PICES funded up to CA$ 5000 for travel support of 2 participants from PICES countries (Canada and China).

17.2.4. GOOD-OARS-CLAP-COPAS Summer School 2023

Date November 6 – 12, 2023, Coquimbo-La Serena, Chile
Venue CEAZA & Universidad Católica del Norte
Sponsor OARS (Global Acidification Research for Sustainability)
GOOD (Global Ocean Oxygen Decade), etc.
PICES funds up to EUR 5000 for travel support of participants from PICES countries (Recipients TBD)
NOTE The travel support was approved at GC-2022.

17.2.5. APN Workshop

PICES received potential PICES-APN collaboration opportunities on their events scheduled for 4-8 March 2024 at the University of the South Pacific in Fiji (TBD), which includes a 3-day Proposal Development Training Workshop. PICES ECOPs are invited to join.
**The workshop is postponed to summer 2024.*

The Proposal Development Training Workshop (PDTW) aims to equip early-career professionals with the essential skills to formulate proposals for the APN call for proposals and other funding opportunities. Topic(s) of the PDTW will be decided among the below

- Global change and its impacts on ecosystems and livelihoods in the Pacific
- Climate adaptation, disaster risk reduction, displacement and relocation
- Climate variability and change, and their impacts in national and regional contexts
- Biodiversity and ecosystem conservation for human well-being and protection in the Pacific.

Opportunities for PICES to become engaged

- Resource person Ideally, resource persons are experts conducting research in the South Pacific or former project leaders of APN-funded projects on the above-mentioned topic(s). Depending on the topic(s), **PICES experts specialising in climate monitoring, projections and downscaling** could be highly suitable contributors to the workshop.
- Trainees **Early-career professionals** nominated by PICES could be invited to the workshop.

Agenda Item 18 PICES-Sponsored Conferences / Symposia

Dr. Chiba reported the upcoming international conferences/symposia co-sponsored by PICES or organized by the PICES partner organizations.

1. ICES Annual Science Meeting, **Sept 2023**, Bilbao, Spain
2. Ocean Science Meeting (OSM) 2024, **Feb 2024,** New Orleans, USA
3. 9th World Fisheries Congress **Mar 2024**, Seattle, USA
4. 7th International Zooplankton Production Symposium, **Mar 2024**, Hobart, Australia.
5. MSEAS Marine Socio-Ecological Systems Symposium, **June 2024**, Yokoyama, Japan
6. International Symposium on Small Pelagic Fish, **2026,** La Paz, Mexico
7. 5th Early Career Scientists Conference, **2027**

18. 1. ICES Annual Science Conference 2023

- Sept 11-14, 2023, Bilbao, Spain
- Local organizer AZTI
- Conference style Hybrid
- **PICES co-convening Session**
  Thema Session B Towards climate-informed ecosystem-based fisheries management (S-CCME)
  Thema Session E   Environmental risk assessment of aquaculture (WG46)

18. 2. ASLO Ocean Science Meeting (OSM 2024)

- Date Feb 18-23, 2024
- Location New Orleans, USA
- Venue Ernest N. Morial Convention Center
- Session proposals deadline May 24, 2023

PICES co-sponsors the OSM following the previous meeting (OSM-2022)
Sung Young Kim (MONITOR Chair) is a Program Committee member.

18. 3. 9th World Fisheries Congress,

Theme Fish and Fisheries at the Food-Water-Energy Nexus

- Date Mar 3-9, 2024
- Location Seattle, USA
- Organizer World Council of Fisheries Societies,
- Venue Ernest N. Morial Convention Center

18. 4. 7th ICES/PICES Zooplankton Production Symposium 2024

- Date & Location March 16-21, 2024, Hobart, Australia
- Venue Hotel Grand Chancellor, Hobart
- Local organizer CSIRO
- Abstract submission closed; speakers are under selection.

PICES Member involvement

Organizing Committee Batten, Chiba (Secretariat), Sastri (BIO)
SSC Bi (WG48), Kobari (WG37),

18. 5. MSEAS Symposium

*Originally planned as MSEAS-2020 but postponed to 2024.

Theme Managing for Sustainable use of the Earth's marine and coastal system

- Date & location June 3-7, 2024, Yokohama, Japan
- Venue Pacifico Yokohama North

- Primary Sponsors PICES, ICES, NOAA Fisheries, FRA
- Local Organizer FRA
- Abstract call opened (Oct 1 ~ Nov. 30)
  * Sessions and abstracts previously approved for MSEAS-2020 are regarded as placeholders.

PICES Member involvement
Symposium Convenor Batten, Brown (Secretariat), Sastri (BIO), Hasegawa (FUTURE)
Symposium Coordinators Chiba (Secretariat)
Local Organizing Committee Makino (HD)

18.6. 3rd International Small Pelagic Fish Symposium (SPF) 2026

- Date March or April 2026
- Location La Paz, Mexico
- Venue TBD (for ~400 participants)
- Primary Sponsor
  - PICES Initial planning was approved by IGC-2023
  - ICES ICES resolution for SPF-2026 submitted by the co-chairs of the ICES-PICES WG on Small Pelagic Fish.
  - FAO's sponsorship/co-convenorship confirmed (Addendum, Oct 25, 2023)
- Local Organizers
  National Fisheries and Aquaculture Institute (InaPESCA), CICIMAR, CIBNOR, CICESE, UABCS, etc.

Small Pelagic Fish Workshop

The ICES-PICES WG on Small Pelagic Fish will convene a 3-day workshop from February 12–14, 2024 in La Paz, Mexico. The main goals of this workshop are (1) to review the work done by WG Task Forces (TF on *Ecological Process Knowledge*, TF on *Translating Process Knowledge*, and TF on *Social-Ecological Approaches*) and to synthesize the outcomes of their activities; (2) to initiate the development of a high-impact manuscript that describes the outputs of working group activities, including papers submitted to a special issue of *Canadian Journal of Fisheries and Aquatic Sciences* (CJFAS) and a Theme Section of *Marine Ecology Progress Series* (MEPS) from SPF-2022; and (3) to discuss the scope, potential scientific program and logistics for SPF-2026. We expect about 20 attendees WG co-chairs, activity leaders and several invitees. A surplus from SPF-2022 (due to our vigorous fundraising efforts) is used to fund the workshop.

18.7. 5th ICES/PICES Early Career Scientists Conference (ECS) 2027

ICES and PICES played as the main organisers of ECS in turn. As the 4th ECS was organized by ICES and held in Newfoundland, Canada, PICES will host the 5th ECS in an Asian nation.

Agenda Item 19 Publications update

19.1. Peer-Reviewed Papers (published)

SB recommended GC approve these papers as PICES EG products to be posted on the PICES website.

EG	Citation	Comment
WG45	Lindmark et al. (2023) Larger but younger fish when growth outpaces mortality in heated ecosystem. eLife, 12 e82996. Lindmark et al. (2023) Evaluating drivers of spatiotemporal variability in individual condition of a bottom-associated marine fish, Atlantic cod (*Gadus morhua)* ICES Journal of Marine Science, 80, 1539–1550, Campana et al. (2023) Growth portfolios buffer climate-linked environmental change in marine systems. Ecology, 104, e3918. Jenkins et al. (2022) Environmental drivers of fish population dynamics in an estuarine ecosystem of south-eastern Australia. Fisheries Management and Ecology, 29, 693-707. Woods et al (2022) Integrative approaches to understanding organismal responses to aquatic deoxygenation. The Biological Bulletin, 243, 85-103. Audzijonyte et al. (2022) Mechanistic temperature-size rule explanation should reconcile physiological and mortality responses to temperature. The Biological Bulletin, 243, 220-238. Lindmark et al. (2022) Temperature impacts on fish physiology and resource abundance lead to faster growth but smaller fish sizes and yields under warming. Global change biology, 28, 6239-6253. https //doi.org/10.1111/gcb.16341 Wootton et al. (2022) Smaller adult fish size in warmer water is not explained by elevated metabolism. Ecology Letters 25 1177-1188. https //doi.org/10.1111/ele.13989 van der Sleen et al. (2022) Interannual temperature variability is a principal driver of low-frequency fluctuations in marine fish populations. Communications Biology 5, 28. https //doi.org/10.1038/s42003-021-02960-y Morrongiello et al. (2021) Synergistic effects of harvest and climate drive synchronous somatic growth within key New Zealand fisheries. Global Change Biology, 27,1470-1484. https //doi.org/10.1111/gcb.15490 Wootton et al. (2021) Multigenerational exposure to warming and fishing causes recruitment collapse, but size diversity and periodic cooling can aid recovery. Proceedings of the National Academy of Sciences, 118, e2100300118. https //doi.org/10.1073/pnas.2100300118	These papers are products of ICES/PICES Joint Working Group. The papers published before 2023 are not reported to PICES previously
WG44	Kodryan K.V., Kivva K.K., Zubarevich V.L., Pedchenko A.P. (2023) Water masses in the western Chukchi Sea in August 2019 and their hydrochemical features. Oceanology, Vol. 63, No. 3, pp. 314–324. DOI 10.1134/S0001437023020078	

AP-NPCOOS	Boyer et al. (2023). Effects of the Pandemic on Observing the Global Ocean. Bulleting of the American Meteorological Society. 104 E389-E410. https //doi.org/10.1175/BAMS-D-21-0210.1	
S-MBM	Sydeman et al. 2023. Effects of currents and temperature on ecosystem productivity in Unimak Pass, Alaska, a premier seabird and biodiversity hotspot, Progress in Oceanography, Volume 216,103082, ISSN 0079-6611, https //doi.org/10.1016/j.pocean.2023.103082.	

19.2. Expert Group Final Reports

SB reviewed these papers as the PICES EGs' Final Reports. SB recommended GC approve these to be published as the SG Final Report, PICES Technical Report and Scientific Report, respectively, and endorsed the disbandment of the SG and WG.

EG	Type of publication & Title	Endorsement
SG-ARC	**Study Group Final Report** (Recommendation of establishment of AP-ARC)(see 11.1) **Appendix 2** **GC suggested revision of the recommendation for AP-ARC*	Endorsed by parent Committee (SB, FIS, MONITOR), submitted to Secretariat.
SG-DATA (TCODE) To be disbanded	**PICES Technical Report** Satterthwaite, E., Garcia, H., Gann, J., et al. Towards a Data Management & Data Sharing Plan for the North Pacific Marine Science Organization (PICES) (SG-DATA Final Report) **Appendix 3**	Endorsed by TCODE, submitted to Secretariat
WG41 (FUTURE, HD) To be disbanded	**PICES Scientific Report** Marine Ecosystem Services in the North Pacific (WG41 Final Report) **Appendix 4**	Endorsed by FUTURE and HD, submitted to Secretariat

19.3. EG Final Reports in Progress

Dr. Chiba reported the progress of the working group final reports. These Final Reports are in various stages (1. In preparation, 2. Being reviewed by the parent Committee(s), 3. submitted to Secretariat, 4. previously approved by SB and nearly completed).

EG	Type of publication & Title	Stages	comments
WG35 (MONITOR /TCODE)	**PICES Special Publication NPESR III online supplemental materials** NPESR III Regional Reports (R11 – R24)	4. **Approved** PICES 2017 The last Report R19 is under revision	All Regional Reports except R19 published
WG36 (FUTURE) Disbanded	**PICES Scientific Report** Common Ecosystem Reference Points across PICES Member Countries	4. **Approved**, under final formatting by Secretariat **Published in Oct 2023*	
WG42 (MEQ)	**PICES Scientific Report** Indicators of Marine Plastic Pollution	2. Being reviewed by parent Committee	

WG43 (FIS, HD)	**Journal Special Issues (2)** Special Issues of Marine Ecology Progress Series (MEPS) and Canadian Journal of Fisheries and Aquatic Sciences (CJFAS) (based on the papers submitted from SPF2022 Symposium, Lisbon, Portugal)	2. Being reviewed by parent Committee (MEPS) 5 papers accepted 14 papers under review (CJFAS) 6 papers accepted, 6 papers under review	To be published in 2024
WG39 (SB)	**PICES Scientific Report**	1. In preparation	
WG44 (HD, FIS)	TBD	No Information	
WG46 (POC, BIO)	TBD	No Information	

Timing of WG disbandment WG disbands upon the submission of its Final Report to Secretariat after review and approval of Parent Committee(s). (Approved at **IGC-2022**)

19.4. Other Products (published)

EG	Citation/link	Comment
AP-ECOP (FUTURE)	Podcast The Ocean Decade Show - ECOP Evolution - New National Nodes with Hannah Lachance https //oceandecade.org/podcasts/	This podcast episode highlighted UN Decade ECOP efforts and other ECOP efforts including PICES AP-ECOP.
Ciguatera/ FishPhytO	• The final scientific report for the Ciguatera project • Catalogue Smartphone application to collect coastal fisheries and environmental information for adaptation to changes in the marine environment (FishGIS) • PICES/MAFF Indonesian workshop report (July 2023) (to be posted on the project website soon)	Posted on PICES Ciguatera website

Agenda Item 20 Other issues

20.1. ISB-2024 Date

Dr. Kang noted that a 3-day ISB-2024 meeting would be held virtually from late April to mid-May 2024. Secretariat was to set the date depending on the SB members' availability.

Review of call

Dr. Kang reviewed the call and adjourned the meeting.

- End of the document -

Appendix 1

PICES Data Policy

PICES Draft Data Policy (proposed changes included in red)

Principles and Definitions

As stated in Article III of the Convention for the North Pacific Marine Science Organization (PICES) the Organization is to promote the collection and exchange of information and data related to marine scientific research in the North Pacific Ocean and its adjacent seas.
The PICES strategy on capacity development identifies TCODE as the committee responsible for the development of communication networks for exchange of data and information.

The timely, free and unrestricted international sharing of oceanographic data, metadata, products and services is essential for a wide variety of purposes and benefits including the prediction of weather and climate, the operational forecasting of the marine environment, the preservation of life, economic welfare, safety and security of society, the mitigation of human-induced changes in the marine and coastal environment, as well as for the advancement of scientific understanding that makes this possible.

Data, metadata and products should be accessible, reproducible, interoperable, freely and openly shared with minimum delay and restrictions. Such sharing of data in both real-time and delayed mode facilitates scientific research and innovation.

Data gathered as a result of PICES activities will be responsibly managed to guard against loss and to ensure continued accessibility. The management of data using external data management systems is preferred to using internal PICES resources. Data should be quality controlled, accompanied by metadata and, when possible, it is best to be stored in an openly accessible data repository and made accessible and discoverable through a web interface and machine-to-machine protocols. PICES members shall, where possible, use IODE data centres linked to the IOC Ocean Data and Information System (ODIS) as repositories for oceanographic data and associated metadata.

For any data provided to PICES, PICES will respect the ownership rights and any restrictions placed on these data by the provider.

Data include data products and model outputs related to PICES activities. Metadata are data about data.

End users include a person, organization, group (including PICES expert groups) using data.

Data providers include a person, organization, group (including PICES expert groups) providing data.

The data inventory refers to data for which PICES has the primary responsibility to manage.

Roles and Responsibilities:

The Technical Committee on Data Exchange (TCODE) is responsible to:

1. Manage the PICES data inventory and promote within PICES and the general public through the TCODE data catalog service (or other new repository as determined by PICES TCODE and/or working group).
2. Communicate and disseminate data and metadata to all PICES members as well as the general public through PICES Catalog (or new option, TBD).

3. Assist Expert Groups to identify data that are to be included in the data inventory.
4. Assist Expert Groups in the development of data management options and strategies.
5. Make recommendations to Science Board on PICES data management and priorities, with particular emphasis on correcting or mitigating any known or anticipated deficiencies.

The PICES Secretariat is responsible to:

1. Support TCODE in the maintenance of the data inventory.
2. Support TCODE to correct or mitigate any known or anticipated deficiencies.

Science Board is responsible to:

1. Include data management requirements in the Terms of Reference of each PICES expert group.
2. Review the recommendations proposed by TCODE and provide recommendations to Governing Council as necessary.

Expert Groups are responsible to:

1. Identify any data developed during the activities of the expert group and inform TCODE and PICES secretariat.
2. Develop, with assistance from TCODE, strategies or options for managing data used by the expert group.

Data Produced by PICES

All data produced by PICES are considered to be publicly available unless explicitly specified otherwise.

Results, conclusions, or recommendations derived from the data associated with PICES do not imply endorsement from PICES.

Contributions of data from PICES expert groups will adhere to the expert groups’ Terms of Reference and be submitted to TCODE for inventory while the group is active.

All data including metadata should be archived using standard codes, formats, and protocols.

Data Provided to PICES

The quality assurance of data is the responsibility of the data provider.

In the event that PICES becomes aware there may be quality issues in the data PICES will inform the data providers as soon as possible.

Data providers should inform PICES secretariat of any policies that may place special conditions on their redistribution.

End users are responsible for the proper use of the data and metadata provided.

PICES may reformat data or metadata but will never change the data provider’s original record.

Data use must be acknowledged, preferably using a formal citation.

To support knowledge discovery and innovation both by humans and machines, data should meet FAIR Guiding Principles (Findable, Accessible, Interoperable and Reusable)[1] to the greatest extent practicable.

Citation

Data citations should facilitate giving scholarly credit and normative and legal attribution to all contributors to the data, recognizing that a single style or mechanism of attribution may not be applicable to all data.

Where DOIs exist (Digital Object Identifier) they should be included in the citation.

[1] Wilkinson, M., Dumontier, M., Aalbersberg, I. *et al.* The FAIR Guiding Principles for scientific data management and stewardship. *Sci Data* **3,** 160018 (2016). https://doi.org/10.1038/sdata.2016.18

Appendix 2

SG-ARC Final Report

Final Report of

Study Group on the Arctic Ocean and the Pacific Gateways
（SG-ARC）

October, 2023

Contents

1 Introduction

1.1 Background

The target Large Marine Ecosystems (LMEs) of WG39 and WG44 are the geographically and dynamically connected Central Arctic Ocean (CAO) and the Northern Bering Sea-Chukchi Sea (NBS-CS) (Figure 1). The CAO is in rapid transition, driven by North Pacific environmental changes in significant part, and has become accessible to a range of commercial activities. Rapid loss of sea ice cover has opened up the CAO for potential fishing opportunities. In this context, the agreement to Prevent Unregulated High Seas Fisheries in the CAO has been signed and entered into force, which will necessitate joint research and monitoring. The NBS-CS is also experiencing unprecedented warming and loss of sea ice as a result of climate change. Declines of seasonal sea ice and rising temperatures have been more prominent in the northern Bering and Chukchi seas as in most portions of the Arctic. Chronic and sudden changes in climate conditions in this Arctic gateway are clearly reshaping the system and its food-webs, and enlarging opportunities for commercial activities (shipping, oil and gas development and fishing), with uncertain and potentially wide-spread cumulative impacts. A coordinated integrated ecosystem assessment (IEA) of the CAO and NBS-CS thus is a useful and pertinent approach in this circumstance, especially given the substantial science and policy challenges emerging in the Arctic.

1.2 Past and current Status

1.2.1 WGICA

The Working Group for Integrated Ecosystem Assessment of the Central Arctic Ocean (WGICA) was established jointly by ICES and PAME in 2016. The goal of the working group is to conduct an Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (CAO), a needed step to provide scientific advice on issues such as the prospect for future fisheries in the Arctic Ocean and sensitivity and vulnerability of marine ecosystems in relation to human activities (including shipping, fisheries, tourism). WGICA links Human activities, pressures and ecosystem vulnerability into a semi-quantitative risk analysis by assessing the spatial and temporal overlap using best available data. The first WGICA meeting was held in May 24-26, 2016, at the ICES headquarters in Copenhagen, Denmark. PICES joined WGICA in 2017 and WGICA became the Joint ICES/PICES/PAME working group for the CAO IEA. WGICA published comprehensive IEA Report No. 1 (Skjoldal, 2022) with IEA Report No. 2 underway.

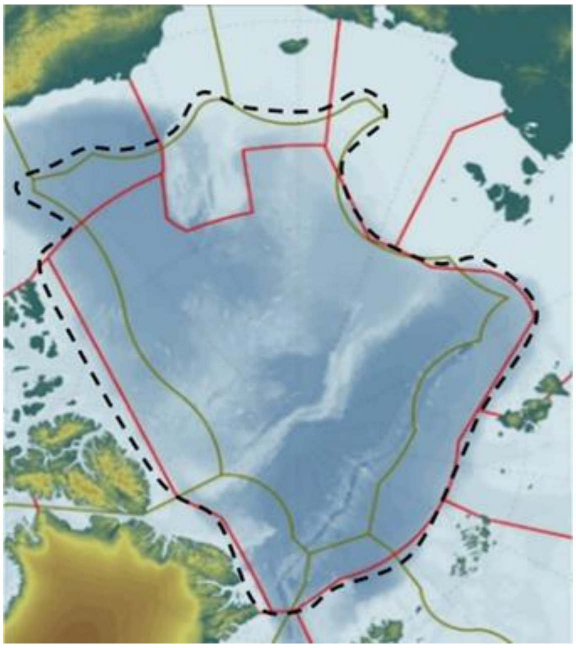

Figure 1. The Central Arctic Ocean study area (black broken line; CAO) with the Large Marine Ecosystems (red lines) as defined by PAME (Protection of the Arctic Marine Environment), one of the working groups in the Arctic Council, the borders of the five National Economic Zones (green), and the High Seas being the center area outside the 200 nautical miles of the five bordering nations.

1.2.2 PICES WG39

At PICES-2016, the ICES President requested that PICES join the existing Working Group for Integrated Ecosystem Assessment of the Central Arctic Ocean (WGICA), established jointly by ICES and PAME in 2016. This request was approved by Governing Council (Decision 2016/6/5). PICES joined as a co-sponsor of the group in 2017, making WGICA an ICES/PICES/PAME Working Group for Integrated Ecosystem Assessment of the Central Arctic Ocean.

WG39 will consider approaches and methodologies for the IEA in the Central Arctic Ocean. In PICES, WG39 was established for supporting WGICA in 2017.

Parent Committee: SB

Term: PICES-2016 – PICES-2022

Extended

at PICES-2018 until PICES-2021 (GC decisions S/4 (vii)) at PICES-2021 until PICES-2022 (GC decisions S/10 (x))

The following are Terms of Reference of WG39 approved in July 2020.

1. Review and consider approaches and methodologies for conducting an IEA of the CAO ecosystem;
2. Review and report on ongoing and recent changes and events in the CAO ecosystem associated with changes such as in sea ice, oceanographic circulation, and hydrographic properties;
3. Continue to examine the effects of climate change on the CAO ecosystem by compiling and reviewing information on changes in response to the ongoing 'Great melt', and assess likely consequences to the CAO ecosystem of projected future changes associated with further loss of sea ice and other climate-related changes (i.e., a climate impact assessment);
4. Assess the consequences of recent and ongoing climatic and oceanographic changes on transport pathways (physical and biological) and potential effects of contaminants in the CAO ecosystem;
5. Review and report on new studies on fish as well as other biological components of the CAO ecosystem;
6. Continue to identify priority research needs and monitor how identified knowledge gaps (needed to improve IEA and management effectiveness) are being addressed and filled;
7. Prepare an Ecosystem Overview for the CAO ecosystem.

The first WG39 business meeting was held on September 24, 2017, at PICES-2017 in Vladivostok, Russia (http://meetings.pices.int/publications/Annual-Reports/2017/2017-WG-39.pdf).

The first workshop of WG39 "PICES contribution to Central Arctic Ocean (CAO) ecosystem assessment was held on March 22-23, 2018 at Hokkaido University, Sapporo, Japan. Since then, WG39 has been promoting workshops in subsequent PICES annual meetings:

- PICES-2018: W2, PICES contribution to Central Arctic Ocean (CAO) ecosystem assessment (Second)
- PICES-2019: W7, PICES contribution to Central Arctic Ocean (CAO) ecosystem assessment (Third)
- PICES-2020: VW4, How does the Pacific Arctic gateway affect the marine system

in the Central Arctic Ocean (WG39 and WG44 joint workshop)

- PICES-2022: W2, Integrated Ecosystem Assessment (IEA) to understand the present and future of the Central Arctic Ocean (CAO) and Northern Bering and Chukchi Seas (NBS-CS) (WG39 and WG44 joint workshop)

1.2.3 PICES WG44

Background and Purpose

The Northern Bering Sea-Chukchi Sea (NBS-CS) region is experiencing unprecedented ocean warming and loss of sea ice as a result of climate change. Seasonal sea ice declines and warming temperatures have been more prominent in the northern Bering and Chukchi seas as almost all other portions of the Arctic. Chronic and sudden changes in climate conditions in this Arctic gateway are increasingly impacting marine species and food-webs and expanding opportunities for commercial activities (shipping, oil and gas development and fishing), with uncertain and potentially wide-spread cumulative impacts. There are strong concerns about the impacts of climate change and industrial activities, and these impacts may be particularly pronounced in Arctic indigenous communities dependent on the health and stability of the ecosystem. The combination of unprecedented, rapid change and increased interest in the Arctic in general and the NBS-CS specifically make this an opportune time for a synthesis of issues and knowledge. An Integrated Ecosystem Assessment (IEA) can accomplish this synthesis.

Reporting to: FIS, HD
Term: Nov. 2019- Nov. 2023

Year 1 Deliverables:

- Inventory of metadata, knowledge, institutions and programs relevant to the Northern Bering Sea-Chukchi Sea LME. (accomplished)

Final Deliverables:

- Ecosystem description from both Indigenous world views and science (shared conceptual models), indicators and hypotheses. PICES Report and/or Journal article. Knowledge Gap and Next Steps Report. PICES Report and/or Journal article.

Current status (as of PICES 2022)

Approach and methodology. We developed three conceptual models with a team of interdisciplinary and multi-national scientists and Indigenous representatives from the Northern Bering and Arctic region. The models themselves were created using Mental Modeler software. Initial models were reviewed and refined over the course of several months. One important finding was the diverse ways of experiencing, thinking and talking about the marine ecosystem as informed by disciplinary training, worldview, and engagement over time. It was a challenge to include these multiple perspectives in a western science model that tends toward linearity and categorization. Indigenous worldviews may take more holistic and relational approaches to ecosystem elements, making kt a challenge to "box" entire concepts or domains as separate from others. In an attempt to bridge (and include) multiple perspectives, working group members offered qualitative descriptions to enhance the conceptual models and provide greater context.

The model results will be released in a PICES Report. Our next steps are to finish our IEA scoping document and finalize IEA goals by spring 2023. We are also planning on identifying indigenous partners this coming fall and winter.

Indigenous Knowledge provides valuable information that reflects deeply meaningful Indigenous worldviews to accommodate and respond to environmental changes. Resource policies, however, often develop outside of this realm of knowledge, instead, primarily relying on Western science. In an effort to better understand the complexities (cultural, linguistic, and institution) of Bering Sea coastal communities, the team developed an institutional model that identified linkages across spatial and governance levels. This model depicted the unweighted local, national, and global connections of individual communities in the area of study, indicating the complex connectivity of highly rural coastal communities. Indigenous knowledge sharing. "Multiple Ways of Knowing the Bering Sea-Chukchi Sea Ecosystem" workshop. Workshop organizers have transcribed the 2022 workshop notes and summarizing the ideas for bridging multiple knowledge systems into our IEA process. Including multiple knowledge systems in IEAs offers a longitudinal perspective across generations of ecological observations, and supports community resilience through information sharing, relationship building, and informed decision-making. The workshop included discussions about the vital importance of relationship building and co-production of knowledge methods in IEAs. Several points were emphasized including: the need to develop a shared language through co-production approaches. By first defining terms and confirming mutual understanding of concepts, it us then possible to build on those ideas that is inclusive of Indigenous worldviews in meaningful ways. A final report was distributed to the team.

Milestones: Shared report from first workshop. Distributed information in digital and hardcopy format. A manuscript is in development to submit for peer review.

We are in the process of organizing a larger workshop in 2023 in Seattle, WA at the PICES Annual meeting (October 20-21, 2023). Working in partnership with the Ocean Decade Collaborative Centre, we have invited 29 Indigenous Knowledge holders, issue experts, and practitioners to share information about bridging multiple knowledge systems in marine ecosystem assessments. The workshop is designed to provide an invited space for Indigenous knowledge holders to share information and experiences with the North Pacific marine environment. The second day will open to all PICES members for presentations to identify lessons learned across multiple regions. Deliverables include a final report and a North Pacific and Arctic marine ecosystem knowledge network.

1.2.4 WGIEANBS-CS

WGIEANBS-CS is ICES/PICES joint working group and the members and activities are fully same as WG44.

1.2.5 PICES SG-ARC

PICES took upon responsibilities concerning the CAO issues when it joined the WGICA (Joint PICES/ICES/PAME Working Group on an Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (CAO)) by establishing WG39 in 2017. In 2019, PICES also established WG44 (Joint PICES/ICES Working Group on Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea) in efforts to understand the Arctic system and its impacts to the sub-Arctic and mid-latitude North Pacific. An integrated ecosystem assessment (IEA) is a useful approach that is shared by these two Working Groups, particularly relevant with substantial science and policy needs emerging for the sustainable Arctic. This renders a coordinated IEA of the CAO and NBS-CS as a priority task. In addition, it is of particular significance to developing future approaches for The United Nations Decade of Ocean Science for Sustainable Development in the Arctic Ocean (UNDOS-Arctic), where science for resilience and sustainability is more important than anywhere else in the world oceans. Despite this continuing significance and unfinished commitment to WGICA and also WGIEANBS-CS, WG 39 ended the term with the closure of PICES 2022 Annual Meeting and WG 44 will end the term with the closure of PICES 2023 Annual Meeting. In this context, PICES established Study Group on the Arctic Ocean and the Pacific Gateways (SG-ARC) to coordinate and integrate PICES scientific activities on the Arctic issues and to further advance the understanding of the Arctic system and linkages and impacts to the North Pacific.

1.3 Impacts of Arctic changes on its marine ecosystem and biodiversity and the linkage to mid-latitude oceans

Ecological monitoring of the Pacific Arctic conducted over the past ten years has shed light on the impacts of recent warming and reduced sea-ice conditions to Arctic marine ecosystems. In the period of 1974-2014, the date of sea ice retreat has occurred earlier in the year at a rate approximately -0.7 d/yr (Serreze et al., 2016). The years 2017-2019 were anomalously warm in the Northern Bering and Chukchi seas and further characterized by substantial winter sea ice loss (Huntington et al., 2020). Additional physical changes in the Pacific Arctic include increased transport of Pacific water through the Bering Strait increased storm activity in the High Arctic (prefaced by Moore and Stabeno 2015). These physical conditions underlie many ecological impacts that span the entire range of the Arctic ecosystem from phytoplankton and marine bacteria to marine mammals and ultimately impact Arctic native communities that rely on the marine ecosystem for sustenance and cultural value (Moore et al. 2018).

Warming ocean temperatures, reduced ice extent, and increased poleward advection of warmer Pacific water to the Chukchi Sea had modified the marine environment and food resources to resemble those of subarctic marine ecosystems. Goldstein et al. (2023) concluded that the combination of those aspects led to poleward shifts in the distributions of large-bodied (i.e., energy-rich) copepods in the Calanus genus and Arctic cod (*Boreogadus saida*) on the Chukchi Shelf with the dominance of subarctic water associated with reduced isotropic niche for forage fishes. The anomalously warm 2017-2019 period also affected the distribution of seabirds in the area (Kuletz et al., 2020), namely a decrease in piscivorous seabirds like murres (i.e., *Uria* spp.; Romano et al., 2020), an increase in planktivorous *Aethia* auklets, and a northern shift for short-tailed shearwaters (*Ardenna tenuirostris*). Benthic macroinvertebrates are a major component of the Chukchi marine ecosystem and while benthic thermal habitats are projected to increase for some benthic taxa (e.g., basketstars), the loss of cold thermal habitats affects the majority of the epibenthic biodiversity present in the Chukchi Sea (Logerwell et al., 2022). However, the expansion or contraction of the spatial distributions of these benthic taxa will depend on how well they can acclimatize to continued long-term warming in the Arctic region.

These changes in the environmental conditions also favor the expansion of boreal marine taxa into a warmer Arctic Ocean. The more striking of these distributional expansions has been for gadids, e.g., walleye pollock, saffron cod, and Pacific cod (Wildes et al., 2022; Cooper et al., 2023; Maznikova et al., 2023). The expansion of large populations of adult pollock into the Western Chukchi Sea (Datsky et al., 2022; Emelin et al., 2022) led to recommendations to the development of a Chukchi Sea Russian pollock fishery in the early 2020s. The success of these subarctic fish populations expanding their ranges into the Arctic Ocean and posing potential competitive pressure to Arctic fish populations, i.e., Arctic cod, will depend on future thermal and advective conditions, successful adaptation, and continued poleward immigration.

Sea ice is an important physical component of many of the life histories of marine mammals. Pacific walrus (*Odobenus rosmarus divergens*) use ice floes to rest in between foraging trips as well as rear their young and molt. During a period of low ice cover in the Chukchi Sea (2008-2011), walruses were observed using more coastal and nearshore areas to forage for benthic invertebrates in lieu of more offshore areas occupied in past periods of higher ice cover (Jay et al., 2012). Polar bears (*Ursus maritimus*) which use both sea ice and land in their life history, utilized land for summering and denning for longer periods when substantial sea ice loss occurred (Rode, 2015). The end of the breeding season for bearded seals (*Erignathus barbatus*) is tied with the sea ice retreat, thus earlier sea ice retreat could alter breeding phenology (Crance et al., 2022). The increase in the number of open water days in the Chukchi and Beaufort seas may also potentially expand the usually Bering Sea-constrained wintering grounds and affect the distribution of summer foraging of bowhead whales (*Balaena mysticetus*). The concurrent expansion in the potential range of killer whales (*Orchinus orca*) into the Arctic Ocean introduces potential changes in the predation of fish and marine mammals (Clarke et al. 2013; Filatova et al. 2019).

1.4 Human activities and Pressures in the Arctic Ocean

Considerable progress has been made to document the levels of human activities and the human induced pressures on the central Arctic Ocean ecoregion. It is important to note at the outset that the focus is limited to the Central Arctic Ocean (CAO) and not the bordering Exclusive Economic Zones in the Arctic. This geographic distinction can create some difficulties accounting for activities and pressures that overlap given that human activities within coastal communities in the region tend to stay within the EEZ. It is important to note however, that the effects of human activities within the CAO may extend well beyond. Work, so far, has generally taken a more inclusive approach rather than an exclusive approach in terms of characterizing activities and pressures. Still, it is useful to point out that historically, the Central Arctic Ocean has had less direct activity and thereby pressures than continental shelf areas which tend to become ice free and thus are more accessible to ship borne activity, have more fish and wildlife, coastal ports and other economic activity, etc.

The human activities on which there has been significant focus are nearly all vessel-based and surface oriented, i.e., transport, tourism, research, and military although research and military activities may have subsurface extensions. Indigenous communities across the region have observed increasing direct human activities offshore, as well as the resulting effects of those activities.

Fisheries are not a current activity. In 2021, Arctic nations agreed to a 16 year moratorium on fishing in the CAO until research demonstrates that sufficient resources to support a commercial fishery exist and can be sustained. That moratorium is set to end in 2037. Most human activities have increased in the CAO in recent years enabled by climate change and decreasing ice cover, but also motivated by a desire to study the rapidly changing Arctic and to take advantage of economic development. Most human activity in the CAO is seasonal with summer accessibility (limited to ice free summer months) Winter months with substantial sea ice cover have not been accessible historically; however technological advances in vessel design, shifts in political will, and warmer winters with less ice coverage continue to drive increases in marine traffic in the CAO. Since 1996, marine traffic in the Arctic has increased by 300% and continues to increase. Research vessels is the one activity on the rise during the winter season to better understand year-round ecosystem changes.

The scale and intensity of human activities is comparatively low given the large area of the CAO and the cost of operations in the high Arctic. Shipping mostly follows the Northern Sea Route with less following the Northwest Passage Route outside of the CAO. A modest amount of curiosity-driven tourism attracts tourists to the North Pole and ice camping. The extreme depths and other operational difficulties so far preclude mineral and oil and gas exploration and development. Such activities are carried out in a few areas on the Continental shelves.

Human generated pressures on the CAO result from both external, and to a limited extent, internal processes. Ship noise is recognized as a new element in the CAO ecosystem, albeit minor at present. Marine debris and plastics, and the settling of air and water borne contaminants in ocean and atmospheric circulation is mostly from external sources. Of recent note is the CAO as an area where water borne plastics collect and there is growing concern about invasive species entering the CAO ecosystem. Further, because some of the seabird and marine mammal species migrate through the CAO, it is recognized that such species may be affected by human activities and pressures to an unknown degree. Indigenous communities in the Arctic are highly dependent on living marine resources in the CAO. As such, these communities will bear the brunt of any human activity driven effects, leading to concerns over inequitable distribution of impacts on vulnerable communities.

A major focus of work in the WGICA is gaining an understanding of the structure and functioning of the CAO an area that is little understood, with enormous gaps in observational data and with very difficult conditions for performing scientific research. Work of WGICA that is underway has sought preliminary ways to characterize the level of risk and our collective confidence in knowledge about by human activities and pressures as a way to better understand the vulnerability of the CAO to them. There is currently a joint author paper under construction for peer review that documents progress being made.

2. SG and the need for new EG

The Study Group on the Arctic Ocean and the Pacific Gateways (SG-ARC) was formed to help PICES better prepare for the new emerging issues in the Central Arctic Ocean and Pacific gateways. Until recently, two relevant working groups have been in operation and in cooperation within PICES, namely WG 39 and WG 44. These two groups share a range of research themes in areas closely connected geographically as well as in an ecosystem context. As mentioned above, joint WG 39/WG 44 workshops were held at the PICES Annual Meeting in 2020 and 2022. This SG-ARC is expected to continue until the WG 44 completes its mission, after which we have proposed to transition the SG into an Expert Group (EG) subject to the decision of PICES.

As mentioned in section 1.2.5, despite this continuing significance and unfinished commitment to WGICA and also WGIEANBS-CS, WG 39 ended the term with the closure of PICES 2022 Annual Meeting and WG 44 will end the term with the closure of PICES 2023 Annual Meeting. PICES need a new EG to serve as the liaison between WGICA and WGIEANBS-CS ICES/PICES joint activities after the conclusion of both WG 39 and WG 44. Time line of each WG/EG are summarized in Figure 2. PICES should understand the impacts of Arctic changes on its marine ecosystem and biodiversity and the linkage to sub-Arctic and mid-latitude oceans (PICES target waters) and new EG could deliver more comprehensive scientific information on this subject including monitoring activities in the Arctic Ocean and Pacific gateways in communication with international initiatives, e.g., MOSAiC, SAS, UNDOS-Arctic, CAOFS, ESSAS etc. (Figure 3).

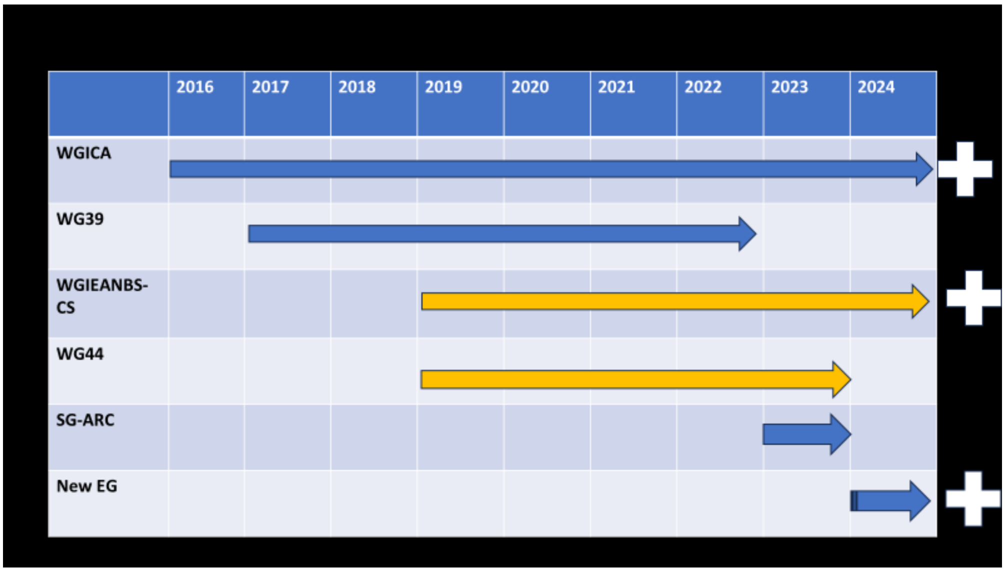

Figure 2. Time line of WG/EG

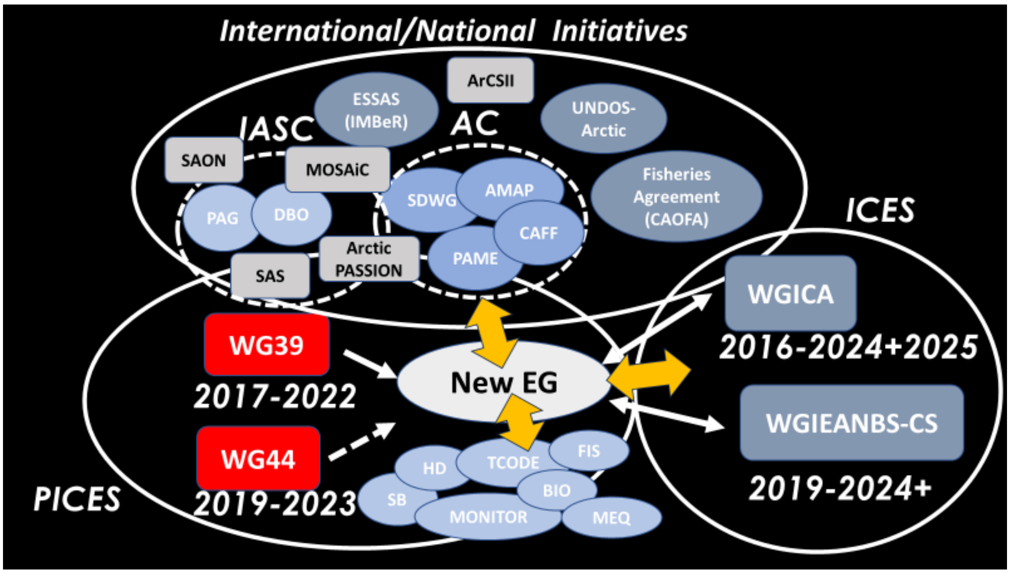

Figure 3. Relationship map between New EG and groups

3. Plan and contributions of new EG and the follow-up

The proposed EG when officially launched is expected to begin early 2024 The responsibilities of the group should include, although these have to be refined and clearly laid down in the Terms of Reference:

a) consolidate relevant PICES research output

b) identify future research agenda and possible areas of cooperation

c) generate advice how to connect with PICES research community and possibly create advice for the policy makers as well as the communities in the high latitude North Pacific

In order to fulfill these responsibilities, the EG will need to review and digest the research findings, continue collaborations with colleagues from the other side of the Arctic and deliver the policy-ready or at least policy-friendly product to the wider PICES community. The EG will also exert efforts to understand the indigenous perspectives on the issues and have those reflected in the deliberations of the group.

The EG will initially develop an agreed-upon three-year timeline. The work of the EG will focus mostly on the available data from published literature, rather than being field survey oriented, or assisting the designing process. Identification of key areas such as biological hotspots both in the sub-Arctic and the Central Arctic and delineating the mutually interacting mechanisms and the pathways will remain at the heart of the task of the EG for the first three years, at least. To undertake its work, the EG will hold online consultations once per year prior to the annual meeting in order to discuss the findings and distill tentative conclusions and to have them ready for report at the annual meeting. In the third year, at its end of the first term, the EG will organize a workshop to encapsulate the outcomes and determine future recommendations.

4. Conclusion

The variabilities of the Arctic Ocean strongly influence the global climate via atmosphere-ocean interactions and Arctic-subarctic freshwater and heat fluxes. The changing ocean has had both local and far-reaching effects on atmospheric circulation, including intensified storms and more frequent extreme weather conditions. PICES should understand the impacts of Arctic changes on its marine ecosystem and biodiversity and the linkage to sub-Arctic and mid-latitude oceans and contribute the development of IEA in CAO and NBS-CS through the joint PICES/ICES cooperation.

Accessing and utilizing the best available information in understanding ecosystem processes requires the inclusion of multiple knowledge systems from an early stage. Drawing from successful methods used in other working groups, this group will work to bridge Indigenous Knowledges across the region with modern science to achieve more robust understanding. In conclusion, we propose new EG as Advisory Panel on the Arctic Ocean and the Pacific Gateways (AP-ARC) for this initiative.

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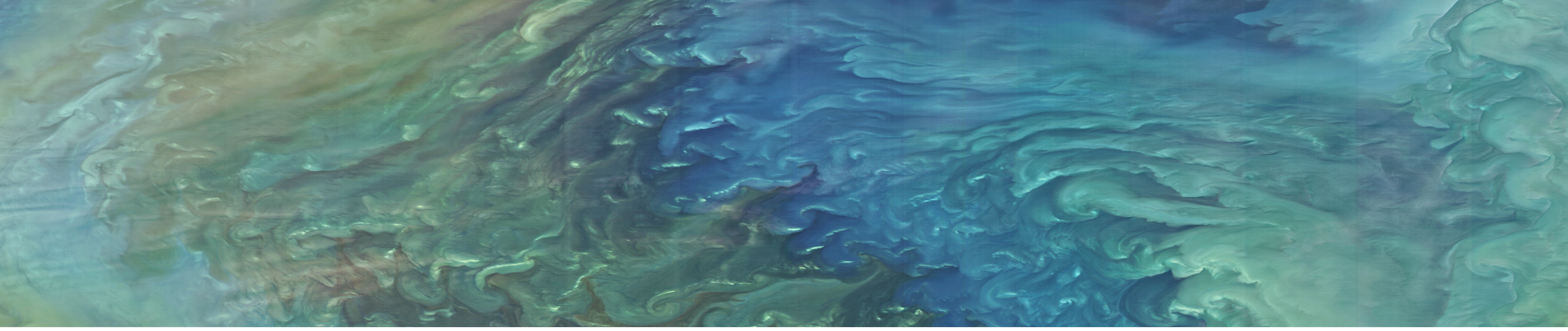
6. Appendix

A. Proposal of AP-ARC (separate file)

Appendix 3

SG-DATA Final Report



Towards a data management & data sharing plan for the North Pacific Marine Science Organization (PICES)

A final report of the Study Group on Encouraging Data Awareness and Increased Transmission and Accessibility

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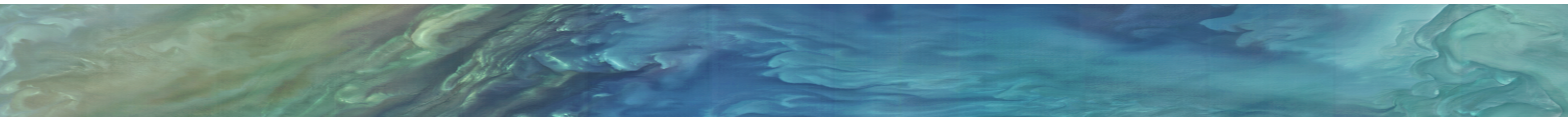
Jill Prewett (USA)

Igor Shevchenko (RUS)*

**In honor of Igor Shevchenko*



Executive Summary

We propose to the PICES Science Board to create a PICES Data Management Working Group under TCODE that will review the current data policy, and provide data management recommendations (2024-2026) for consideration by TCODE and, where relevant, the PICES Science Board. It is recommended that PICES committees identify a point of contact for data-related business for connection with the proposed data management working group to help provide input relating to the role of PICES Expert Groups in data management and sharing.

Below are three priorities, adapted from the original Terms of Reference for SG-DATA, that we will address and refine should the PICES Science Board approve the proposed Working Group. These include: 1. Revise & update the PICES Data Policy, 2. Promote a culture of data sharing within PICES, and 3. Recommend data management platforms, standards, and technologies, and resources.

We envision that the process of refining and addressing these priorities will be a collaborative approach with PICES Expert Groups.

Introduction

Effective data and information management and sharing are essential to promote collaboration within the North Pacific Marine Science Organization (PICES). Development and utilization of a comprehensive data and information strategy will facilitate data-intensive science, advance scientific research, ensure long-term storage and security for all data and information, and increase the reach of PICES science to a wider international audience. The purpose of SG-DATA is to provide key considerations and recommendations to the Technical Committee on Data Exchange (TCODE) and the PICES Science Board for modernizing and streamlining data and information management and sharing within PICES. In order to effectively carry out the tasks in this report, action will be needed by all PICES committees and expert groups to implement best practices. PICES Expert Groups, summer school activities, and special projects generate data and information that represent unique international collaborations across the north Pacific. The resulting reports, documents, and manuscripts often cover information on regions with limited open data access. This underscores the importance of the information PICES scientists can offer at the international level. Data currently within PICES consists mainly of reports generated from Expert Groups, a small list of datasets stored in various repositories (Appendix A), a searchable metadata catalog (TCODE Catalog) that includes PICES reports, cruise reports from various PICES member countries, information on some datasets in the North Pacific and beyond, and published manuscripts resulting directly from PICES collaborations (including Expert Group products and biannual PICES Press articles).

This Data Management & Sharing Plan recommends best practices for PICES committees and Expert Groups to ensure safeguarding, tracking, and efficient discovery, access, and sharing of all generated data and information emanating from the PICES organization (for definitions see Box 1 & Appendix B). This data management and sharing plan sets the stage for a more collaborative and data-driven future for PICES, ensuring that its scientific contributions continue to make a meaningful impact on the North Pacific and beyond.

Box 1. Data Strategy Definitions

- '**Data**' is a set of values, symbols or signs (recorded on any type of medium) that represent one or more properties of an entity.
- '**Metadata**' is 'data about data' describing the content, quality, condition, and other characteristics of data that allows their inventory, discovery, evaluation or use.
- '**Timely**' in this context means the distribution of data and/or products, sufficiently rapidly to be of value for a given application
- '**Openly**' means data that can be freely used, re-used and redistributed by anyone - subject only, at most, to the requirement to attribute and share alike.
- '**Product**' means a value-added enhancement of data applied to a particular use.
- '**Free and unrestricted**' means non-discriminatory and without charge. "Without charge", in the context of this resolution means at no more than the cost of reproduction and delivery, without charge for the data and products themselves
- '**Non-commercial**' means not conducted for profit, cost-recovery or re-sale.

With a focus on data openness, discoverability, accessibility, and collaboration, while aligning with international and community-developed standards and initiatives, and data sharing principles, this strategy aims to enhance the effectiveness and impact of PICES projects and Expert Groups. The points outlined are aimed at making it easier to share and find data generated by PICES and foster a culture of data sharing and stewardship within the PICES community. These modernization efforts will improve the reach of PICES data and information, advance long-term storage security, increase access to easily searchable information, and facilitate data-intensive marine science in the North Pacific region.

Key aspects of this plan are to 1) recommend revising and updating the PICES Data Policy aligned with the new UNESCO Intergovernmental Oceanographic Commission's (IOC) Data

Policy and Terms of Use and UN Decade of Ocean Science implementation plan, 2) highlight and provide recommendations on how to resolve barriers to data sharing within PICES, and 3) recommend data management platforms, data and metadata standards, and technologies that can be adopted by PICES that enable open data sharing, discovery, access, interoperability, data (re)use, and licensing (Box 2).

> ***Box 2*. Goals of this strategy**
>
> Goal 1 – Revise & update the PICES Data Policy
>
> Goal 2 – Promote data sharing within PICES
>
> Goal 3 – Recommend data management platforms, standards, and technologies, and resources

We hope that this strategy will evolve and the implementation developed in a second year of an Expert Group, preferentially as a PICES Working Group.

Recommendations

Goal 1: Revise & update the PICES Data Policy (2018/A/6: Data Management Policy)

PICES' Data Management Policy (2018/A/6) is a working draft with anticipated completion by May 2024 (Appendix C). The current policy refers heavily to managing data with scarce reference to sharing data, metadata, and information. The new PICES data policy should align with U.N. Ocean Decade Goals, and the recent revisions to the IOC Data Policy revised and approved in March 2023. The PICES data management policy should provide direction on wider access, sharing, and management of PICES data and information. Two data sharing principles that are currently recognized and being implemented to varying degrees around the world, are FAIR and CARE. The 'FAIR Guiding Principles for scientific data management and stewardship' were published in 2016 in *Scientific Data*. FAIR is an acronym for Findable, Accessible, Interoperable, and Reusable. CARE principles refer to Indigenous data and are meant to complement FAIR principles by ensuring that data are used ethically. CARE is an acronym for Collective benefit, Authority to control, Responsibility, and Ethics. We suggest changes to the current PICES data management policy by incorporating the following:

- **Update PICES data policy** (proposed changes Appendix C)
  - Incorporate **FAIR and CARE** principles

    - Include language that help **facilitate a data sharing culture** among PICES member countries
- Recommend **specific data licenses** with minimal restrictions
- Incorporate **plans for Expert Groups** to initiate data and information strategies at the onset of newly formed groups for where and how to store and share reports, data, and publications, etc. This should be stored and added to a searchable metadata catalog
- **Develop metadata catalogue** to improve or migrate TCODE catalog to modernized option
- **Communicate data storage and sharing** information on an easily accessed page on PICES website

Goal 2: Promote a culture of data sharing within PICES

The global ocean area and depth makes it difficult to sustainably and synoptically observe subsurface ocean processes and variability for sub-seasonal to decadal time-scales. Our understanding of the ocean is largely derived from compilations of historical and recent ocean data collected and shared by many countries and programs over many years. Sustained and routine international data sharing, quality control, and integration are necessary to all countries to document, understand, and model ocean climate variability and respond to its socioeconomic impacts at relevant spatial and temporal scales. The following recommendations are intended to incentivize a culture of internal and external data sharing within and across participating groups in PICES and partners, improve ocean data literacy, and foster community adopted best practices and FAIR-compliant data discovery, accessibility, and reuse.

- **Identify** and **acknowledge barriers** to data sharing within PICES. Building on barriers identified at the 2022 PICES Workshop, an annual survey for PICES members is recommended to continue identifying barriers to data sharing and monitor adoption of data management and sharing practices, and familiarity with domain-specific repositories and standards.
- Create a **data management and stewardship resource webpage**. This could include updating the TCODE products website to include additional resources and/or migrating the TCODE website to a new platform.
- Provide **education and training** opportunities around **identified data sharing barriers** and needs. This could include a recommended list of resources, workshops, course

material or reference sites to improve ocean data literacy and data management practices (e.g. through the Global Teacher Academy).

- Develop an adaptive and actionable **data management road map.** This will require (a) **documenting** current data management lifecycle, data flows and management processes, and challenges for PICES projects and Expert Groups; and (b) **diagramming** a data management lifecycle to be used as template, providing a checklist for current and future projects to adhere to this Data Management Strategy.
- Create an **inventory table** to discover and access current PICES data and information assets. A landing page on the PICES homepage could include guidance on how to find information on data discovery, access, quality control, resources, how to search the PICES data catalogue, and any relevant links to TCODE.
- **Incentivize data sharing** within PICES, for example by hosting an **annual 'Data Excellence' award - in honor of Igor Shevchenko** - for PICES members or groups that demonstrate effective and impactful data management and sharing practices within projects and Expert Groups. Recommended data sharing best practices can be further incentivized by PICES minting unique digital object identifiers (DOIs), or pointing individual researchers or Expert Groups to databases or repositories that offer this service.
- **Encourage 'data publications'** through PICES following data publishing requirements, recommendations for open data licensing such as Creative Commons public licenses (i.e., Attribution 4.0 International — CC BY 4.0) and data DOI citation standards .

Goal 3: Recommend data management platforms, standards, and technologies, and resources

Specific data management platforms that facilitate the recommendations above are needed so that researchers involved in PICES Programs, Projects, Committees, Working Groups, Study Groups, Task Teams and Advisory Panels can easily apply these recommendations. This strategy has a strong focus on leveraging pre-existing tools recommended or supported by the International Oceanographic Data Exchange (IODE) and that meet the needs of PICES with regards to effective data management and sharing. These recommendations are to:

- **Create a data management plan template** following the recommendations outlined in the IODE Guidelines for a Data Management Plan and host it on a free online tool such as https://dmptool.org

- PICES Secretariat should continue to **publish PICES reports to Aquadocs** & recommend members **publish methods and protocols to the Ocean Best Practices System (OBPS)**: an open access, permanent, digital repository of community best practices in ocean-related sciences and applications maintained by the IOC IODE. For PICES members to be able to contribute, an OBPS community collection must be established.
- **Assess free third-party data and metadata catalogs to transition the PICES TCODE Catalog to** that uses ocean science specific standards recommended by the Global Ocean Observing System and the UN Decade of Ocean Science Data and Information Strategy Implementation Plan. Key criteria for selection include: 1) minimal maintenance required by PICES or TCODE members; 2) is actively developed by third-party provider that ensures modern technologies and standards are used; 3) is user-friendly for PICES members to submit to; 4) able to not only publish metadata but also provides a place to store data if required; and 5) offers Digital Object Identifiers for datasets and the ability to assign open licenses for data to be reused.
- **Encourage minting Digital Object Identifiers (DOI) for PICES reports and datasets**. For simplified DOI issuance, explore free platforms such as zenodo.org in addition to the paid membership PICES has with DataCite Canada Consortium. To improve accessibility of DOIs consider a hybrid approach depending on categories of research outputs that would need to be established: 1) the self-serve model on zenodo.org with a dedicated 'PICES community' for streamlined DOI issuance by data providers; and 2) PICES DOI minting services through the DataCite Canada Consortium. There must also be guidelines for including PICES in appropriate DOI metadata fields.
- **Identify a cloud-based, collaborative word-processing platform available in all countries**. For example, Microsoft OneDrive collaboratively edit word documents in the browser if the document is hosted on OneDrive
- **Establish a PICES Data Stewardship Officer (DSO)** that would advise the SB and implement the management and coordination of data across PICES and partners. The DSO would be knowledgeable in scientific data sharing, management, FAIR principles and metadata best practices, and would be responsible for ensuring best practices are followed by PICES activities. For example, the PICES DSO could serve an advisory role to the Science Board, interact with international programs such as the UN Decade of Ocean Science, be a chair/vice chair/officer within TCODE or within the PICES Secretariat.

Conclusion

In conclusion, this comprehensive data management and sharing plan is a vital step forward for the North Pacific Marine Science Organization (PICES). Key recommendations include:

- *Revise & update the PICES Data Policy*: The existing data policy needs to be updated to align with modern data management practices. This includes incorporating FAIR and CARE principles, promoting a culture of data sharing, recommending specific data licenses, and ensuring data storage and sharing strategies are initiated at the onset of newly formed Expert Groups.
- *Promote a culture of data sharing within PICES*: Encouraging a culture of data sharing is vital for PICES. This includes identifying and addressing barriers to data sharing, creating a data management and stewardship resource webpage, developing a data management roadmap, establishing an inventory table for discovering and accessing data assets, and incentivizing data sharing within PICES.
- *Recommend data management platforms, standards, and technologies*: PICES should adopt specific data management platforms, follow international standards, publish reports and protocols through recognized repositories, review and enhance the PICES TCODE Catalog, encourage the use of Digital Object Identifiers (DOIs), and identify a cloud-based, collaborative word-processing platform.

By adopting these recommendations, PICES will enhance data accessibility, collaboration, and the global impact of its scientific efforts. This plan will help PICES stay at the forefront of marine science, contributing significantly to our understanding of the North Pacific region and beyond.

Acknowledgements

We would like to express our gratitude to all the members of SG-DATA and everyone who contributed to the development of this data management and sharing plan. Special thanks to Igor Shevchenko for his dedication and support in advancing data management within PICES.

Recommended citation

Satterthwaite, E., Garcia, H., Gann, J., Johnson, B., van der Stap, T., Hamilton, S., Alcinov, T., Fangfang, W., Chunhua, H., Ito, D., Ambe, D., & Prewett, J. 2023. Towards a Data Management & Data Sharing Plan for the North Pacific Marine Science Organization (PICES): A Final Report of the Study Group on Encouraging Data Awareness and Increased Transmission and Accessibility.

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- CARE Principles for Indigenous Data Governance: https://www.gida-global.org/care
- Creative Commons data licences: https://creativecommons.org/about/cclicenses/
- Ocean Decade Implementation Plan: https://unesdoc.unesco.org/ark:/48223/pf0000376780

Appendices

Appendix A: PICES data inventory

Dataset/Data Product Name	Expert Group Responsible	Report or Publication	Current home/host for these data?	PICES contacts	Data URL
non-indigenous species database	WG 21 / AP-NIS	PICES Sci. Rep. No. 48, 2015 Report of Working Group 21 on Non-indigenous Aquatic Species;	held at the PICES Secretariat	Tom Therriault	
PICES Metadata federation	TCODE	PICES Technical Report No. 1 (2007)	PICES rented server	Igor Shevchenko	http://67.212.128.196/geonetwork/srv/en/main.home
CPR Survey	MONITOR	http://pices.int/projects/tcprsotnp/default.aspx	MBA/ Sonia Batten	Sonia Batten	http://pices.int/projects/tcprsotnp/data.aspx
NPESR data portal	MONITOR / WG 35		uses a commercial system (Submittable)	Peter Chandler Hal Batchelder	https://pices.submittable.com/submit
Micronekton Sampling intercalibration data	BIO/WG 23	PICES Sci. Rep. No. 38, 2010			<< published by report and paper >>

ADRIFT-Hawaiian Islands Marine Debris Aerial Imagery Surveys (2015-2016)	ADRIFT Project Team	Special Issue Editorial, Volume 132, Pages 1–106 (July 2018) ADRIFT in the North Pacific: The movement, surveillance, and impact of Japanese tsunami debris, Marine Pollution Bulletin, –			http://histategis.maps.arcgis.com/apps/MapSeries/index.html?appid=e1e1464e56b14d80bf096b6e2fe132c4
ADRIFT-Webcam monitoring Webcam monitoring of marine/tsunami debris (2014–2017)	ADRIFT Project Team	Kako et al. 2018. Marine Pollution Bulletin: Special Issue Editorial, Volume 132, Pages 1–106 (July 2018)	Atsuhiko Isobe - by request		
ADRIFT-Development of life history database for Japanese Tsunami Marine Debris (JTMD) biota (2015–2016)	ADRIFT Project Team	Miller et al. 2018a. Trait-based characterization of species transported on Japanese tsunami marine debris:	Smithsonian Environmental Research Center	Greg Ruiz	http://invasions.si.edu/nemesis/jtmd/index.jsp
ADRIFT - Japan Tsunami Debris species database (2012-2017)	ADRIFT Project Team	Carlton et al 2017: Hansen et al (2018); Hanyuda et al (2018); Hansen (2013); Hansen et al (2017a,b,c); Report to MoE.	Dryad Oregon State University	Jim Carlton	Supplementary material: www.sciencemag.org/content/357/6358/1402/suppl/DC1 Dryad open data resource https://datadryad.org/resource/doi:10.5061/dryad.rh01m
ADRIFT-BC Coast Marine Debris Aerial Imagery Surveys	ADRIFT Project Team	Report to MoE.; ADRIFT in the North Pacific: Special Issue Editorial, Volume 132, Pages 1–106 (July 2018)	Province of BC	Cathryn Clarke Murray	http://governmentofbc.maps.arcgis.com/home/webmap/viewer.html?webmap=3c5fb88b7f3f4d97974615acad67af3e or http://www.arcgis.com/home/webmap/viewer.html?webmap=3c5fb88b7f3f4d97974615acad67af3e
Coral and Sponge data	WG-32/BIO	TBA	TBA	Janelle Curtis, Masashi Kiyota	TBA
Key environmental data	WG-32/BIO	TBA	TBA	Janelle Curtis, Chris Rooper (USA), Anya Dunham(CANADA)	TBA
Well-being analysis in PICES nations and Indonesia	MarWeB Project Team	PICES Scientific Report. No. 52 Marine Ecosystems and Human Well-being	PICES(also MaFF - TBC)	Mitsutaku Makino	http://meetings.pices.int/publications/projects/MarWeB/PICES_7_well-being.xlsx
data from 2014, 2015 and 2016 Indonesian Pond Aquaculture Experiments	MarWeB Project Team	PICES Scientific Report. No. 52 Marine Ecosystems and Human Well-being	PICES - Others?		

Clicker survey data - Las Lisas	MarWeB Project Team	Marine Ecosystems and Human Well-being	PICES - Others?		http://meetings.pices.int/publications/projects/MarWeB/Guatemala_LasLisasALL_English.xlsm
Clicker survey data - Monterrico	MarWeB Project Team	(MarWeb PICES Scientific Report in preparation)	PICES - Others?		http://meetings.pices.int/publications/projects/MarWeb/Guatemala_MonterricoALL_English.xlsm
Bibliographies (2) on the key concepts used in the project	MarWeB Project Team	(MarWeb PICES Scientific Report in preparation)	PICES - Others?		http://meetings.pices.int/publications/projects/MarWeb/well-being.xlsx http://meetings.pices.int/publications/projects/MarWeb/satoumi.xlsx
Dissolved iron data set in the North Pacific	WG-22/BIO	PICES Scientific Report. No. 42 Iron Supply and its Impacts on Biogeochemistry and Ecosystems in the North Pacific Ocean	PICES - Others?		https://meetings.pices.int/publications/other/members/WG22_dissolved_iron_dataset.pdf http://www.pices.int/members/working_groups/Disbanded_working_groups/products/Fe_data_set_Aug2012.xlsx

Appendix B: Data Strategy Definitions

- '**Data**' is a set of values, symbols or signs (recorded on any type of medium) that represent one or more properties of an entity.
- '**Metadata**' is 'data about data' describing the content, quality, condition, and other characteristics of data that allows their inventory, discovery, evaluation or use.
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- '**Free and unrestricted**' means non-discriminatory and without charge. "Without charge", in the context of this resolution means at no more than the cost of reproduction and delivery, without charge for the data and products themselves
- '**Non-commercial**' means not conducted for profit, cost-recovery or re-sale.

Appendix C: PICES Draft Data Policy

PICES Draft Data Policy (proposed changes included in red, anticipated completion May-2024)

Principles and Definitions

As stated in Article III of the Convention for the North Pacific Marine Science Organization (PICES) the Organization is to promote the collection and exchange of information and data related to marine scientific research in the North Pacific Ocean and its adjacent seas.
The PICES strategy on capacity development identifies TCODE as the committee responsible for the development of communication networks for exchange of data and information.

The timely, free and unrestricted international sharing of oceanographic data, metadata, products and services is essential for a wide variety of purposes and benefits including the prediction of weather and climate, the operational forecasting of the marine environment, the preservation of life, economic welfare, safety and security of society, the mitigation of human-induced changes in the marine and coastal environment, as well as for the advancement of scientific understanding that makes this possible.

Data, metadata and products should be accessible, reproducible, interoperable, freely and openly shared with minimum delay and restrictions. Such sharing of data in both real-time and delayed mode facilitates scientific research and innovation.

Data gathered as a result of PICES activities will be responsibly managed to guard against loss and to ensure continued accessibility. The management of data using external data management systems is preferred to using internal PICES resources. Data should be quality controlled, accompanied by metadata and, when possible, it is best to be stored in an openly accessible data repository and made accessible and discoverable through a web interface and machine-to-machine protocols. PICES members shall, where possible, use IODE data centres linked to the IOC Ocean Data and Information System (ODIS) as repositories for oceanographic data and associated metadata.

For any data provided to PICES, PICES will respect the ownership rights and any restrictions placed on these data by the provider.

Data include data products and model outputs related to PICES activities. Metadata are data about data.

End users include a person, organization, group (including PICES expert groups) using data.

Data providers include a person, organization, group (including PICES expert groups) providing data.

The data inventory refers to data for which PICES has the primary responsibility to manage

Roles and Responsibilities:

The Technical Committee on Data Exchange (TCODE) is responsible to:

1. Manage the PICES data inventory and promote within PICES and the general public through the TCODE data catalog service (or other new repository as determined by PICES TCODE and/or working group).
2. Communicate and disseminate data and metadata to all PICES members as well as the general public through PICES Catalog (or new option, TBD).
3. Assist Expert Groups to identify data that are to be included in the data inventory.

4. Assist Expert Groups in the development of data management options and strategies.
5. Make recommendations to Science Board on PICES data management and priorities, with particular emphasis on correcting or mitigating any known or anticipated deficiencies.

The PICES Secretariat is responsible to:

1. Support TCODE in the maintenance of the data inventory.
2. Support TCODE to correct or mitigate any known or anticipated deficiencies.

Science Board is responsible to:

1. Include data management requirements in the Terms of Reference of each PICES expert group.
2. Review the recommendations proposed by TCODE and provide recommendations to Governing Council as necessary.

Expert Groups are responsible to:

1. Identify any data developed during the activities of the expert group and inform TCODE and PICES secretariat.
2. Develop, with assistance from TCODE, strategies or options for managing data used by the expert group.

Data Produced by PICES

All data produced by PICES are considered to be publicly available unless explicitly specified otherwise.

Results, conclusions, or recommendations derived from the data associated with PICES do not imply endorsement from PICES.

Contributions of data from PICES expert groups will adhere to the expert groups' Terms of Reference and be submitted to TCODE for inventory while the group is active.

All data including metadata should be archived using standard codes, formats, and protocols.

Data Provided to PICES

The quality assurance of data is the responsibility of the data provider.

In the event that PICES becomes aware there may be quality issues in the data PICES will inform the data providers as soon as possible.

Data providers should inform PICES secretariat of any policies that may place special conditions on their redistribution.

End users are responsible for the proper use of the data and metadata provided.

PICES may reformat data or metadata but will never change the data provider's original record.

Data use must be acknowledged, preferably using a formal citation.

To support knowledge discovery and innovation both by humans and machines, data should meet FAIR Guiding Principles (Findable, Accessible, Interoperable and Reusable) to the greatest extent practicable.

Citation

Data citations should facilitate giving scholarly credit and normative and legal attribution to all contributors to the data, recognizing that a single style or mechanism of attribution may not be applicable to all data.

Where DOIs exist (Digital Object Identifier) they should be included in the citation.

Wilkinson, M., Dumontier, M., Aalbersberg, I. *et al.* The FAIR Guiding Principles for scientific data management and stewardship. *Sci Data* **3,** 160018 (2016). https://doi.org/10.1038/sdata.2016.18

Appendix 4

WG41 Final Report

PICES SCIENTIFIC REPORT
No. XX, 2023

Marine Ecosystem Services in the North Pacific

Edited by
Daniel K. Lew, Gisele Magnusson, and Kevin D. Ray

PICES Scientific Reports

Published since 1993, the PICES Scientific Report series includes final reports of PICES expert groups, proceedings of PICES workshops, data reports and reports of planning activities. Formal peer reviews of the scientific content of these publications are not generally conducted.

PICES Scientific Reports can be found at: https://meetings.pices.int/publications/scientific-reports

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Acknowledgements

We wish to acknowledge and thank all the participants who attended topic sessions, workshops, and meetings of the PICES Working Group on Marine Ecosystem Services (WG41/WG-MES). We also wish to thank the Human Dimensions (HD) committee and FUTURE program for their valuable support. Lastly, we acknowledge study group chair and working group co-chair, Professor Shang "Sunny" Chen, for his encouragement and leadership. Without his significant efforts, the WG41/WG-MES would not have been possible.

Preface

This report is a product of the PICES Working Group on Marine Ecosystem Services (WG41/WG-MES). 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.

This report provides an overview of marine ecosystem services in the North Pacific. We include chapters presenting the concepts and classifications for MES, an overview of assessment methods, a review of the 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 nations view and use information on MES and their values.

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 TOR5, but also fulfills the other TORs. Chapter 1 addresses TOR2 by reviewing typologies of ecosystem services. Chapter 2 addresses TOR1 by providing a comprehensive overview of methods to assess marine ecosystem services. Chapter 3 fulfills TOR3 by presenting a comparative review of aquaculture-related ecosystem services across multiple PICES nations. Chapter 4 presents the results from surveys of key participants in ecosystem service science and/or management in several PICES countries, and thus further contributes to fulfillment of TOR3 and our understanding of how ecosystem services and their values are viewed in the North Pacific. The collaborative elements of TOR4 are captured through participation and contributions by WG-36 and WG-40 members in the working group's activities.

Marine Ecosystem Services: Concepts and Classifications

Daniel K. Lew[1]

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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 (Kumar, Esen, and Yashiro, 2013; Gómez-Baggethun and Barton, 2013). It is central to payment for ecosystem services (PES) programs (Bulte et al., 2008; Farley and Costanza, 2010; Jack, Kousky, and Sims, 2008) 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; United Nations, 2016).

This chapter 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 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 chapter presents key concepts and definitions needed to understand what marine ecosystem services 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, WG41 or WG-MES.[1] The work described within the broader report is intended to contribute to PICES' integrative scientific program, 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 (Figure 1.1). By providing a framework for assessment, MES generally, 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?

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

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 humans receive 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 chapter is organized as follows: Section 1.2 briefly illustrates the growing interest in ecosystem services 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 the chapter and provides an outline of the remainder of the report.

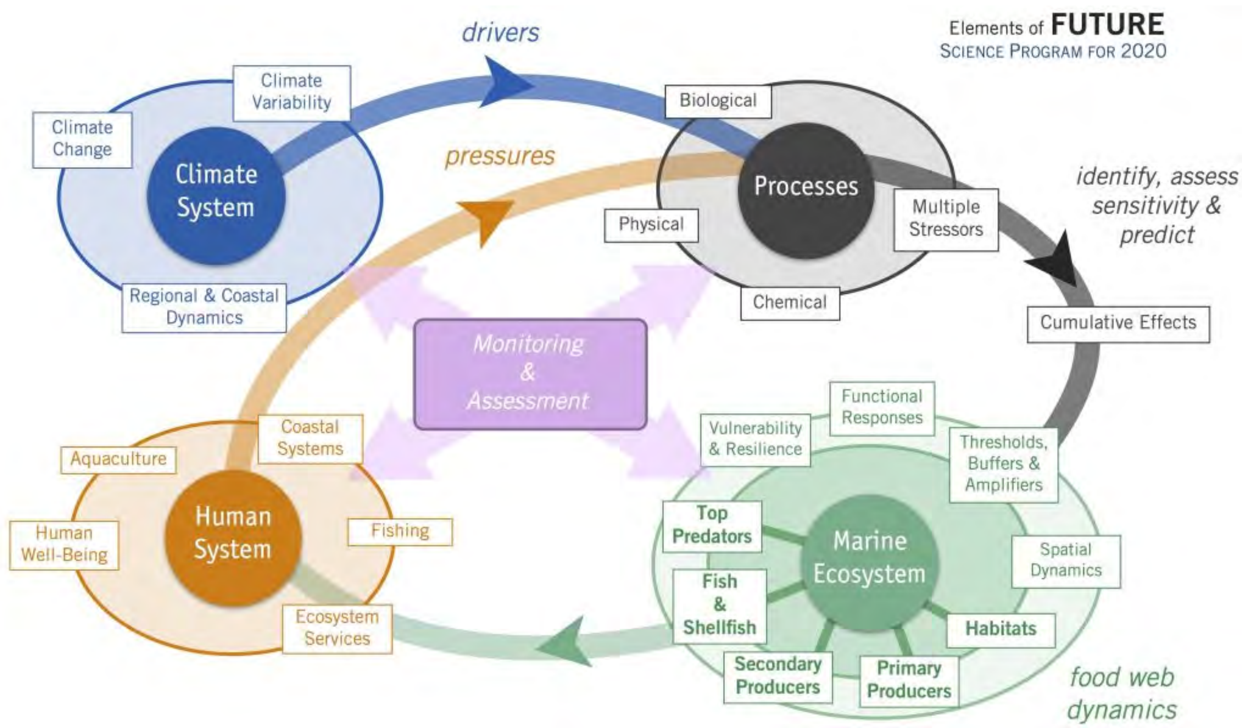

Figure 1.1. PICES FUTURE SES-based conceptual framework

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 over topics that include the keywords "ecosystem service*" to identify all published documents that had "ecosystem service" or "ecosystem services" in the title, keywords, or abstract. We found

[2] See https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/ for more details.

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]

Over the period 1999-2019, the number of published ecosystem service documents grew steadily each year (Figure 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 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 over 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

[3] See Gómez-Baggethun et al. (2010) for a useful history of the early ES literature.
[4] Note that every journal and book in WoS are 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.

"environmental science" (46.6%) and "ecology" (28.3%). The third largest number of studies were 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 ecosystem services and MES literatures.

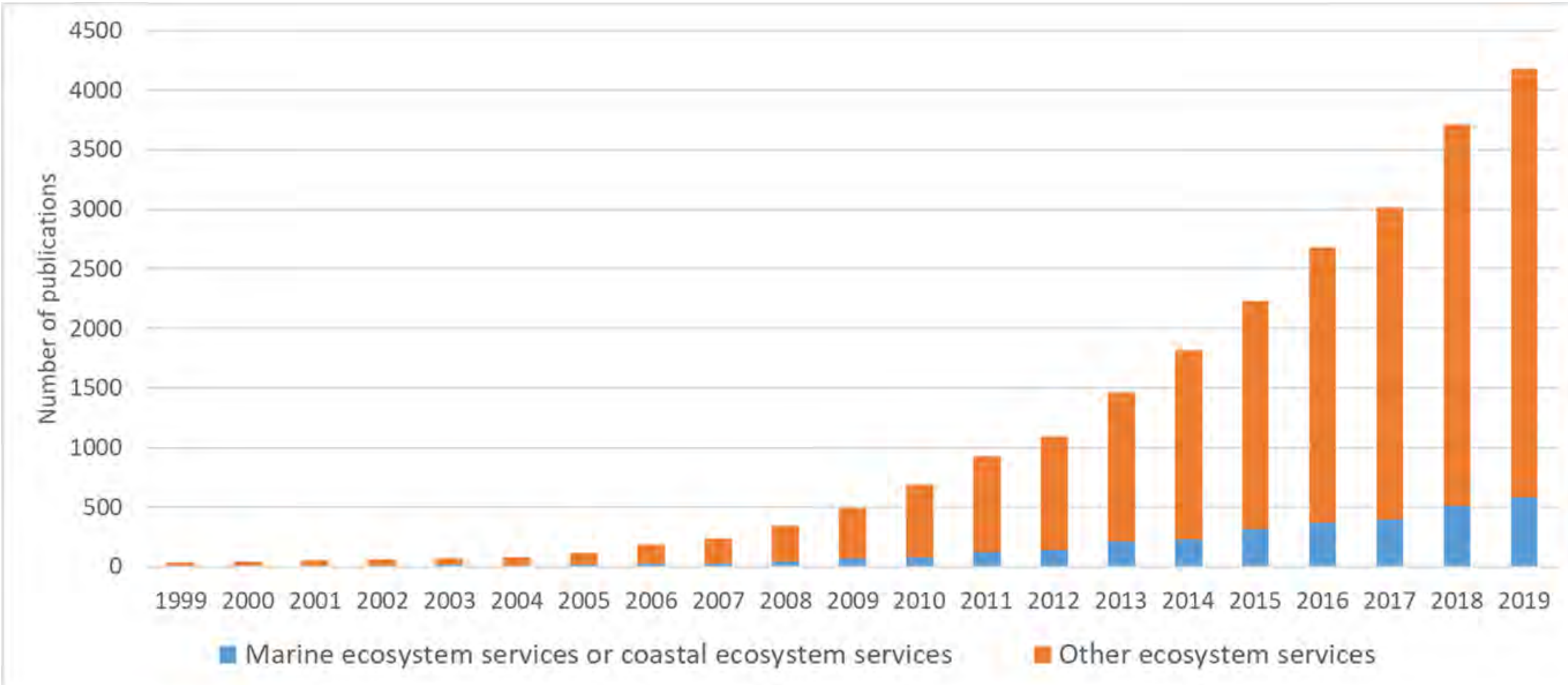

Figure 1.2. Comparison of the growth of the general ecosystem services literature and the coastal and marine ecosystem service literature, 1999-2019. Number of publications by year resulting from a search of the Web of Science Core Collection (http://apps.webofknowledge.com) using the keywords "ecosystem 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.

1.3 MES: 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 ecosystem services to enable more concrete, quantitative inquiries. Two of the earliest definitions for ecosystem services (ES) were put forth by Costanza et al. (1997) and Daily (1997). Daily (1997) describes 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) refer 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, p.3). While all of these definitions suggest ecosystem services are intrinsically anthropocentric and relate to the benefits humans derive from nature, they do differ in important ways. The last two define ecosystem services (and ecosystem goods) as equal to the benefits provided to humans, while the first suggests that ecosystem services 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) propose narrowing the focus from all ecosystem goods and services to "final" ecosystem goods and services (FEGS), which they define as "components of nature, directly enjoyed, consumed, or used to yield human well-being." Ringold et al. (2013) further articulate 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 ecosystem services that are not FEGS, Fisher et al. (2008) propose distinguishing between FEGS and "intermediate ecosystem services," which are ecosystem services 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 fish 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) discuss 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 of Fisher, Turner, and Morling (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) propose a set of four guiding principles for developing a definition and classification scheme for ecosystem services (pp. 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 note 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 view the FEGS definition as having four strengths relative to others, specifically that it (1) avoids ambiguity by being restricted to the ecosystem services that directly interact with beneficiaries; (2) eliminates double-counting of ecosystem services 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 propose 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 (Figure 1.1). This relationship could be captured in a more complete SES model that highlights individual and collective human actions act as (positive or negative) stressors on the natural environment.

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, Gould, and Pascual 2018; Stalhammar and Thoren 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.

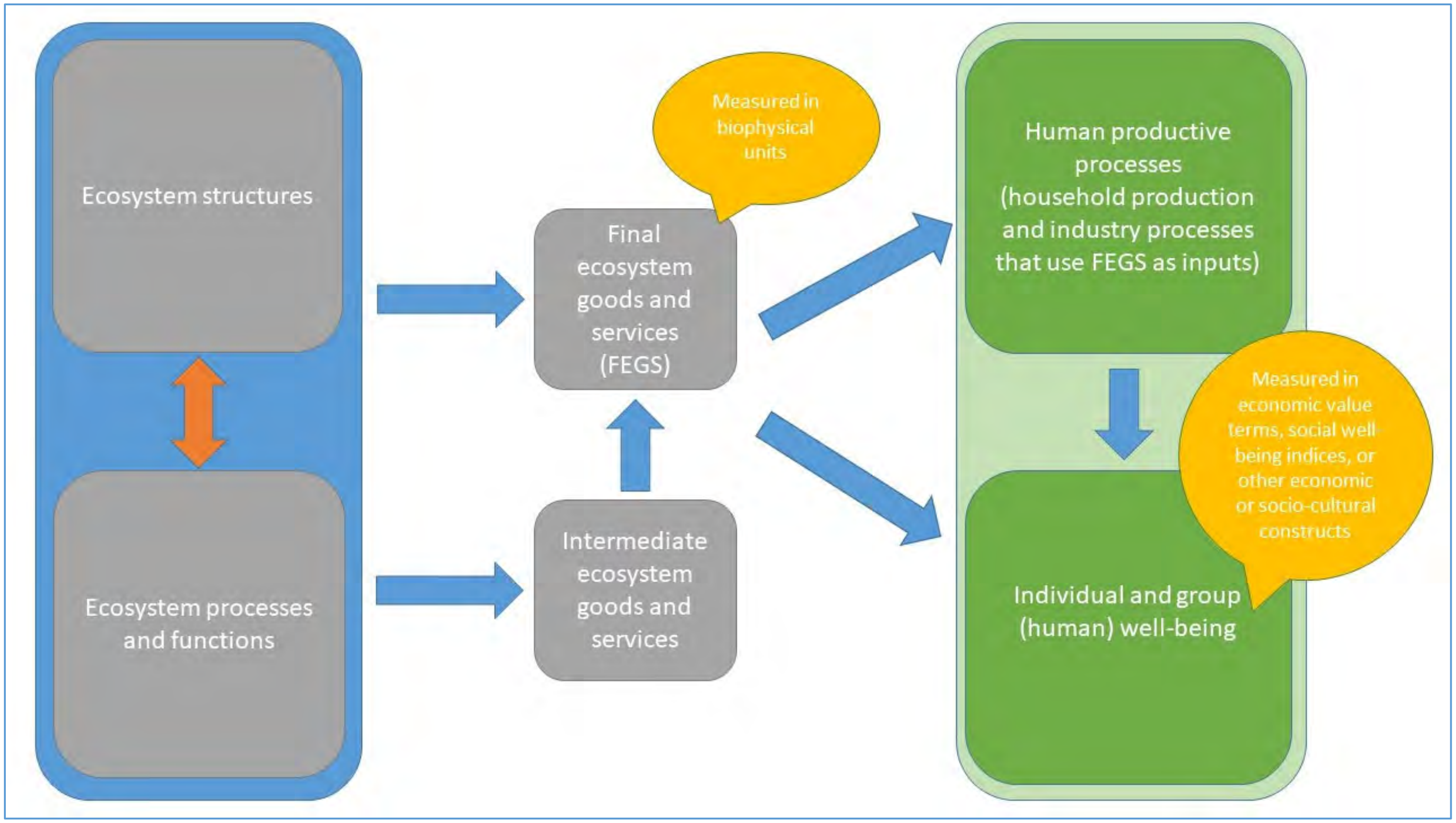

Figure 1.3. Conceptual diagram of relationship between the ecosystem, intermediate and final ecosystem services, and humans. On the left are the ecosystem structures and ecosystem processes and functions that represent the ecosystem. The bidirectional arrow between them represents the feedback mechanisms 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.

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, 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, p. 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 ecosystem services 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 services, 31 regulating, and 17 cultural. This hierarchical structure allows users to determine the most appropriate level of ES detail for a given application (Haines-Young and Potschin, 2018).

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

Beyond providing a functional organization for types of ES to capture the full scope of ES, another purpose for these ES 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) review the ES definitions to evaluate how useful they are for guiding operationalization and advocate 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) develop 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 in a set of workshops with natural and social scientists.

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

(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 Appendix 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 upon 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, I do not advocate 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, Gould, and Pascual 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 nations 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—like 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 of the types 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. Appendix Table A1.2 provides the MES classified under the CICES classification system.

Table 1.1 Common Marine Ecosystem Services and Mapping to MA and 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 incl. 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

Recreational benefits (cultural)		
• Water recreation (e.g., scuba diving, snorkeling, swimming, surfing, paddle boarding, kayaking, sailing, motor-boating, etc.)	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 chapter illustrated the growth of the marine ecosystem services literature, reviewed several common definitions and classifications of ecosystem services generally, and identified a number of common marine ecosystem services common in the North Pacific.

This chapter sought to provide an answer to the question, "what are marine ecosystem services?" Subsequent chapters 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 socio-cultural ones (Chapter 2). Another chapter compares how the MES concept is applied and researched in relation to aquaculture in PICES nations (Chapter 3). The final chapter reports on how MES and MES values are viewed by researchers and policy analysts in PICES nations using results from a survey conducted in several PICES nations (Chapter 4). Taken together, the report represents a first step towards a fuller understanding of MES in the North Pacific.

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Appendix 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

Appendix Table A1.2. Marine Ecosystem Services in the CICES classification scheme linked to MA and 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 (excluding genetic materials)	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

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
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	*Material by type/source*	*Materials from wild plants, fungi and algae used for energy*	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 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 use or processing (excluding genetic materials)	1.1.6.2	*Material 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*	*Material 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

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
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
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 micro-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 substance type*	*Filtering wastes*	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
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
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 flows 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

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
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
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 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

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	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
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 to as a national or local emblem*	Spiritual and religious values	Inspiration for culture, art and design, aesthetic information

Section	Division	Group	Class	Code	Class type	Simple descriptor	MA	TEEB
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

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

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2.1 Introduction

This chapter 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 sections present ES assessment approaches for three broad scientific disciplinary perspectives that see the world through different lenses: the *ecological* sciences perspective (section 2), the *economic* perspective (section 3), and the *socio-cultural* perspective (section 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 indicates 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.

The following sections provide an overview of the different approaches for assessing ES from the ecological, economic and socio-cultural perspectives.

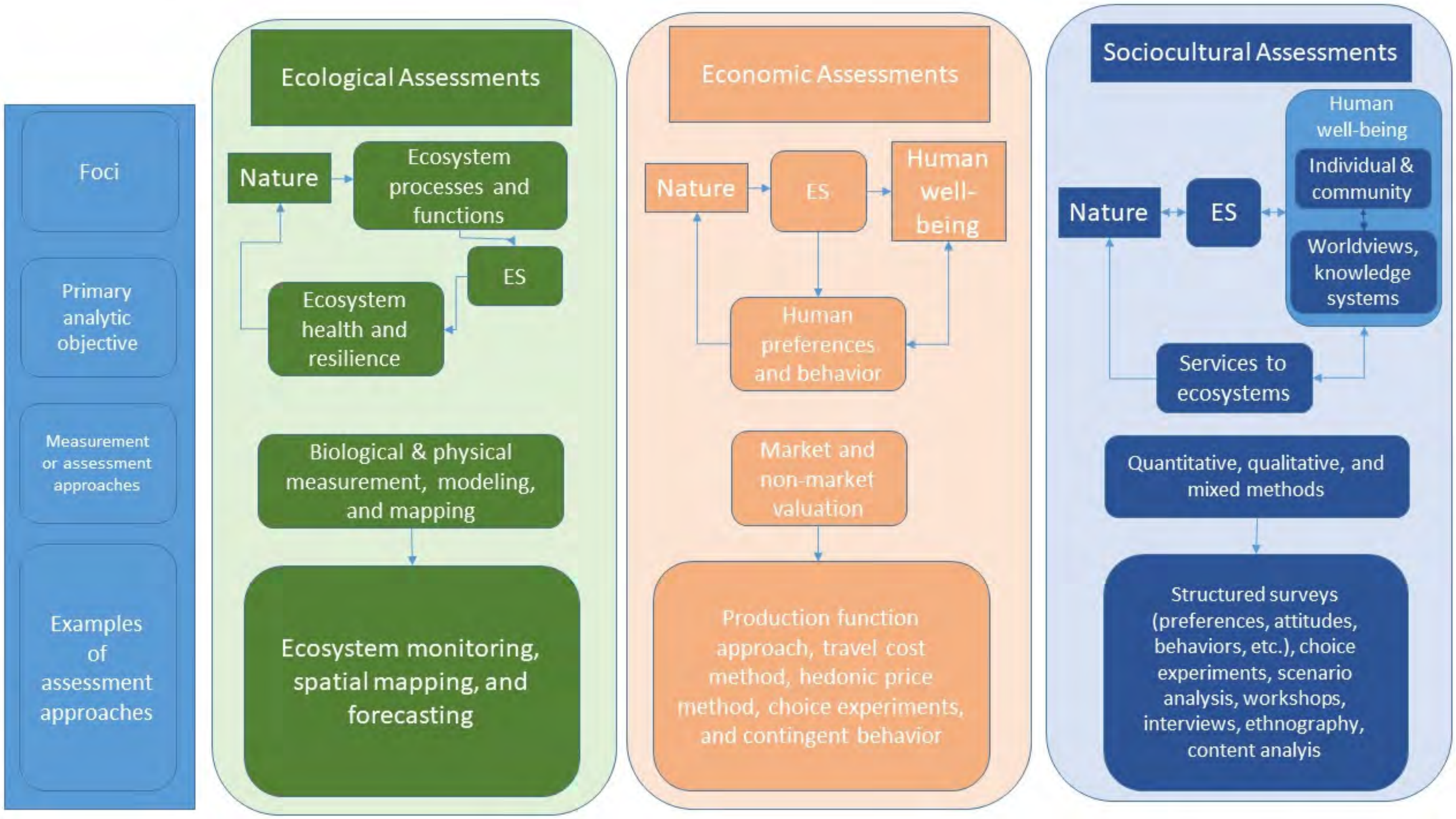

Figure 2.1. Different disciplinary perspectives influence what aspects of marine ecosystem services are focused on and how to assess them.

2.2 Ecological Assessment

Ecologically, ecosystem services are the physical, chemical, and biological processes provided by the natural environment. As ecosystem services broadly encapsulate the direct or indirect benefits to humans derived from ecosystems, ecological ecosystem services result from the organisms that form the biotic community and the abiotic habitat they occupy (Lindeman, 1942; Costanza et al., 1997a; Millennium and Assessment, 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, Millennium and Assessment, 2005). A notable portion of these services are evident within, and vital to the preservation of, marine ecosystems, especially coastal zones, and they have been termed 'marine ecosystem services' (MES) (Costanza et al., 1997b; Martinez 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 reef fish communities' resilience to changing climatic conditions (Duffy *et al.*, 2016).

Evaluating the MES provided to humanity 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 ecosystem services requires the application of several techniques due to the diversity of services that sustain natural environments (Nahlik *et al.*, 2012; Figure 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 (Supplementary Table 2.1). Monitoring these and other metrics allows for ecosystem services 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 ecosystem services, health, and resilience to be examined.

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 or 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.

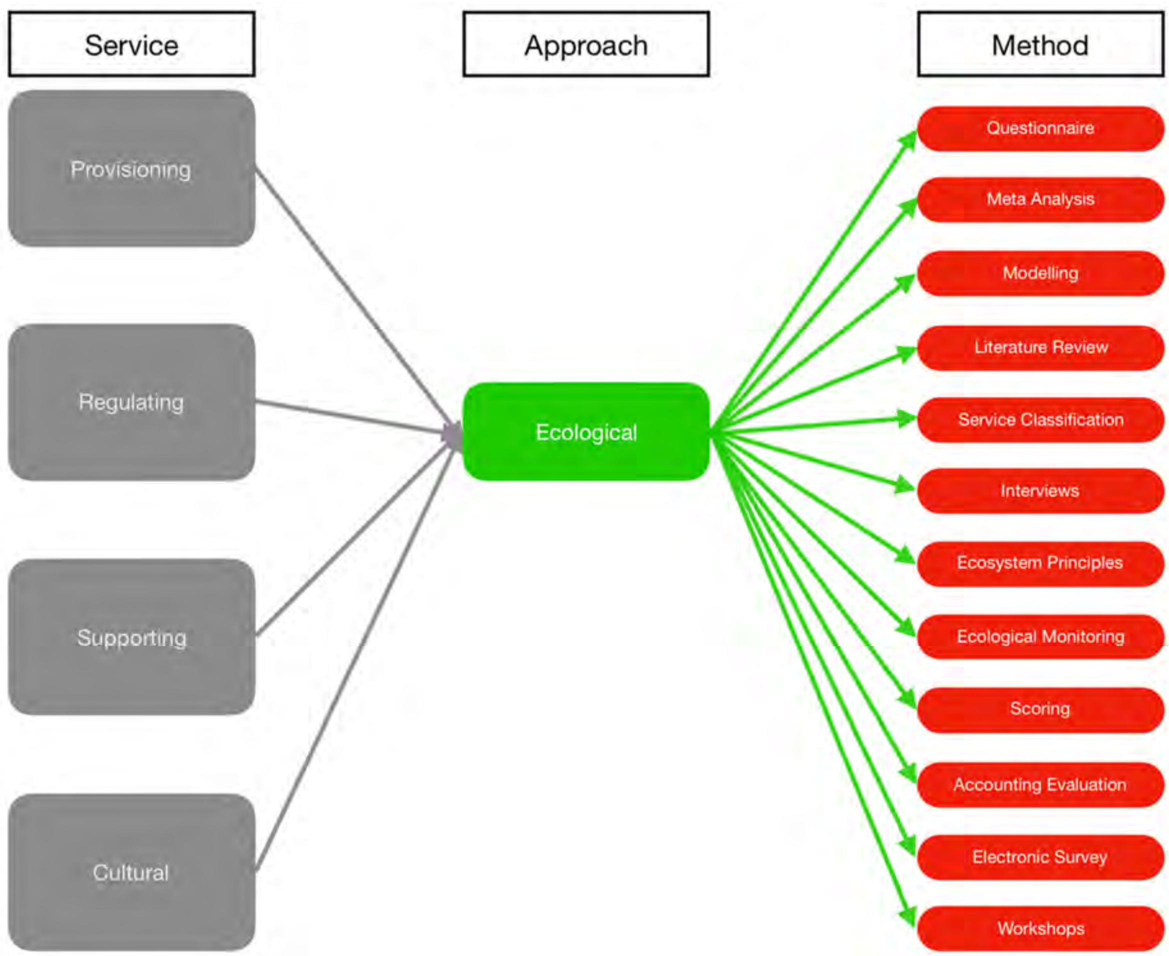

Figure 2.2. An illustration of the connection between the ecosystem service assessed, the approach taken for the assessment, and the method utilized.

Table 2.1: A summary of ecological services, assessment categories, and approaches utilized when examining the ecological aspects of marine ecosystem services. Reference sources, metrics, and ecosystem service types (*e.g.,* provisioning, regulating) relating to this data can be found in Supplemental Table 2.1.

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
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

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 (Figure 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 (Figure 2.2). All of these can assess the ecological aspects of provisioning, regulating, supporting and cultural ecosystem services (Figure 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; Supplemental Table 2.1). For example, examining ESs that stem from fisheries, such as life cycle maintenance or fish biomass, should consider assessment approaches such as 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, nursey area, juvenile and spawning fish density (Supplemental 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 are employed (Figure 2.3).

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 ecosystem services 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 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.

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 an 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 and spatial analyses for examining MES has recently began expanding due to 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 ecosystem services 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.

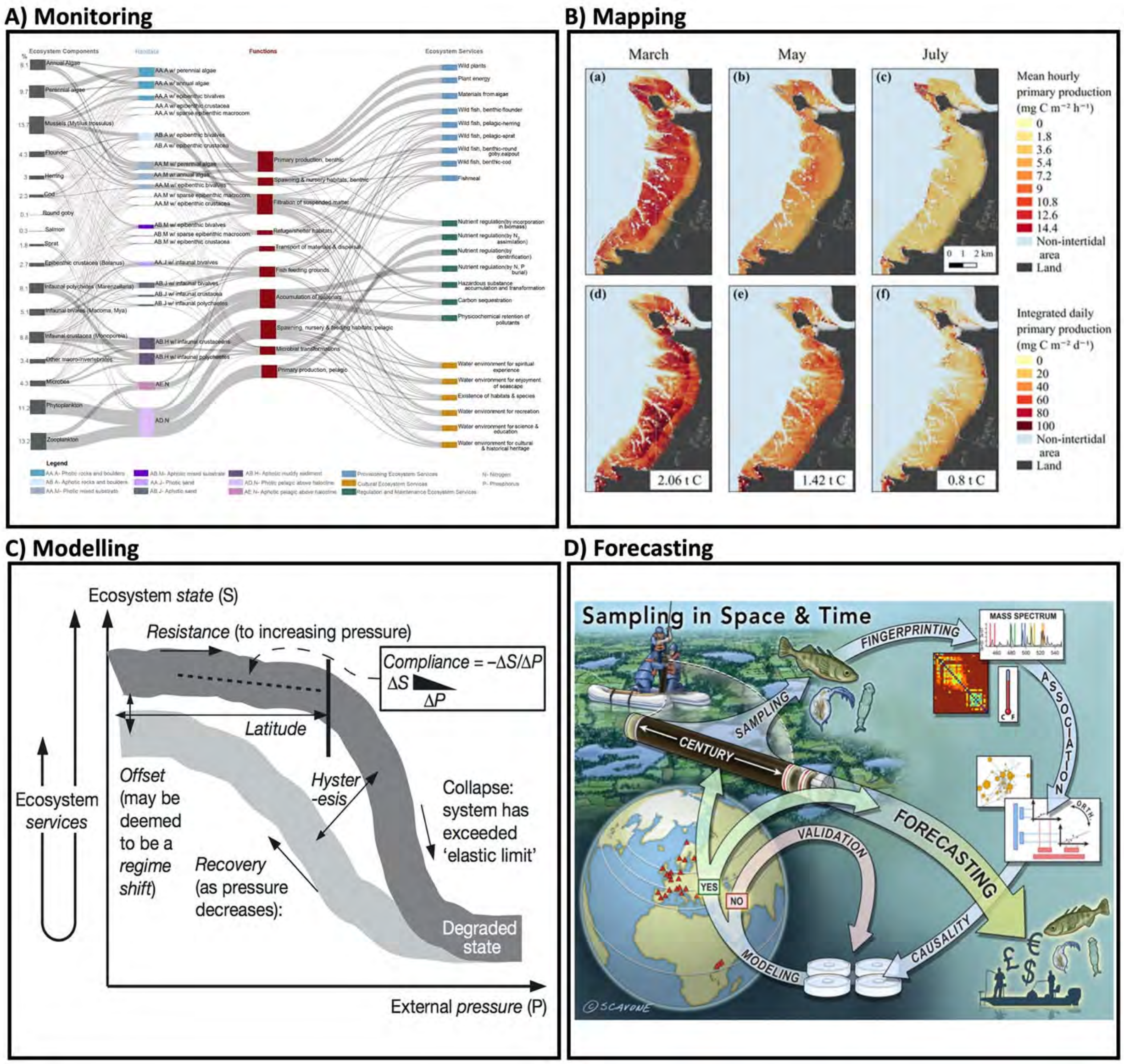

Figure 2.3. Graphical depictions of monitoring, mapping, modelling, and forecasting the ecological attributes of marine ecosystem services. A) *Armoškaite et al., 2020* B) Méléder et al. 2020 C) Tett et al. 2013 D) (Eastwood *et al.*, 2020). All Figures are open-access adapted from open-access articles distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

2.2.2 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 ecosystem services. 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, Supplemental Table 2.1, Figure 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 ecosystem services (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 humans, 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 (National Research Council, 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), but they rather 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 socio-cultural 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, management of marine protected areas, 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 ecosystem services 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 ES 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, 1989; 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 provides an indication of the value people place on them. For example, for *market goods and services* the prices people pay indicates that how much they value these goods and services is at least 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. [1993], 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 before the change. 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 (Figure 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) (NRC, 2005; MA, 2005; Freeman et al., 2014). A common decomposition of the TEV of a good or service is into use and nonuse values (Freeman, Herriges, and Kling, 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

[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.

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 or studying about the 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 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).

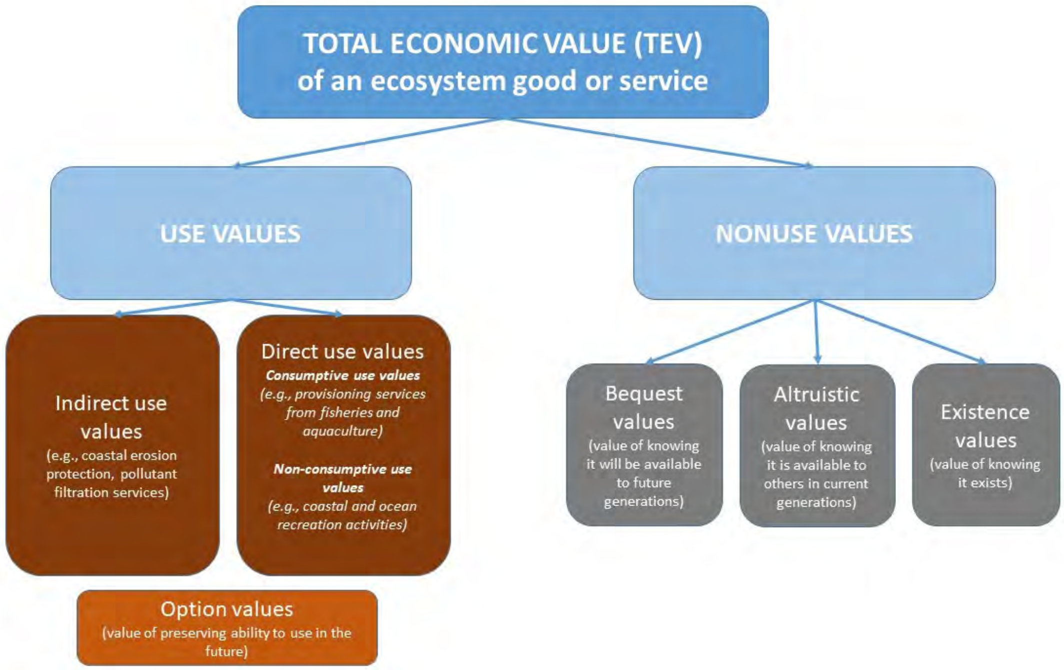

Figure 2.4. Total Economic Value and its constituent values

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 ES, 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 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.

[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).

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 ES 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 ES or to substitute or replace the ES. 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 ES 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.

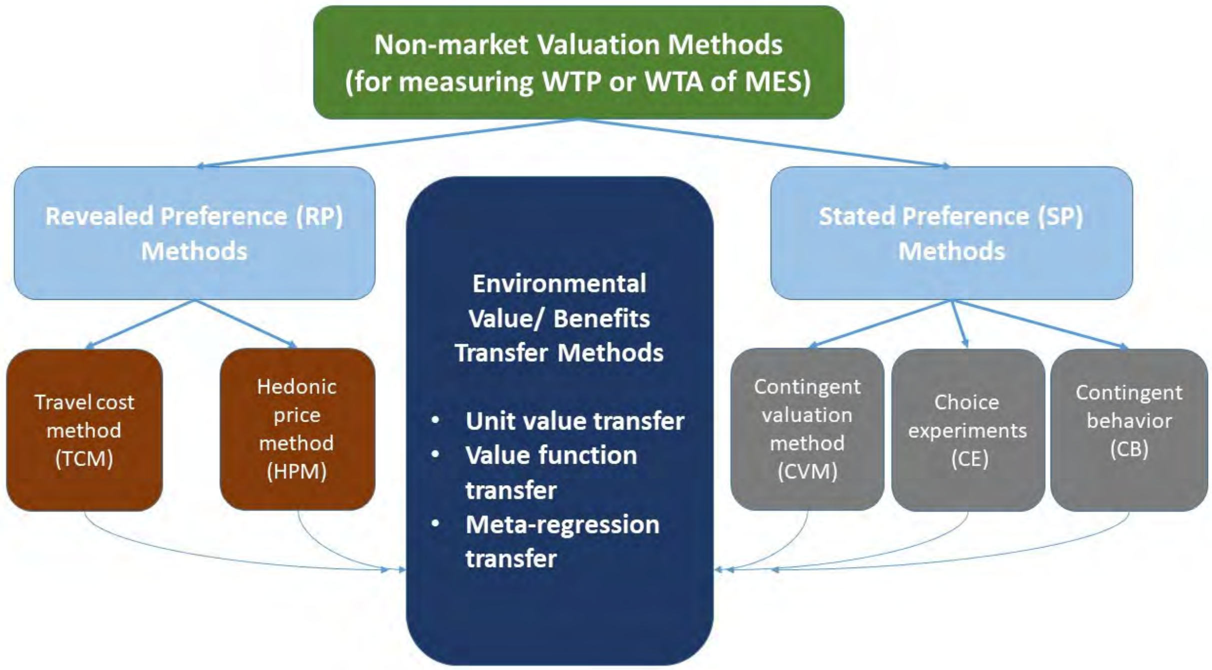

Figure 2.5. Non-market Valuation approaches.

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 (Figure 2.5). RP valuation methods use information on observed behavior to infer the preferences for, and value of, the non-market good or service (Bockstael and McConnell, 2007; Boyle, 2003). 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 RP and SP methods is the data used. Revealed preference methods use data on observed behavior to infer economic values, while stated preference 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.

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 socioeconomic information. A common variant of the TCM is the random utility maximization (RUM) travel cost model 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 ecosystem services, such as the scenic ocean view (or lack thereof) from that house. Estimates of the value of these ecosystem services (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 (Asche et al., 2021; Bronnmann and Asche, 2016). 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 (Alpízar et al., Carlsson, and Martinsson 2001; Johnston et al., 2017; Hanley et al., 1998). In the 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 (Siikamäki and Layton,, 2007; Boyle et al., 2001).

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 and Lew, 2020; Whitehead et al., 2008). 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 ES 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 (Johnston et al., 2021; Smith, 2018). 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 (Desvousges et al., 1992; Boyle and Bergstrom, 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 in the new policy application.

3. *Meta-regression transfer*: Meta-analyses have been used to synthesize and summarize existing valuation studies of ecosystem services (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 socioeconomic characteristics in different countries, a natural question that arises is whether one could reasonably transfer values for an ES 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.

Table 2.2. MES and economic valuation (similar to Goulder and Kennedy [2011])

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

2.3.3 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 Chapter 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.

2.4 Sociocultural Assessment

Sociocultural analyses aim to understand how people create knowledge and meaning about ecological components of the physical environment (Ciftcioglu, 2017; Morishige et al., 2018; Pascua et al., 2017; Sterling et al., 2017). All social science inquiry assumes a degree of relativism and constructivism, which recognizes that reality is constructed within a human mind and is influenced by social and cultural contexts such as social norms, traditions, and history (Moon and Blackman, 2014; Tashakkori and Teddlie, 1998). 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, marine ecosystem services (MES) are shaped by people's perceptions and interactions with the environment (Christie et al., 2019; Díaz et al., 2015).

Sociocultural ecosystem services assessments have typically focused on non-material goods and services derived from the biotic and abiotic components of an ecosystem (Chan et al., 2012; Comberti et al., 2015; Fish et al., 2016; Millennium Ecosystem Assessment, 2005; 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 (Kenter et al., 2019, 2015; Raymond et al., 2014; van Riper et al., 2019).

Sociocultural analyses also seek to include multiple value and knowledge systems, also known as worldviews or paradigms (Calcagni et al., 2019; Chan et al., 2012; Comberti et al., 2015). Since stakeholders think about and interact with marine resources in a variety of ways, it is critical to understand these diverse perspectives to achieve an equitable analysis (Horcea-Milcu et al., 2019; Ives and Kendal, 2014; 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 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 need 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 both through 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 human and nature (Chan et al., 2018; Comberti et al., 2015; 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 humans but also 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 ecosystem services comes from the Millennium Ecosystem Assessment (2005). Within this framework, sociocultural considerations are categorized as Cultural Ecosystem Services (CES) and limited to non-material services and benefits (Millennium Ecosystem Assessment, 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 ecosystem services framework (Calcagni et al., 2019; Chan et al., 2012;

Fish et al., 2016), the incommensurable nature of CES (Calcagni et al., 2019), the conceptualization of CES as a one-way, linear flow (Calcagni et al., 2019; Chan et al., 2018; Comberti et al., 2015), 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 ecosystem services 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; Gould et al., 2019; Pascua et al., 2017).

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 we will explore in this section. There is a promising movement to increase inclusivity of sociocultural connections to, relations with, and influences on the environment (Ciftcioglu, 2017; Morishige et al., 2018; Pascua et al., 2017; Sterling et al., 2017). 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 ecosystem services framing to make room to acknowledge and include relational values. Bringing relational values into an ecosystem services framework helps to move away from perceiving ecosystem services 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 assessments 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 ecosystem services 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 methods are better suited to study established indices of instrumental and intrinsic values. These methods 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 national 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 (Section 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, but 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 regards 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 in regards to Indigenous cultures wherein many cultural 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 regards 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 socio-cultural 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, 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 marine ecosystem services, qualitative studies strive to provide data that illuminates 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 because the researchers depend on participants to give full and honest responses and participants are at the mercy of researchers to accurately and adequately interpret and reflect participant 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 (Fordham and Robinson, 2019; Neef et al., 2018). 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 Hawaiʻi 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 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 (Eriksson et al., 2019; Kenter et al., 2015; Zimmermann et al., 2021). Pascua et al. (2017) conducted workshops in Hawaiʻi 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. Challenges to using workshops as a research method can include poor or inadequate facilitation, 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 done at a cultural level studying 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 (Clifford, 1998; Creswell and Poth, 2016; Spradley, 1979). 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 ecosystem services in the United Kingdom. Some challenges of ethnographic research include that it often results in narratives that work best as a storytelling approach, which can limit applicability to diverse audiences (Creswell and Poth, 2016). Additionally, there is a responsibility on ethnographers to enter into typically unfamiliar cultures, assimilate, be sensitive to ongoing issues and cultural norms, answer their own research questions, and fairly and accurately represent the cultures being studied. This is a significant burden on the researcher and 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 externally understood.

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 et al., 2014; Miles and Huberman, 1994; Strauss and Corbin, 1998). 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 provide for a deeper understanding in 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 cultural ecosystem services in West

Hawaiʻi. To ensure interviewees were accurately reflected, the authors confirmed appropriateness of the way results were described with 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 ecosystem services, researchers often employ multi-step processes or mixed methods to have a more holistic and diverse understanding of ecosystem services. 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 phenomena when different sources or data converge on similar results. There are a diversity of worldviews among peoples and across times, and we need multiple methods that can accurately represent and understand them. 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 (Kenter et al., 2019; Kronenberg and Andersson, 2019; Raymond et al., 2014). Examples of mixed-method socio-ecological assessments of ecosystem services include Bremer et al. (2018), Eriksson et al. (2019), and Iniesta-Arandia et al. (2014). 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 ecosystem services, well-being, and drivers of environmental change in south-eastern 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. Q method aims 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 socio-cultural ecosystem services are perceived spatially. Social value mapping methods integrate a mapping exercise to add location data to perceptions of ecosystem services, including socio-cultural ecosystem services. 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 of ecosystem services and then identify on a map where these ecosystem services are located and/or preferred (Sherrouse et al., 2014, 2011; 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 socio-cultural benefits with specific locations (Gould et al., 2015; Levine and Feinholz, 2015; Nahuelhual et al., 2016; Plieninger et al., 2013). Photo elicitation has also been used as a tool to bring out or understand the benefits, preferences, perceptions, or values of ecosystem services at particular locations (Angradi et al., 2018; Berbés-Blázquez, 2012; 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 ecosystem services. Maps are then created from data collected by these various approaches. Maps aim to look at 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. In regards to the sociocultural dynamics of ecosystem services, we have grouped methods into three types – quantitative, qualitative, and mixed methods – so as 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 ecosystem services, 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 ecosystem services 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 ecosystem services 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 ecosystem services 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 ecosystem services, 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 sociocultural dimensions of ecosystem services 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 marine ecosystem services. They include:

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

2) To seek methodologies and analyses that highlight their generalizable aspects and implement shared terminologies that 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 ecosystem services, respectively, illustrating the need for mixed methods approaches to ensure the power of future investigations into, and assessments of, sociocultural aspects of ecosystem services.

2.5 Discussion

As research on 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 systems and ecological systems. In this chapter, we examined the diverse approaches for assessing MES. Assessment methods were presented from three broad scientific disciplinary perspectives—ecological, economic, and sociocultural—each with differing foci and analytic objectives. This leads to different assessment methods being employed from different disciplinary perspectives.

However, the chapter 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, 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 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 an overall synthesis and evaluation is 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 meaningfully be incorporated 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 chapter 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 policymakers 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 dialogues about the benefits and limitations of the assessments used, as well as the processes to determine which to use, is a crucial step in informed decision-making.

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APPENDIX

Supplemental Table 2.1: Marine and coastal ecosystem services (MCES) indicators identified by Liquete et al. (2013) in 'Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review' using a cascade scheme. Adapted from Liquete et al. (2013) Supplemental Table 3.

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 purificatio n	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 colliform [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 nour	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]	

Supplemental Table 2.1 References

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3. Aquaculture-related Ecosystem Services in PICES Nations

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3.1 Introduction

3.1.1 *Overview of Ecosystem Services and Aquaculture*

The relationship between aquaculture and marine ecosystem services is complex. Aquaculture can serve to augment existing ecosystem services 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 ecosystem services 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 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 ecosystem services 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 ecosystem services. 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 are 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 marine ecosystem services 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 ecosystem services is stated preference methods such as contingent valuation. These methods are particularly useful to value the cultural ecosystem services 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 ecosystem services, 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 ecosystem services is the net effect of benefits and damages, but this has not received sufficient attention in the literature. As the research into marine ecosystem services and aquaculture continues, it will be important for these negative effects to be included. This will also mean incorporating the ecosystem services 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 (Racine et al., 2021; Rose et al., 2014). On the other hand, the culture of carnivorous finfish has been recognized to have a number of negative impacts on the surrounding environment (Naylor & Burke, 2005). Optimally managing the expansion of aquaculture will require incorporating the existing state of knowledge about ecosystem services into decision-making, as well as encouraging further research.

This chapter will summarize the existing body of knowledge along with the notable gaps with respect to the marine ecosystem services provided by aquaculture in PICES nations. There are several recently published literature surveys on the topic of marine aquaculture ecosystem services (Alleway et al., 2019; Barrett et al., 2022; Gentry et al., 2020; Weitzman, 2019), but these provide only a broad overview of the topic and its associated literature. This chapter includes a systematic literature review and gap analysis for each member nation, 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 marine ecosystem services in the PICES nations of USA, Canada, Japan, and China. In addition to identifying what ecosystem services are assessed and the employed methodologies, the project also 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 ecosystem services associated with aquaculture, only studies which produce new quantified measures of ecosystem services 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 nation, individual states or provinces, or particular bodies of water. The abstracts of the search results were reviewed and the 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 marine ecosystem services 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 nations in this search, there was a large difference in the number of included studies. In descending order, the search for the USA turned up forty-one 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 ecosystem services being measured vary across the participating nations. Studies in China are broadly focused, considering ecosystem services 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 forty-one quantifying the service provision across two categories.[8] Most of the US 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 US studies do estimate the quantity and value of shellfish that are produced, this is never linked to the concept of provisioning ecosystem services. 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 ecosystem services 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 US report, seven of eight for

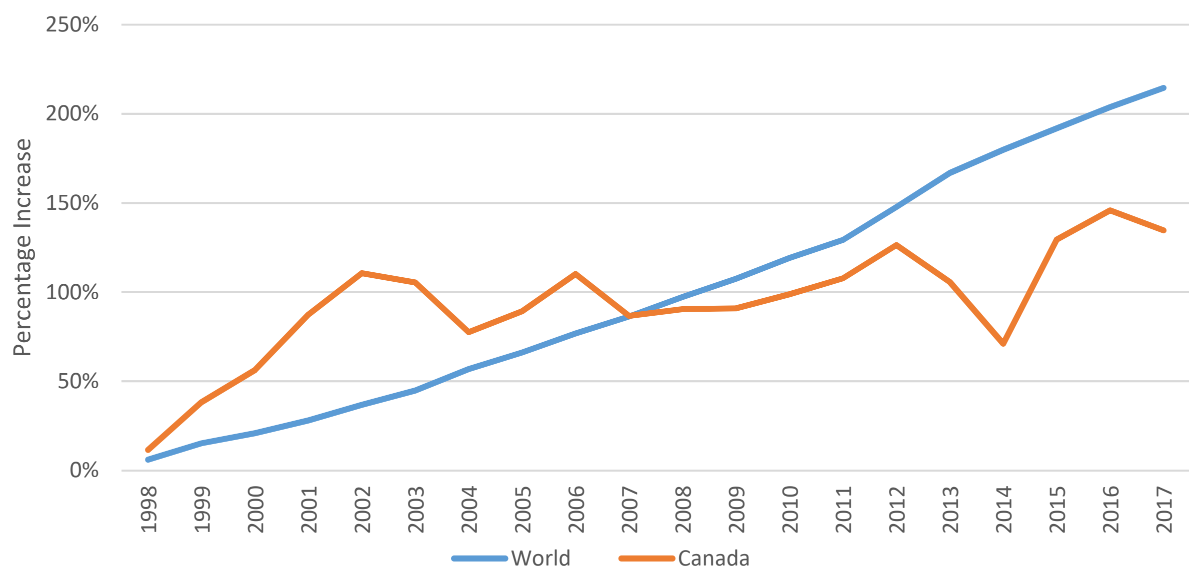
[8] In Ayvazian et al. (2022) the regulating services of bioextraction and denitrification are measured along with the supporting service related to associated macrofaunal species including fish and crabs.

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 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 marine ecosystem services will need to be calculate and communicate the associated economic values to policy makers.

3.2 Canadian Case Studies

3.2.1 Aquaculture Production in Canada

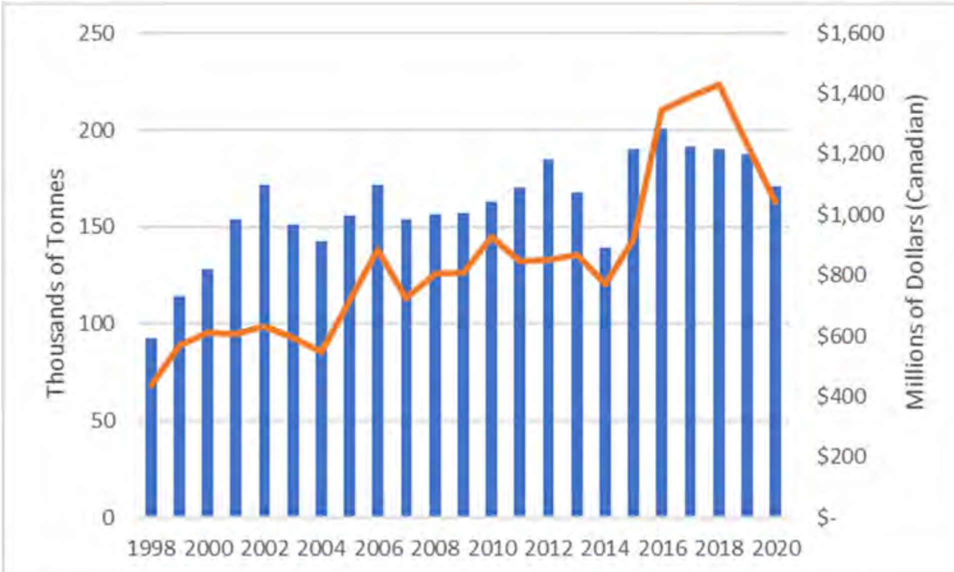
Canada ranked 20th in global aquaculture production in 2017, accounting for 0.2% of global production (191,416 tonnes valued at $1.4B).[9] Canada ranked 4th in terms of global farmed salmon production, accounting for 6% of global salmon production (121,000 tonnes in 2017). Canada's production volume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



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

Figure 3.1: Canada vs. Global Aquaculture Relative Growth Since 1997 (1998-2017)

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

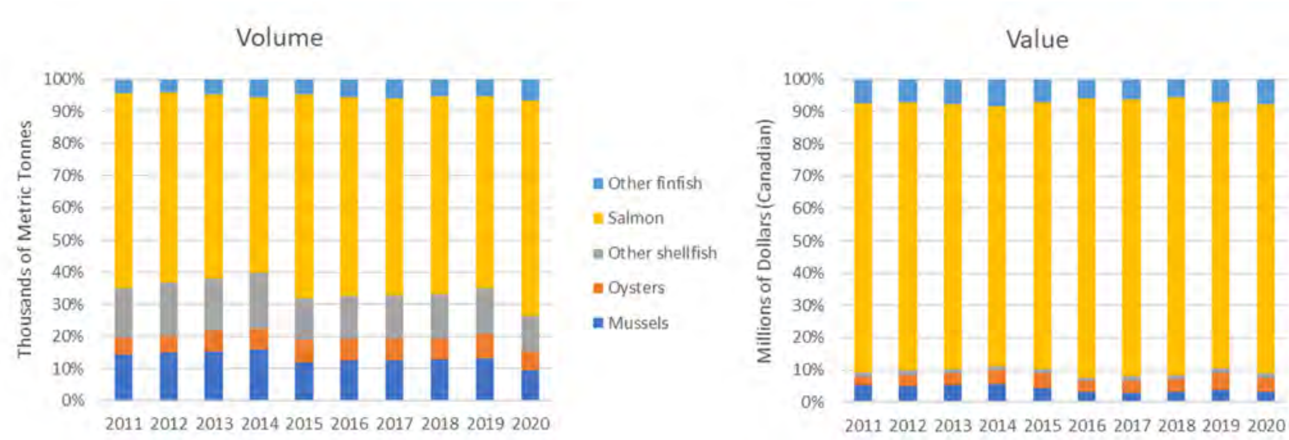


Source: Statistics Canada. Table 32-10-0107-01 Aquaculture, production and value. Retrieved February 28, 2022. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210010701

Figure 3.1: Total Canadian aquaculture production including marine and freshwater, 1998-2020

Canadian aquaculture has grown over time. From 1991 to 2020, total production grew from about 50,000 tons to 171,000 tons in volume and $234 million to $1.0 billion in value (Figure 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 (Figure 3.3). Almost 60% of total production volumes and 64% of total value was from British Columbia (BC) in 2020. This is 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.



Source: Statistics Canada. Table 32-10-0107-01 Aquaculture, production and value.
Retrieved February 28, 2022. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210010701

Figure 3.2: Distribution of Canadian aquaculture production volume and value by species, 2011-2020

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 grown 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, with smaller amounts from NL and NS. Key salmon producing areas include the Discovery Islands and Campbell River in BC, Bay of Fundy for NB

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

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 accounts for about 18% of the farmed seafood production volume in 2020, it accounted for just 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 of shellfish, they 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, ropes and trays suspended from longlines or rafts, among others.

3.2.2 Literature Search Structure and Results

To identify literature that measures the ecosystem services provided by aquaculture, or potentially the services impacted by aquaculture, an iterative literature search was conducted on Web of Science. Two alternative query structures were used with limited overlap in the results. Both

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[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.

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*))

The search yielded 32 articles. Upon review, only two were identifed as meeting the inclusion criteria (Clements & Comeau, 2019; Wieland et al., 2016). 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 ecosystem services 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 meet the inclusion criteria based on review (Cranford et al., 2007; Ridlon, Wasson, 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 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 & Chan, 2012).

3.2.3 Review of Studies

While all six of the identified articles considered marine ecosystem services 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 British Columbia examined cultural services, but only one (Klain & 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 & 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

Reference	Reference to Ecosystem Services	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 & 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	Olympic 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

*Province: 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 do 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 M, using the range of replacement cost estimates from Rose et al. (2015) (Clements & Comeau, 2019: Table 6)

Cranford et al. (2007) examined suspended mussel culture (the species is not specified, but most likely *Mytilus edulis*) in Tracadie Bay, PEI. The study uses a nitrogen budget and an ecosystem model based on extensive field data to estimate the amount of nitrogen contained in the mussels removed by harvest. This was compared to the nitrogen inputs from agriculture. The study found 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 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 cultural ecosystem services for an area in BC. A number of valued ecosystem services were identified by participants, including tangible and intangible non-monetary benefits, although aquaculture was not described as a benefit. Rather,

[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.

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 participant 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) mentions 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 measures expert opinions about whether restoration aquaculture was providing the desired ecosystem services, but does 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, costs etc.) respondents were asked if increasing ecosystem services was an objective of the project. As the paper describes, restored oyster beds may provide a range of ecosystem services 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 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 ecosystem services is in the form of a negative impact. The primary focus of the

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

study is 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 ecosystem services (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 ecosystem services provided by aquaculture in Canada, or the impact of aquaculture on other ecosystem services. 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 ecosystem services. A positive impact of aquaculture on ecosystem services is 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 ecosystem services (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 ecosystem services 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, and 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 (L. 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 & 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 ecosystem services of mariculture are the benefits that people can get directly or indirectly from the structure and function of mariculture. Quantifying the value of ecosystem services provided by mariculture can not only add to the academic knowledge base, but may also inform critical policy decisions regarding mariculture siting decisions and marine spatial planning. Therefore, calculating the value of ecosystem services associated with mariculture can help contribute to the sustainable development of mariculture.

Costanza et al. (1997) classified global ecosystem services into 17 categories and estimated the value of all ecosystem services. Based on the classification of ecosystem services, some studies estimate the value of ecosystem services for categories such as marine, wetland, forest, and river (Brenner et al., 2010; Lamhamedi et al., 2021; Quoc Vo et al., 2015; 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 marine ecosystem services along the Pacific coast of Canada to study the sensitivity of coastal areas to oil spills. Ghermandi et al. (2019) discusses the interaction between aquaculture and the tourism, cultural, and provisioning services of mangroves. Mangroves provide valuable coastal protection, carbon sequestration, and other ecosystem services, but the economic pressures to replace mangroves with prawn aquaculture threatens the continued provision of these services. Some scholars study 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 & Bhunia, 2021; Makwinja et al., 2021; Peng et al., 2021; Tolessa et al., 2021). In addition, scholars also study landscape pattern (W. Chen et al., 2021; Hu et al., 2021). The relationship and influence between the presence of certain species and ecosystem service value are expounded from the perspectives of temporal and spatial evolution of 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 marine ecosystem services 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 marine ecosystem service value is established from the theoretical level (Shi et al., 2007; Xu & Han, 2003). On this basis, empirical studies on the value of marine ecosystem services continue to emerge. A few of them have calculated the value of China's overall marine ecosystem services (Z. Chen & Zhang, 2000; Gengyuan et al., 2021). Most of the studies have estimated the value of regional marine ecosystem services. The value of offshore ecosystem services has been estimated in Shandong Province, Zhejiang Province, Jiangsu Province, Hainan Province, Guangdong Province and Guangxi Province (Han et al., 2008; H. Li & Tan, 2013; Z. Li et al., 2011; M. Wang, 2012; Xia et al., 2014; H. Yu et al., 2016). We identified only one article related to aquaculture and ecosystem services 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, China, 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 survey reveals that there are few studies estimating the value of mariculture ecosystem services, which may be related to the relatively recent interest in marine ecosystem services. Based on the search methodology, to be described subsequently, nine relevant papers published from 2007 to 2019 on mariculture ecosystem service valuation in China were found. The sea areas studied in the literature are 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 this chapter, 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 includes value estimation for the ecosystem services of marine ranching. Search for relevant articles from the English Literature Library only returned one paper that estimated the value of ecosystem services in Sanggou Bay (Zhang et al., 2007). Since three of the nine Chinese-language studies selected in this paper evaluate the ecosystem services of mariculture in Sanggou Bay, this English-language study will not be included in the following analysis.

In terms of the classification of ecosystem services, most researchers draw from the classification method of the Millennium Ecosystem Assessment (2005), where ecosystem services are divided into provisioning, regulating, cultural, and supporting services (Figure 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, and control of pests and diseases, etc. Cultural services include leisure and entertainment, cultural uses, employment income, scientific research value, and so on. Supporting services include primary productivity, nutrient cycling, species diversity maintenance, provision of habitat services, etc. The supporting services in mariculture marine ecosystem 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 ecosystem services associated with aquaculture in China mainly focuses 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, particularly 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 and 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.

There is a diversity of culturing methods employed in these areas. In Sanggou Bay in 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 in 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 in Guangdong Province also has adopted long oyster raft hanging culture.[17] Single-species oyster culture is adopted in the Dapeng'ao area of Guangdong

[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.

Province, and the mixed culture mode of fish, shrimp, shellfish, and algae is adopted along the coast of Fujian Province.

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 sub classification

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 & 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

Figure 3.3: Definition and classification structure of mariculture ecosystem services

Table 3.2: Regional mariculture ecosystem service value assessment

Study	The service functions of 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)	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, etc
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 et al. (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, scallop, mussel, oyster, abalone, razor clam, clam, sea cucumber, shrimp, various fish and other varieties
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)	Oysters, kelp, clams, scallops, etc
9. Lv et al. (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, etc.)	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 (Figure 3.5). The highest proportion is in the oyster culture area of Dapeng'ao in 2012, where the value of aquaculture production in the supply service in that year was 31.58 million yuan, 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 sizable decrease in the service value was due to the excessive scale of oyster farming in 2013, the aging of the sea area and unreasonable development. The various measures of the proportion of food production services calculated in the literature is shown in Figure 3.6, although two of the studies do not address the valuation of this service (Lv, 2017; H. Zhu, 2017) and are therefore not reflected in the figure.

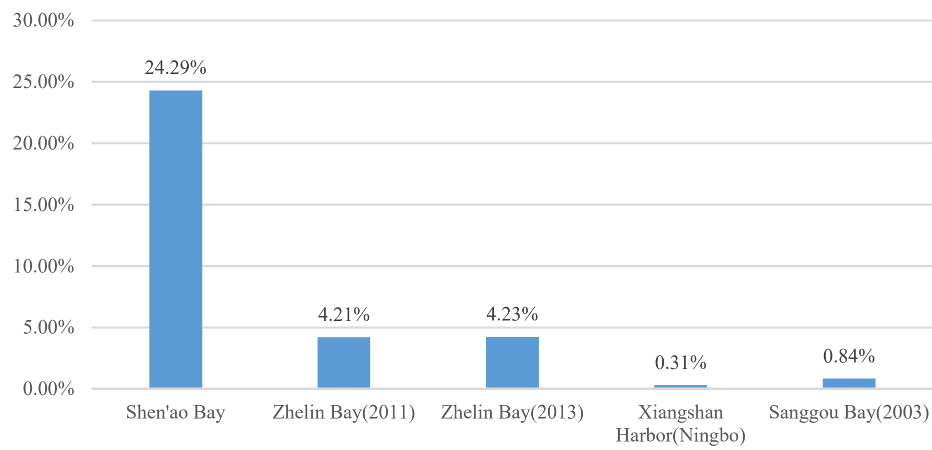

Figure 3.4: Proportion of raw material supply service value in total service value

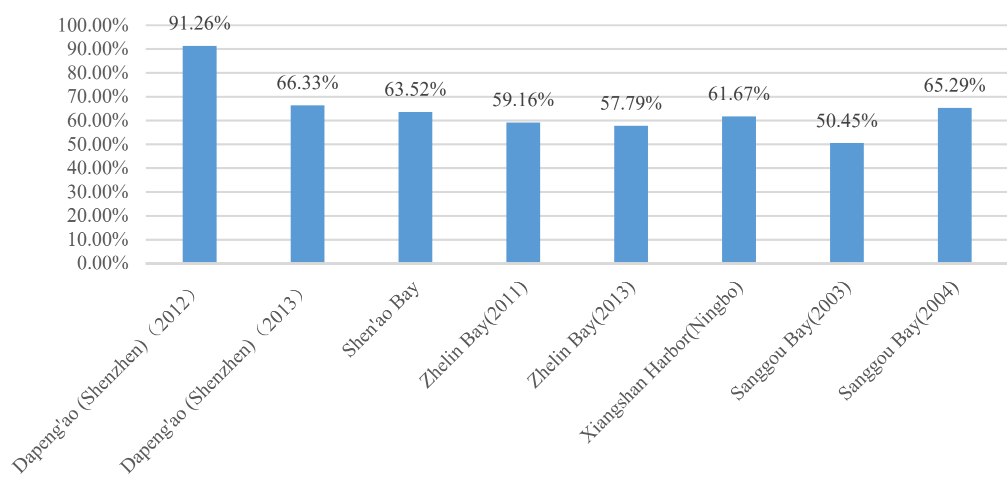

Figure 3.5: Proportion of food supply service value in total service value

Aquaculture can provide raw non-food materials such as shells. Four of the papers assess the value of raw material supply services (Figure 3.4). According to the assessment 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%) is 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 mainly works 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 ($HCO3-$) in seawater form calcium carbonate ($CaCO3$) 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 (Figure 3.6), the value of carbon sequestration as a proportion of the total service value ranged from a high of 14% to a low of 1.2%. 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.

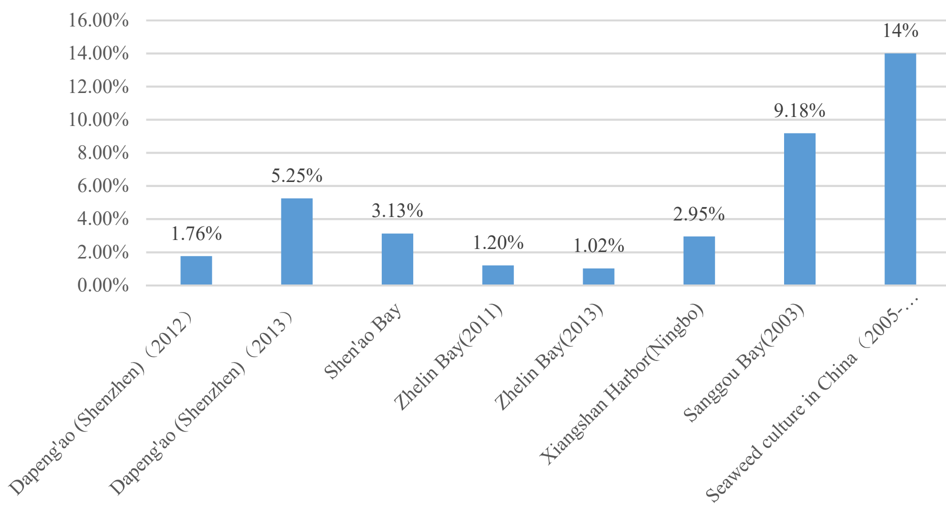

Figure 3.6: Proportion of climate regulation service value in total service value

Farmed algae and phytoplankton provide air quality regulation services by fixing carbon and releasing oxygen through photosynthesis, and by absorbing harmful gases such as SO2 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 Zhaohui 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 Bay 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 emissions of these nutrients. An excess of these nutrients leads to eutrophication, which can cause an excess of algae/plant life and a lack of dissolved oxygen, which can be dangerous for 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 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, accounting for a relatively high 10.8% of the total service value. The 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 (L. 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 (Figure 3.7). The cultural service function of Sanggou Bay in Shandong Province is more prominent, with the value of cultural services (including knowledge expansion services and tourism and recreation services) accounting 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 (L. Wang, 2010). Across studies, the results of the assessment of the value of cultural service functions in the same sea area in similar years vary considerably, in part because the authors use 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 L. 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.

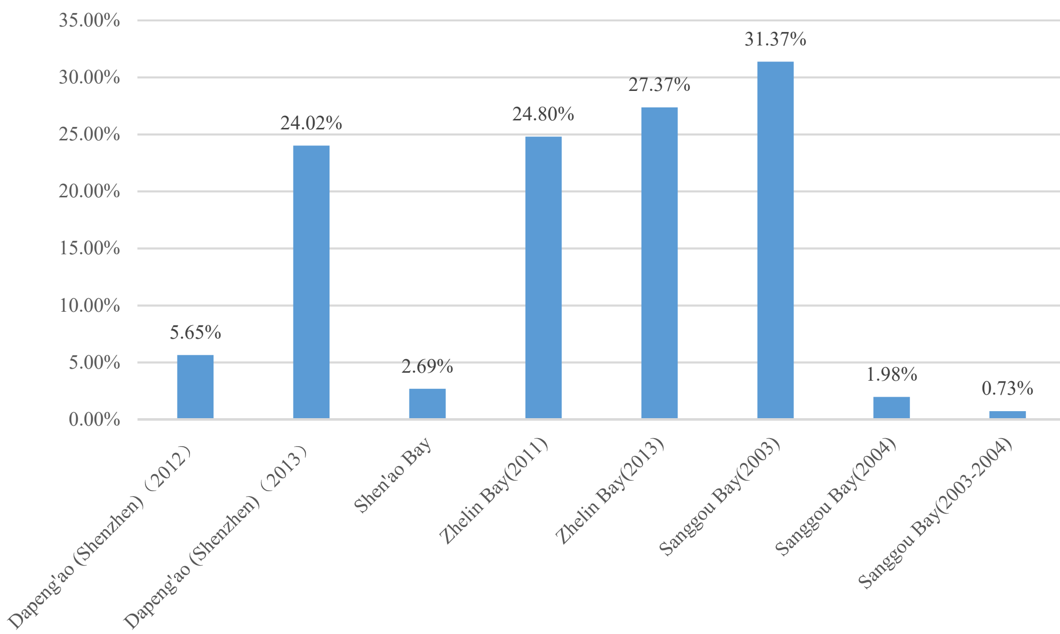

Figure 3.7: Proportion of cultural service value in total service value

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 mariculture ecosystem services and valuation methods, Chinese scholars mainly 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. Zhaoli 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 Shenao 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, Guangdong Province. The study uses 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 Bay.

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). This 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, Honghua 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. Z. Yu et al. (2014) used the research cost method to assess the value of research services in Dapeng'ao sea 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 the 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 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. L. Wang (2010) surveyed 40 experts in marine ecology and mariculture in Sanggou Bay who provided scores for the weights of various ecosystem services and the impacts of aquaculture on ecosystem services in Sanggou Bay. H. Zhu (2017) established a mariculture service value assessment model to assess the total and average values and marginal values of mariculture services in Fujian Province separately.

3.3.2.5 Assessment results

The published results include the total value of ecosystem services provided by the sea area, and in most cases also include the annual service value per unit of farmed sea area, with only two of the nine papers not including per unit area results (Figure 3.8). As the size of the assessed marine area varies, the total assessed ecosystem value of marine areas may not be comparable across the literature, so we focus on the value per unit area of marine area to perform a comparative analysis. In terms of the assessed value of ecosystem services per unit area of farmed marine area per year, the highest was RMB 173,000/ha in Daya Bay, Shenzhen, Guangdong Province in 2012 and the lowest was RMB 25,600/ha per unit area of farmed marine area in Fujian Province. The value of ecosystem services per unit area of farmed marine area in these regions ranges from RMB 65,000/ha to RMB 48,000/ha. Three of these studies are in Guangdong Province waters, totaling four assessments of the ecosystem service value per unit area of culture. The estimated values of ecosystem services per unit area of mariculture fluctuate considerably even for the same region. For example, the value per unit area of culture in Daya Bay was assessed at RMB 170,300/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 ecosystem services per unit area of farmed marine area were valued at RMB 42,400/ha in 2003 and RMB

64,300/ha in 2004, 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.

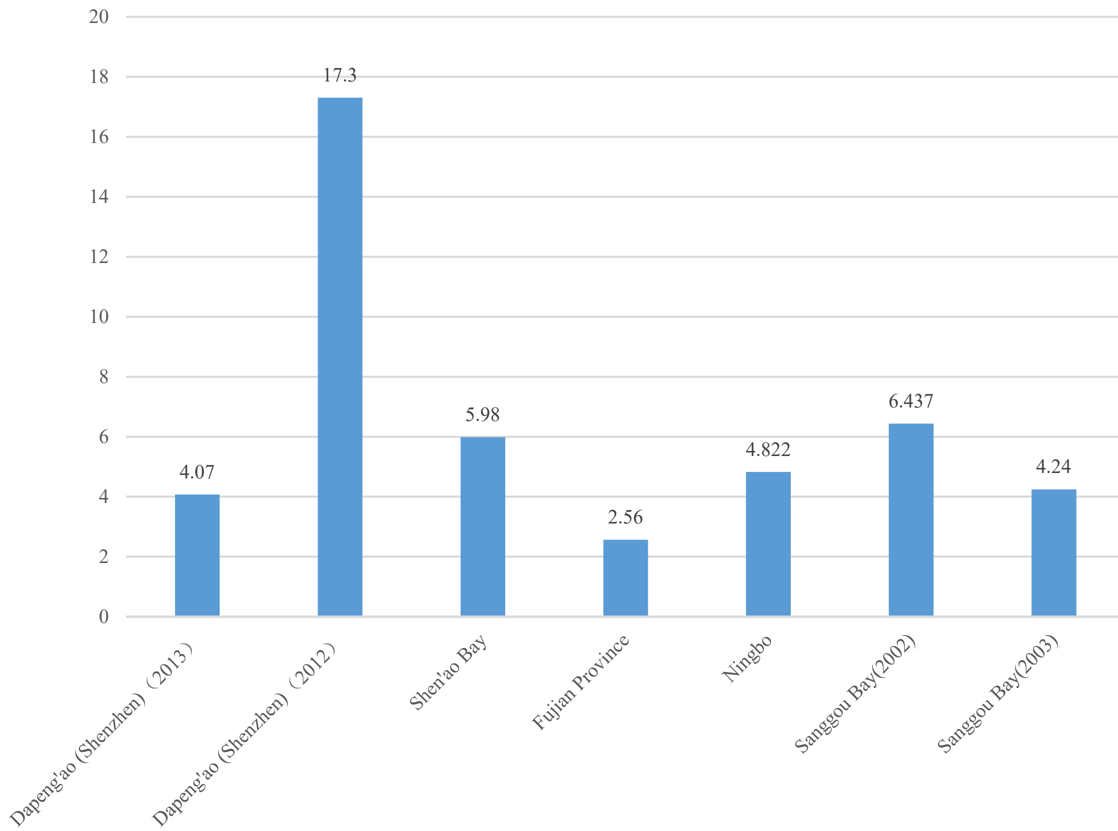

Figure 3.8: Ecosystem service value per unit area in the study area (10k yuan/ha)

Finally, most of the literature assesses the total value as well as the individual functional values, and in the cases of Shen Ao Bay and Fujian Province, an assessment and comparison of the service values of different cultured species is 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 ecosystem services 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 marine ecosystem services 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 Bay, their cultural service values related to tourism services and scientific research services are also an important part of the total ecosystem service value.

3.3.3 Concluding Remarks

3.3.3.1 Summary of findings

The research on the value of ecosystem services and mariculture started late in the domestic academic community. Although compared to other countries in the world, there is a relatively large amount of published literature on the valuation of ecosystem services 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 is focused on the dominant mariculture regions and species, The breadth of the research we found ranges 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 is 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 measure 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 is the greatest for Sanggou Bay in 2003 at 31.4%. The cultural service value exceeds the regulating service value in four studies, but the classification criteria for the cultural service function are not uniform. (4) The economic value is primarily assessed by one of three methods, namely the direct market method, alternative market method, and virtual (hypothetical) market method. Other evaluation methods are infrequently employed. (5) Seven of the papers standardize 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 ranges from RMB 40,700/ha to RMB 64,400/ha. The difference in assessment results is mainly due to the different assessment methods. (6) The research is 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 ecosystem services 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 ecosystem services.

Firstly, it would be valuable to develop a dynamic analysis of the value generated by ecosystem services and mariculture. Current research on mariculture ecosystem services 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 ecosystem services 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 ecosystem services 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 mariculture ecosystem services.

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 and ignore 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 ecosystem services 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 tons) (Ministry of Agriculture, Forest and Fishery, 2020). Aquaculture production reached a peak of 1.34 million 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 3.9 shows the recent downward trend of fisheries and aquaculture.

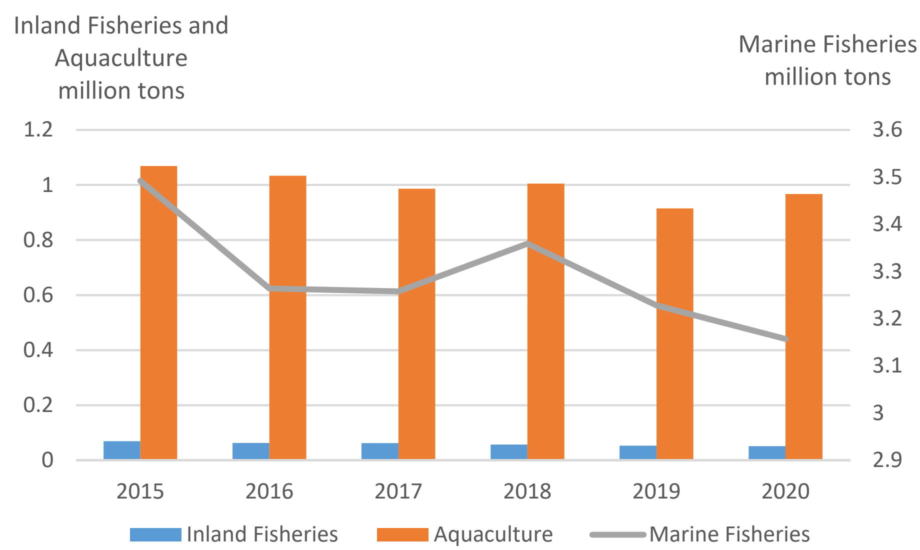

Figure 3.9: Production of Fisheries and Aquaculture in Japan (Ministry of Agriculture, Forest and Fishery, 2020)

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 nations in the North Pacific region. We perform a literature search to summarize the body of knowledge related to ecosystem services and aquaculture in Japan.

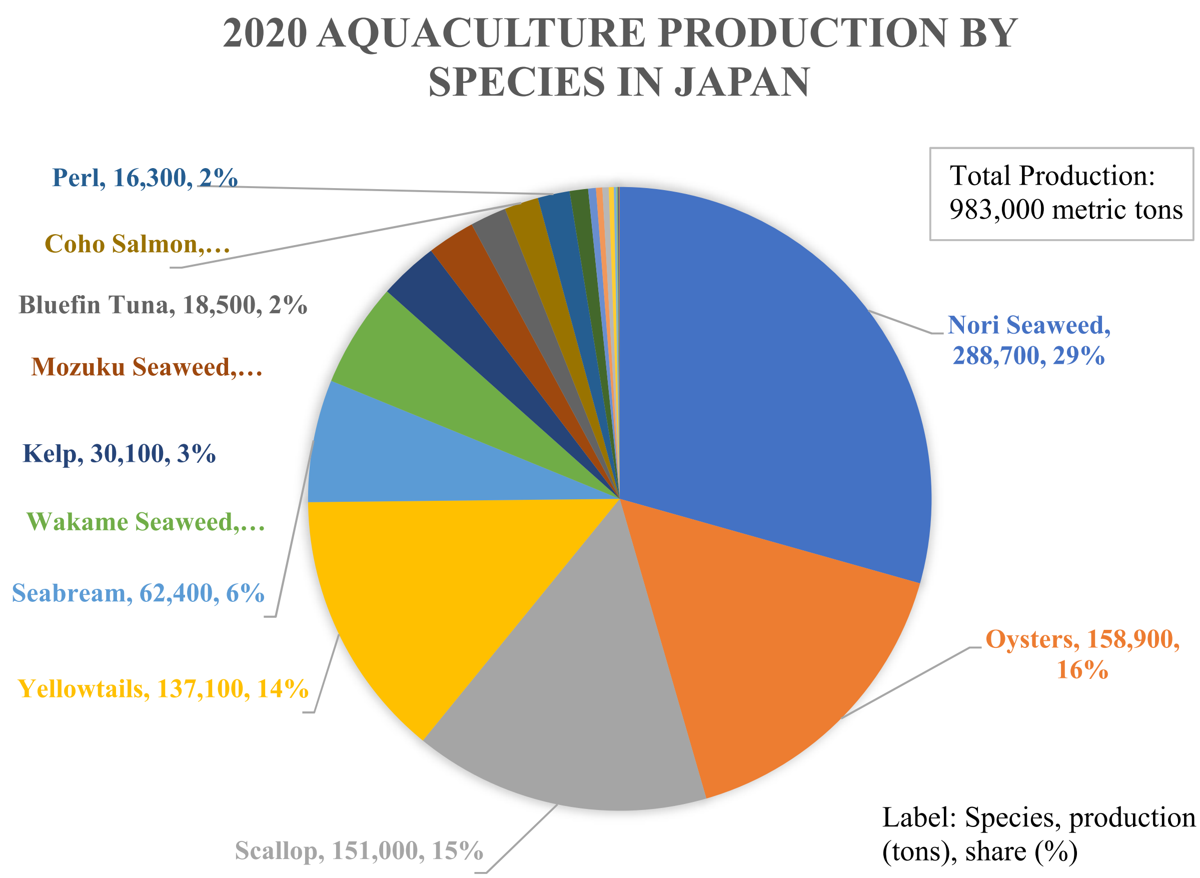

Figure 3.11. Share of Aquaculture Production by Species in Japan (Ministry of Agriculture, Forest and Fishery, 2020)

The Japanese government has historically used the term "multifunctional services" of ecosystems (multifunctionality) as a synonym for ecosystem services. This tearm has been used in the agricultural field in Japan since the 1990s (Kunii, 2016). Since the 2000s ecosystem services 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) to maintain/support ecosystem services, and “multifunctionality” is included in the name of the grant/subsidy (MAFF, multifunction payment grant).[18] This grant has been 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 ecosystem services in Japan may not include the term ecosystem services, but instead include multifunctionality for the purpose of grant application. Hence, we consider multifunctionality or related words as a search word in this case study.

Similarly to the other countries’ case studies, we use a common set of search terms, but also include “multifunctionality” as a country specific search word. In addition, we employed backward- and forward-referencing to make up for shortcoming 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 other nations.

> (“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*")

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

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*")

   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 ecosystem services 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 the WoS and manual searching, we found three articles related to aquaculture ecosystem services in Japan. The WoS search query with the basic search words found three articles related to aquaculture ecosystem services, 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 article related to ecosystem services (Nos. 3, 4 and 5 in Figure 3.12). With forward reference, we found no additional studies related to quantifying marine aquaculture ecosystem services. The country-specific search in the WoS found nine articles. However, four articles are not related to ecosystem services; three are related to agriculture or freshwater (pond, paddy field); and one is about marine ecosystem services but related to fisheries management rather than aquaculture. In conclusion, the country-specific query found no studies related to aquaculture-based ecosystem services.

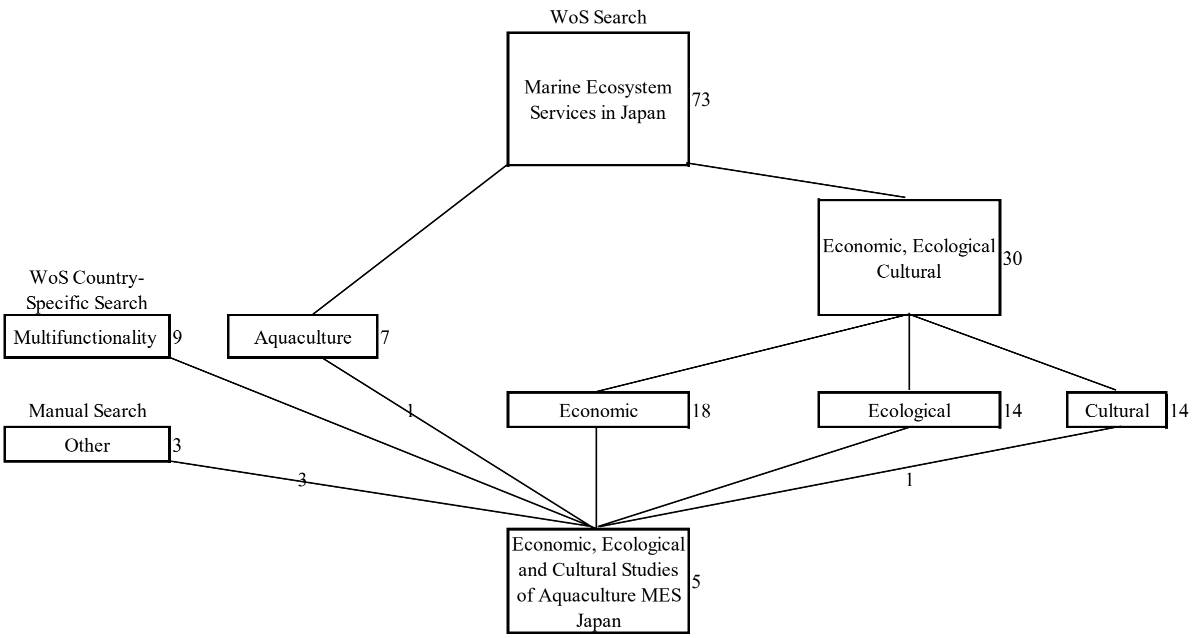

Figure 3.10: Structure of Search Results

Thus, in total our search procedure returned five relevant articles with details in Table 3.3. Chakraboty and Gasparatos (2019) uses 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 ecosystem services are related to the wellbeing 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 ecosystem services have degraded over time, which leads to habitat change/loss and overexploitation. The role of aquaculture in producing ecosystem services receives 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 is focused on the trade-offs associated with the lost natural ecosystem services due to habitat change/loss.

Table 3.3: Japanese Search Results

No	Authors	Year	Methods	Targets	General summary	Types of ES
1	Chakraborty et al.	2009	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

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, Japan. Using stratified random sampling, they found that *Zostera marina* seagrass are 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) did differ in seagrasses near aquaculture. The result suggests that long-line oyster aquaculture may be sustainable with careful management and monitoring.

Liu et al. (2012) investigated differences in genes of wild and farmed kelps (*Saccharina japonica*) in different countries including Japan. They tested genetic structure using the simple sequence repeat markers and found that the genetic diversity in the wild kelps in Russia 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 and kelp with thallus excision and found kelp with early thallus excision in January and February show significantly larger compensatory abilities, in which thallus excision would increase kelp production. Sato et al. also compared 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 ecosystems, and looked at ecosystem management, but not at the effect of management on ecosystems (Chakraborty & Gasparatos, 2019). Another study focuses on the effects of oyster farming on the seagrass in the same farming site (Smith et al., 2018). The other studies are not related to the effects of aquaculture on an ecosystem, but biological, chemical or environmental science of certain species (Gao et al., 2013; Liu et al., 2012; Sato et al., 2016). Hence, very few studies exist on the evaluation of ecosystem services in Japan.

Considering that 30 studies exist in economic, ecological and cultural studies of the ecosystem services 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 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 & 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 between 2013 and 2018, the value of production for U.S. marine aquaculture has been increasing since 2014 (see Figure 3.11). 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 Figure 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 the state of Washington 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.

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%

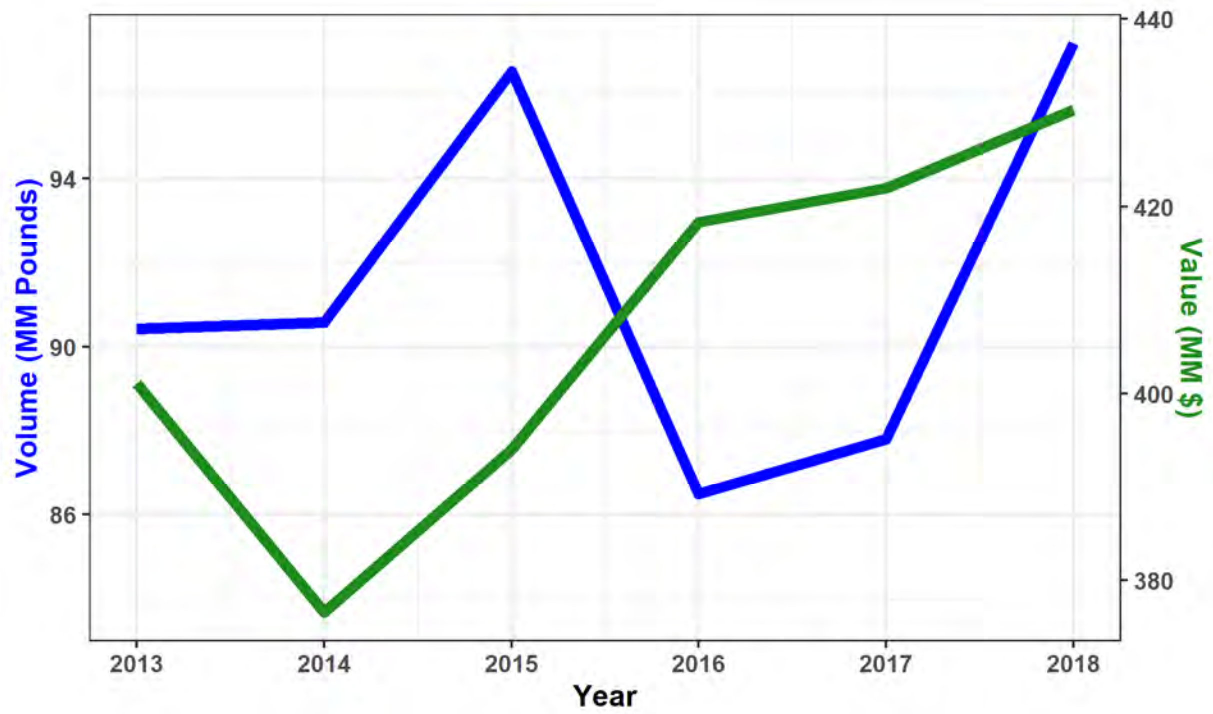

Figure 3.11: U.S. Total Aquaculture Production by Volume and Value

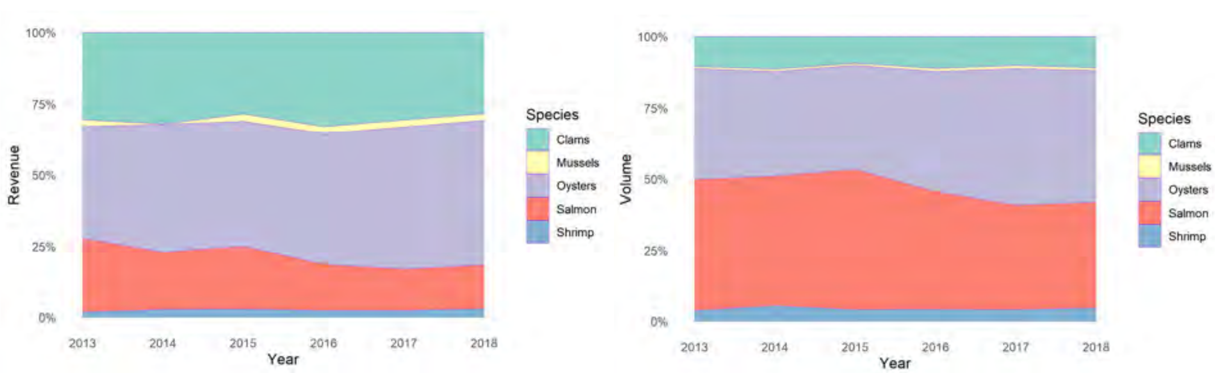

Figure 3.12: U.S. Aquaculture Proportion of Revenue and Volume for Major Species Groups

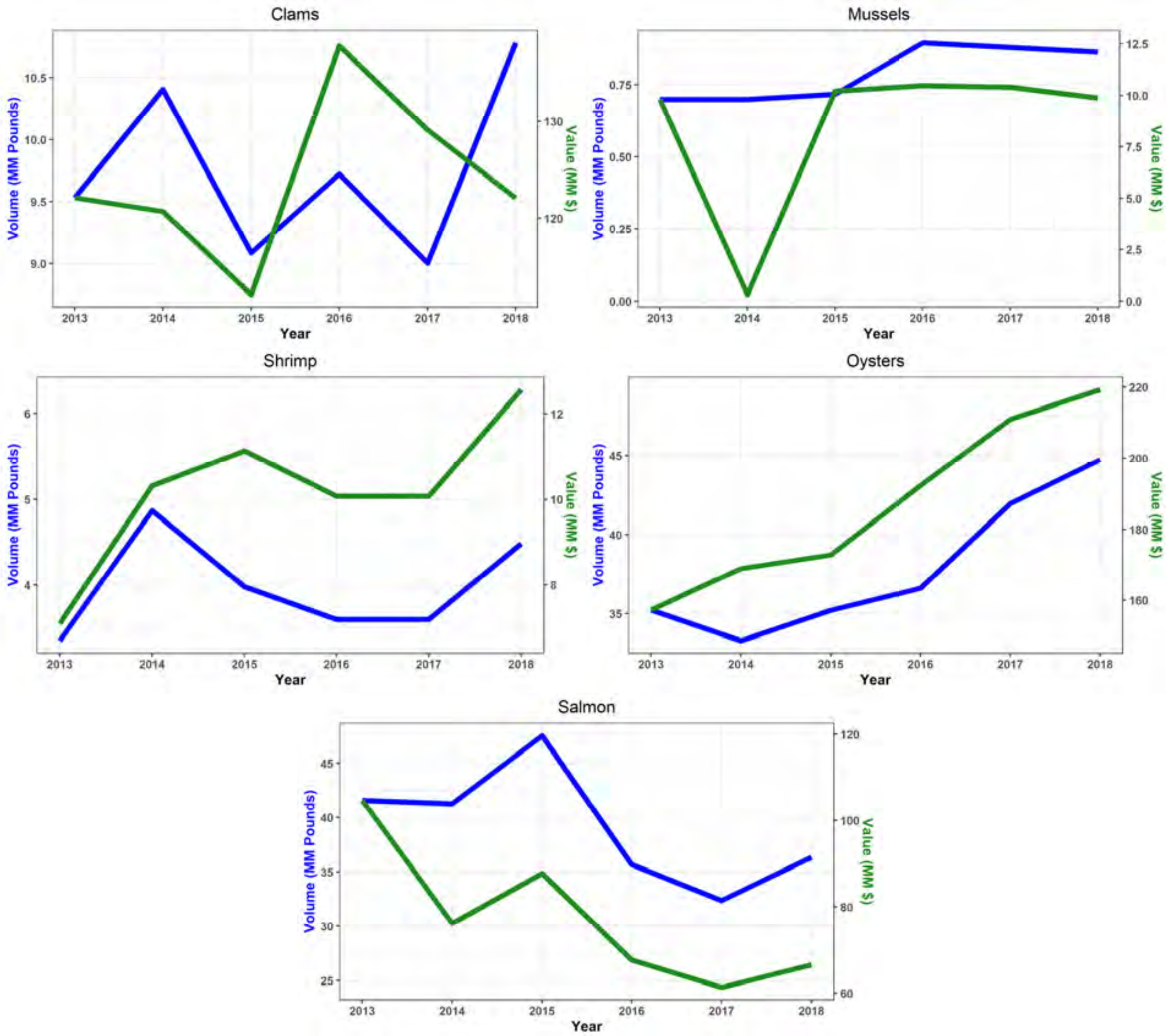

Figure 3.13: U.S. Aquaculture Production Volume and Value by Major Species Group

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 studies were 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 includes 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 marine ecosystem services studies being performed in the United States. There are thirty-eight studies of bivalves, four studies of kelp, and none of finfish. Some studies include multiple species, but the totals by species are: six studies of Pacific Oyster (*Crassostrea gigas)*, twenty-four studies of Eastern Oyster (*Crassostrea virginica)*, as well as one study that does not specify the species but is likely to be *C.*

[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.

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 ecosystem services studied are 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 is the subject of all of the nutrient removal papers, although seven also estimate the removal of carbon and three also include phosphorous removal. Of these studies, eleven measure the direct removal of nutrients into the living organism (bioextraction) and nine measure the impact of aquaculture on the microbial processes of denitrification and dissimilatory nitrate reduction to ammonium (DNRA). Cultural services are explored in two closely related studies, in which surveys of oyster farmers and hatchery workers reveal 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 ecosystem services related to aquaculture. The first branch are studies of 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 United States, 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.

3.5.3 Results

3.5.3.1 Bioextraction

Bioextraction (or bioassimilation) is defined in Rose et al. (2015, p. 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 & 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.

3.5.3.2 Shellfish

Eastern Oyster (Crassostrea virginica)

In Higgins, Stephenson, and Brown (2011) the nitrogen, carbon, and phosphorous content of *C. virginica* cultured in Chesapeake Bay, Virginia is measured directly. They estimate that the farmed oysters would remove 331 kg N per hectare, 47 kg P per hectare, and 9,567 kg C per hectare for each seed-to-harvest cycle (typically 12-24 months), but do not compute an economic value. The differences in nitrogen content are compared across seasons, and for on-bottom versus off-bottom culture in Reitsma et al. (2017) for Cape Cod, Massachusetts. Overall, the nitrogen content is 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 hectare 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) reports a stocking density in nearby Connecticut of 62 oysters per square meter with 55% mortality (28 surviving oysters per square meter) and Bricker et al. (2020) reports a stocking density in nearby New Hampshire of 100-200 oysters per square meter. 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 hectare per year.

The FARM and EcoWin computer models are 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 hectare per year). Using the avoided cost method for various control technologies and levels of abatement requirements they estimate a value of $32, $37, and $98 per kg N annually. In another estimate based on computer simulations, Bricker et al. (2020) estimates nitrogen removal in Great Bay Piscataqua River Estuary, New Hampshire to be 0.072 metric tons per acre per year (177 kg N per hectare per year). Based on Kessler (2010) they use a replacement cost ranging from $150 to $172 per kg N annually. Another computer model estimation for Chesapeake Bay, Maryland is performed in Parker and Bricker (2020). They report a very large range of possible nitrogen removal values, between 28 and 457 kg per acre per year (69 – 1,129 kg per hectare per year). Furthermore, they report 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) reports 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 hectare annually although 150-350 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 & Bricker, 2020).

Hard Clam (Mercenaria mercenaria)

Reitsma et al. (2017) measures 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 Clams (Venerupis philippinarum)

Saurel et al. (2014) estimates the nitrogen removal of farmed Manila Clams in North Puget Sound, Washington with the FARM model. They estimate a farm-scale nitrogen removal rate of 3,423 kg N per year for a 2.6 ha site, and they apply the Meybeck, Chapman, and Helmer (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 hectare per year.

Geoduck Clam (Panopea generosa)

The nutrient removal potential for farmed Pacific Geoduck Clams in South Puget Sound, Washington is estimated using the FARM and Net Energy Balance models in Cubillo et al. (2018). They report the removal of 149 kg N per year on a farm of 0.26 ha, which converts to 573 kg N per hectare 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 estimate the carbon sequestration to be 2,534 kg C per year (9,746 kg C per hectare per year). Using the $12.40 per kg N valuation of Lindahl et al. (2005)[22], they compute the economic value

[21] See Reitsma et al. (2017)

[22] Note that this is a second distinct source of a $12.40 per kg N valuation.

of the ecosystem service, noting that this is on the low end of the replacement cost method values used in other studies.

3.5.3.3 Kelp

Kim, Kraemer, and Yarish (2014) directly measure the nutrient removal of the kelp species *Gracilaria tikvahiae* Mclachlan in the waters off of New York and Connecticut. At the Long Island Sound (LIS) site, they estimate a removal of 28 kg N per hectare and 300 kg C per hectare, and at the Bronx River Estuary (BRE) site they estimate a removal of 94 kg N per hectare and 727 kg C per hectare. Using cap-and-trade market values to derive the economic value, they estimate ecosystem service values of $311 (LIS) and $940 per hectare (BRE) for N, and $5.51 (LIS) and $13.32 per hectare (BRE) for C. They followed up on this study in Kim, Kraemer, and Yarish (2015) to estimate the nutrient removal from Sugar kelp (*Saccharina latissima)* which could be cultured in conjunction with the *Gracilaria tikvahiae* Mclachlan to provide year-round nutrient removal. Additionally, they report separate values for Western Long Island Sound (WLIS) and Central Long Island Sound (CLIS). They estimate nitrogen removal of 180 (BRE), 67 (WLIS), and 38 (CLIS) kg per hectare, and a carbon removal of 1350 (BRE), 1800 (WLIS) and 1100 (CLIS) kg per hectare. Again using cap-and-trade permit values they value the nitrogen removal at $1600 (BRE), $760 (WLIS) and $430 (CLIS) per hectare, and carbon sequestration is valued at $30−300 (BRE), $40−400 (WLIS), and $24−240 (CLIS) per hectare. Augyte et al. (2017) directly measures 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 hectare and 1666.7 kg C per hectare. Grebe et al. (2021) also measured the tissue levels of nitrogen in *S. latissima* farmed in Maine, estimating that a hectare cultivated for 6-7 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 hectare.

Table 3.5: Summary of Bioextraction Studies

Study	Species	State	Method	N removal (kg ha^{-1} yr^{-1})
Bivalves				
Higgins, Stephenson, and Brown (2011)	*C. 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)	*V. philippinarum*	WA	Simulation	1317
Cubillo et al. (2018)	*P. generosa*	WA	Simulation	573
Kelp				
Kim, Kraemer, and Yarish (2014)	*G. tikvahiae*	NY	Direct	28
Kim, Kraemer, and Yarish (2014)	*G. tikvahiae*	NY	Direct	94
Kim, Kraemer, and Yarish (2015)	*S. latissima*	NY	Direct	180
Kim, Kraemer, and Yarish (2015)	*S. latissima*	NY	Direct	67
Kim, Kraemer, and Yarish (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.

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 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 conclude that the aquaculture cannot be credited with enhancing denitrification. The researchers note that bioextraction is a much more reliable and readily measured nutrient removal mechanism.

An oyster farm in Chesapeake Bay, Maryland, is analyzed in Testa et al. (2015) using sediment core intubations. They report denitrification rates of 9−115 μmol N m^{-2} h^{-1}, but note that the "sediment denitrification did not change in response to the introduction of the aquaculture operation." (p. 215). Humphries et al. (2016) use a novel *in situ* methodology to measure the gas fluxes at oyster beds in Ninigret Pond, Rhode Island. This study compares both restored wild oyster reefs and oyster aquaculture with reference sites having bare sediment and cultch. Wild reefs are found to enhance denitrification more (581.9 N_2–N m^{-2} h^{-1}) than aquaculture (346.0) [23], but the difference is 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, McGlathery, and Smyth (2017) use 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. (2017) analyzes 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 is significant seasonal variation in the effects. The results are 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 conclude that bivalve aquaculture can be a net source or sink of N in the

[23] It appears that N_2-N is another scientifically accepted way of denoting "denitrification."

ecosystem depending on local conditions and species. In Ray and Fulweiler (2020) the researchers estimate the nutrient fluxes from wild oyster reefs and a farm in Narragansett Bay, Rhode Island. The study does not directly state the species of oyster in the body, but the context strongly suggests it is *C. virginica*. Estimating the fluxes over the seasons, they measure 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 is approximately zero, but the effects on the ecosystem of the seasonal variation in alternatively removing or adding nitrogen merit consideration. Ayvazian et al. (2020) provides 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 do not clearly report rates of denitrification or DNRA but do state that they do not observe stimulated rates of denitrification relative to bare sediment. Regarding the pathway of oysters on nitrogen cycling through macrofaunal abundance, they report 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.

Mercenaria mercenaria

Murphy et al. (2016) took sediment core and porewater samples from ten 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 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) explore the denitrification and DNRA enhancement of clam aquaculture across different species and ecosystems. The American *M. mercenaria* grown in Chesapeake Bay, Virginia, are compared to *Ruditapes philipinarum* cultured in Italy with sediment core analyses. The biomass of clams is 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 are 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 in 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 of aquaculture's impact on other species focused predominantly on animals with twelve studies exclusively focused on animals, with only five studies exclusively studying submerged aquatic vegetation and two studies including 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 ecosystem services 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. We organize the results by cultured species.

The Pacific Oyster (*C. gigas)* was introduced to the U.S. Pacific coast for aquaculture purposes, as well as to replace some of the ecosystem services 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) use 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 conclude 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 has 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 conjecture 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 are 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 tag the fish to measure growth and disappearance rates. Cunners preferred natural reefs to oyster cages, while Scup and Tautogs were the opposite. Black Seabass showed no difference across the two habitats. Recapture analysis indicated that Scups had a lower disappearance rate at oyster cages but also a slower growth rate. This growth rate/mortality tradeoff is significantly overshadowed by the three times greater abundance at oyster cages, suggesting it is still a net positive for Scups. Both macro-faunal and infaunal assemblages around modified rack and bag gear in Delaware are compared by Erbland and Ozbay (2008). They use basket-traps to compare the macro-faunal assemblages between the aquaculture gear and a wild reef, and use 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, the infaunal species were less abundant under the oyster gear.

Marenghi et al. (2010) compares 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". In Ayvazian et al. (2020) the researchers compare 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 is 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 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) tests 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.

[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.

is the Pacific Oyster (*C. gigas*). 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 are 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 is 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 vary the density of oysters and test the effect of empty shell, nutrients, and their combination. For their study site, nutrients have no impact on eelgrass growth. However, the presence of live adults and empty shells decreased eelgrass density in excess of their physical footprint. There is a non-linear density-dependent relationship, with a threshold of about 22% oyster coverage beyond which there are exponential declines in eelgrass shoot density. Interestingly, they report that 20% is 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 ecosystem services is rarely mentioned along with these findings of aquaculture negatively impacting eelgrass.

The impact of the Geoduck Clam (*Panopea generosa*) culture on eelgrass in Washington State is 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 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 (*M. mercenaria*) culture provides anchoring structure for seaweed is 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 (*C. virginica*) in Connecticut is 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, but its cultural services have received scant research.

We only located two studies on the topic for the United States, 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 ecosystem services 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 ecosystem services of oyster aquaculture in their decision, but over 80% mentioned some form of cultural ecosystem service. These cultural ecosystem services referenced by the growers are 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 cultural ecosystem services 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 cultural ecosystem services were categorized into contributions to identities, experiences, and capabilities according to the framework introduced by Fish, Church, and Winter (2016). They identify 46 distinct benefits associated with working with shellfish, including six regulating and supporting services, eight provisioning services, and thirty-two cultural services divided into ten identities, seventeen 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 ecosystem services associated with aquaculture. By interviewing wild oyster fishers as well, they are able to identify how the cultural ecosystem services associated with aquaculture differ 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.

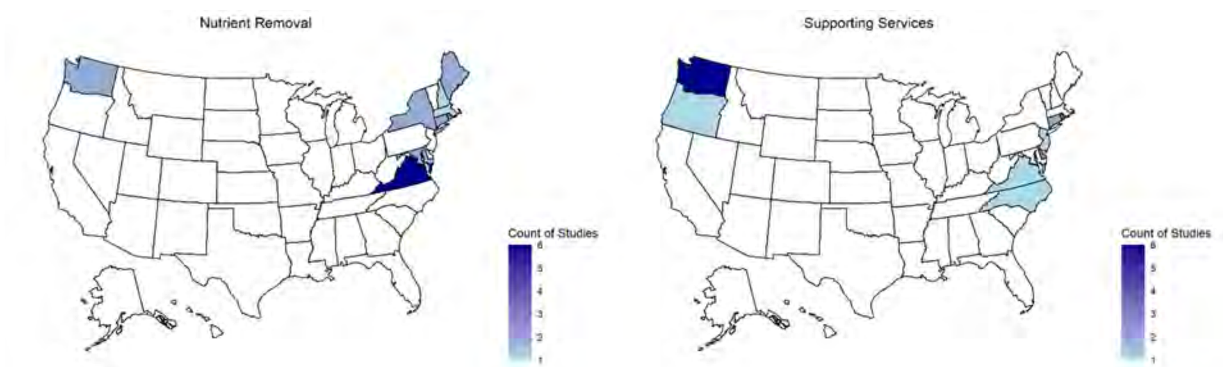

Figure 3.14: Heat Map of Study Sites by Study Type

3.5.4 Concluding Remarks

There are a number of significant gaps in the literature relating aquaculture and ecosystem services in the United States. The absences 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 United States, 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 thirty-two for the Atlantic. Alaska, California, and Hawaii 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 cultural ecosystem services associated with the restoration of native fish pond (*loko i'a)* aquaculture practices in Hawaii. 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 cultural ecosystem services from aquaculture (Michaelis et al., 2021). It is also surprising that there have been no U.S. studies of 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 (L. Zhu et al., 2020, 2021).

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 P. 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 ecosystem services. The oft-cited concern of the negative aesthetic impact of aquaculture would represent a loss of cultural ecosystem services. 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 & Fleming, 2007). Each of these negative externalities could be mapped to ecosystem services lost as a result of aquaculture. Not only have these negative externalities not been considered in the U.S. aquaculture ecosystem services 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 because similar papers did include the ecosystem services terminology. There could be other types of relevant studies for which *none* include the ecosystem services terminology and are thus absent from this report. The ecosystem services 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 nations of Canada, China, Japan, and the United States. With respect to the categories of ecosystem services described in the Millennium Ecosystem Assessment, much of the research has focused on the regulating ecosystem services 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 nation uncovered only five studies for Japan, six in Canada, nine studies for China, and forty-one 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 nations, but is a worldwide phenomenon. For example, a report on the effects of aquaculture in North Atlantic nations by Mikkelsen et al. (2021, p. 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 ecosystem services 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 ecosystem services is both infrequent and of questionable accuracy. Assigning an economic value to the ecosystem services 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 forty-one studies in the US 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 this chapter 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.

Another 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 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 USA in order to provide compensation for the positive ecosystem services (Racine et al., 2021; Rose et al., 2014). 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 ecosystems services terminology in the

[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.

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 ecosystem services. 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, Swearer, and Dempster (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 nations has covered an array of species and ecosystem services, 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 papers 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 of 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 ecosystem services 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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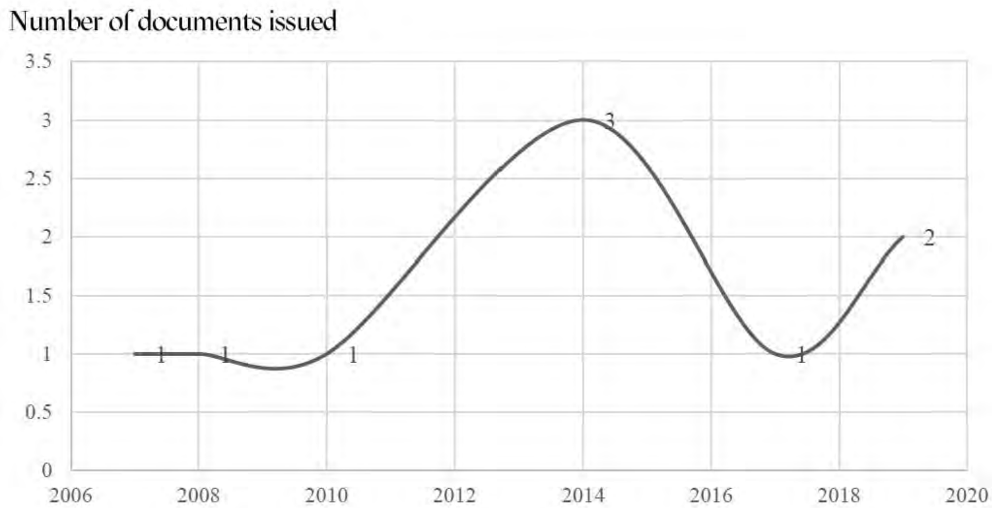
APPENDIX

Detailed Bibliometric Analysis of Chinese Literature

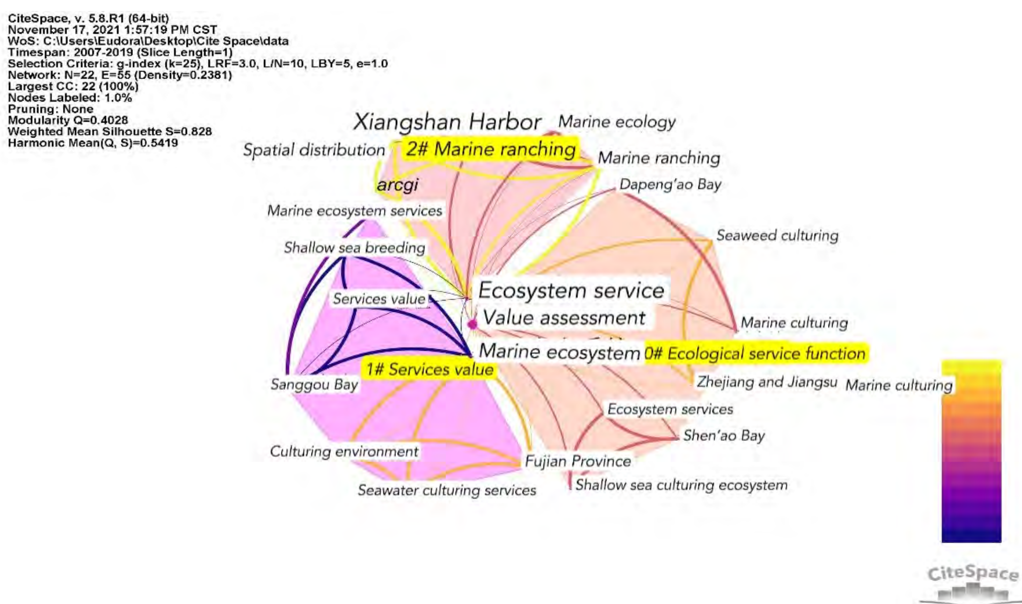
CiteSpace is a Java-based software for visual analysis of literature surveys developed by Professor Chen Chaomei of the Dalian University of Technology. It can generate a map of scientific knowledge, collect documents in a certain discipline, and provide knowledge structure analysis services. It shows the structure, medium centrality, dissemination, future development trends, and cutting-edge hot spots 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 aquaculture. 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.



Appendix Figure A15: Mariculture ecosystem services papers by year



Appendix Figure A2: Keyword clustering analysis view

Research frontier and hot spot analysis

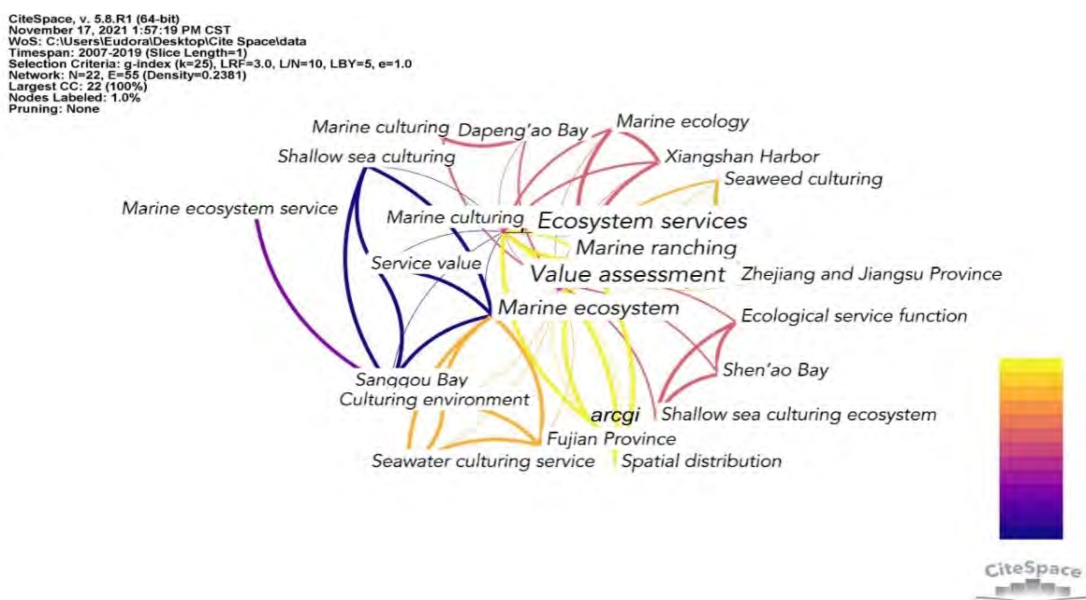
Through the visual analysis of documents by CiteSpace, the clustering map of nine studies is drawn (Appendix Figure A2). According to the clustering analysis, three clusters can be obtained: ecological service function, service value, and marine pasture (the clustering number in the figure does not represent 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. In Appendix Figure A1, the clustering data in the keyword map is modular q = 0.4028 > 0.3, mean silhouette = 0.828 > 0.5, which shows that the results and structure of the map are reliable.

(1) 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 sea areas, classify and study the ecosystem services and functions of aquaculture sea 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 Millennium Ecosystem Assessment: Zhang et al. (2007), Honghua Shi et al. (2008) and L. 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 sea areas in China, such as Dapeng'ao, Xiangshan Harbor, Shen'ao Bay, Zhelin Bay and Fujian Province (Cheng et al., 2014; Huan et al., 2019; Z. Yu et al., 2014; Zhaoli et al., 2014; H. Zhu, 2017); Lv (2017) estimated the direct ecological value and indirect ecological value of seaweed culture in China.

(2) Cluster #1: service value. This cluster mainly evaluates the ecosystem service value of mariculture. Nine documents have evaluated the ecosystem service value of aquaculture sea areas, taking China's Typical Mariculture bays as the object to evaluate the ecosystem service value of mariculture: Sanggou Bay (Shi et al., 2008; L. Wang, 2010; Zhang et al., 2007), Xiangshan Bay (Cheng et al., 2014), Shenzhen Bay (Zhaoli et al., 2014), Dapeng'ao (Z. Yu et al., 2014), and Zhelin Bay (Huan et al., 2019); H. Zhu (2017) assessed the service value of mariculture in Fujian Province

by taking the province as the boundary, and assessed the ecological service value of mariculture in China as the object from the whole (Lv, 2017).

(3) Cluster #2: Marine ranch. This cluster studies the ecological service value and carbon sink value of marine ranches. Marine ranches are similar to terrestrial ranches, 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 reef, proliferation and release in a certain sea 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 pasture (Cheng et al., 2014; Huan et al., 2019).



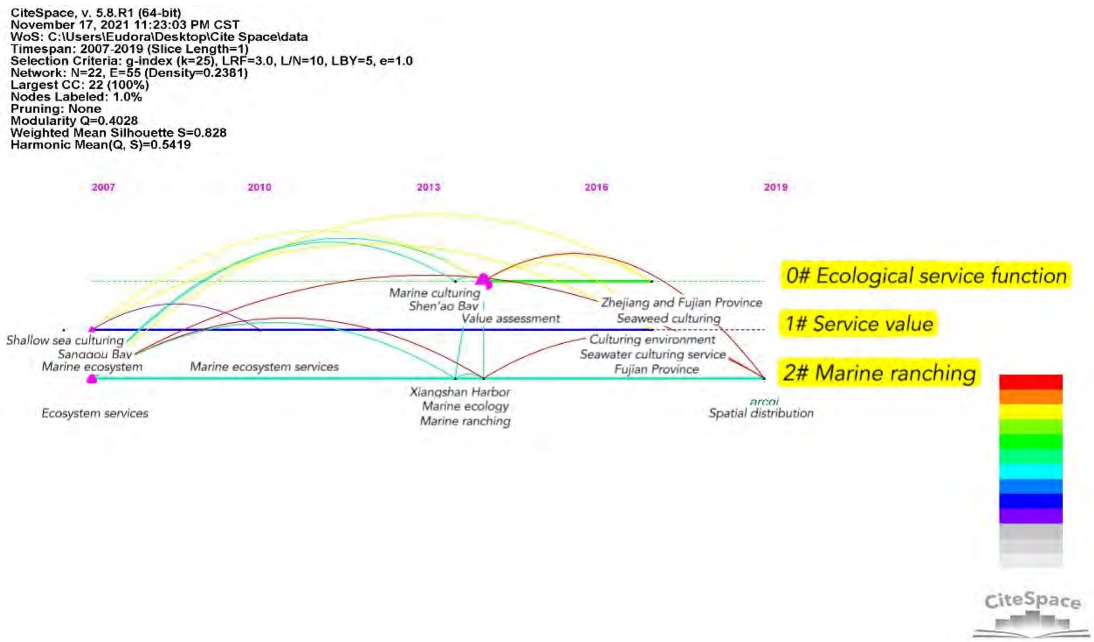
Appendix Figure A3: Keyword co-occurrence analysis view

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 (Appendix Figure A.3). 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 can be seen from Appendix Figure , 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 mariculture ecosystem also needs the assistance of geography and ecology to make the research results more convincing.

Appendix 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 by scholars. The higher the intermediary centrality, the higher the degree to which the keyword is concerned and 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,; Secondly, 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.

Appendix 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



Appendix Figure 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. Appendix Figure A4 shows the time line map drawn by CiteSpace, 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 the 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 include the value assessment of ecosystem services in three different mariculture areas: Shangang, Dapeng'ao and Shenao 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 extends to new geographical areas.

To sum up, in the research 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 mariculture ecosystem has gradually increased.

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

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4.1 Ecosystem Services and Decision Making

As expanded on in earlier chapters of this report, the term ecosystem services (ES) broadly refers to the direct or indirect benefits to humans derived 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 ecosystem services 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 socio-cultural; concepts and methods of measuring ESV are discussed in more detail in earlier chapters. 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; Farley and Costanza, 2010; Jack et al., 2008) 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 (La Notte and Rhodes, 2020; United Nations, 2014). 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 ecosystem services 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 Marttunen et al., 2021; Johnston 2018), to fully represent the benefits of ecosystem services 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 PICES 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 sections 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 chapter. The chapter 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* (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" (p. 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 *Species at Risk Act* (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." Going forward, 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 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, 2021 and December 24, 2021. An initial email was sent to each participant inviting them to participate with information provided on the purpose of the survey and providing a link to a short video with background on ecosystem services 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 sections (see Annex A for a copy of the survey). The *first section* 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 Likert-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 section* 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 section* 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 USA survey.

The *fourth section* collected work-based demographic information on respondents such as 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 in 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 regions. The mailing list was assembled from a number 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. It took respondents an average of 32 minutes to complete the survey.

4.2.4 Results

4.2.4.1 Respondent characteristics

All DFO regions were represented in the responses, with 25% of respondents from Pacific region (British Columbia), 44% from Atlantic regions (Newfoundland and Labrador, Maritimes, and Gulf), 31% in 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 is the most heavily represented, accounting for 45% of survey respondents; this sector includes 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 (Figure 4.1). Respondents are 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 account for 30%, 28%, 20% and 16% of respondents, respectively. In terms of the classification or level of position held, respondents appear to be representatively spread between analysis and management. Senior and intermediate level analysts and researchers are the most represented categories, accounting for 31% and 30% of respondents, respectively. These are followed by managers, directors, and senior management above director, which account for 19%, 13%, and 7% of respondents, respectively.

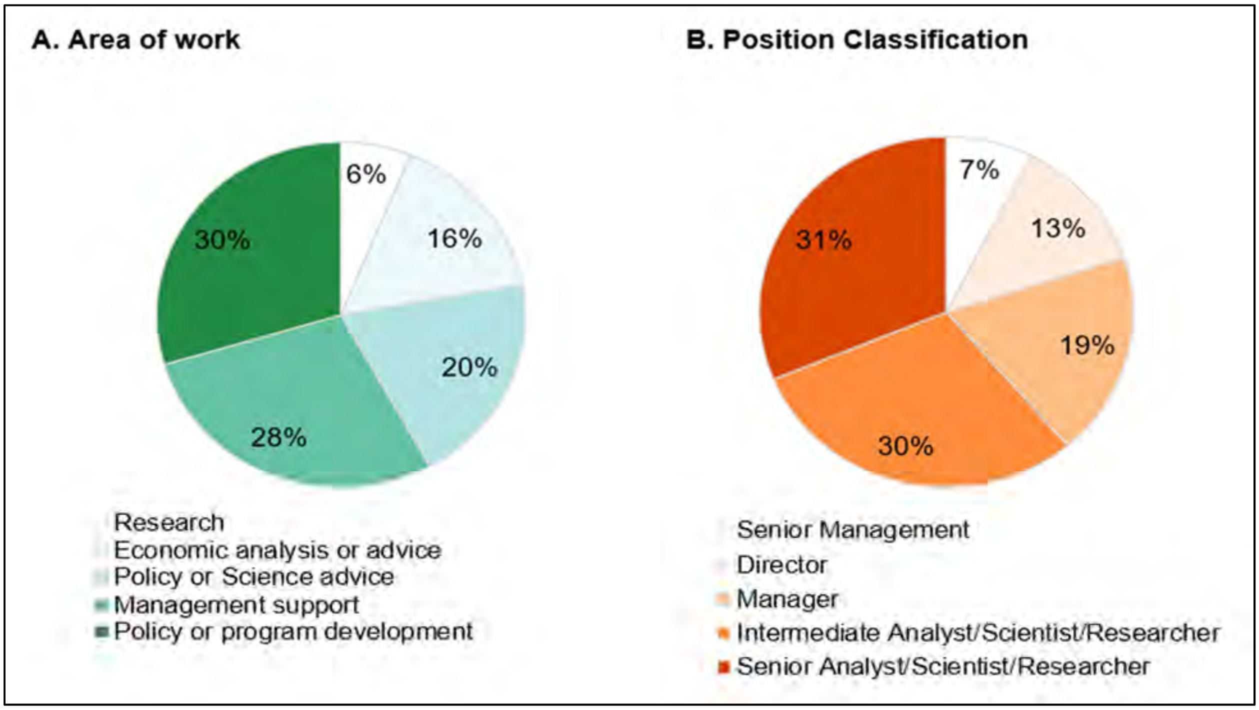


Figure 4.1. Canada: Respondents by area of work (A) and position classification or level (B).

Respondents had a high level of work experience and were well educated (Figure 4.2). The majority of respondents have 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.

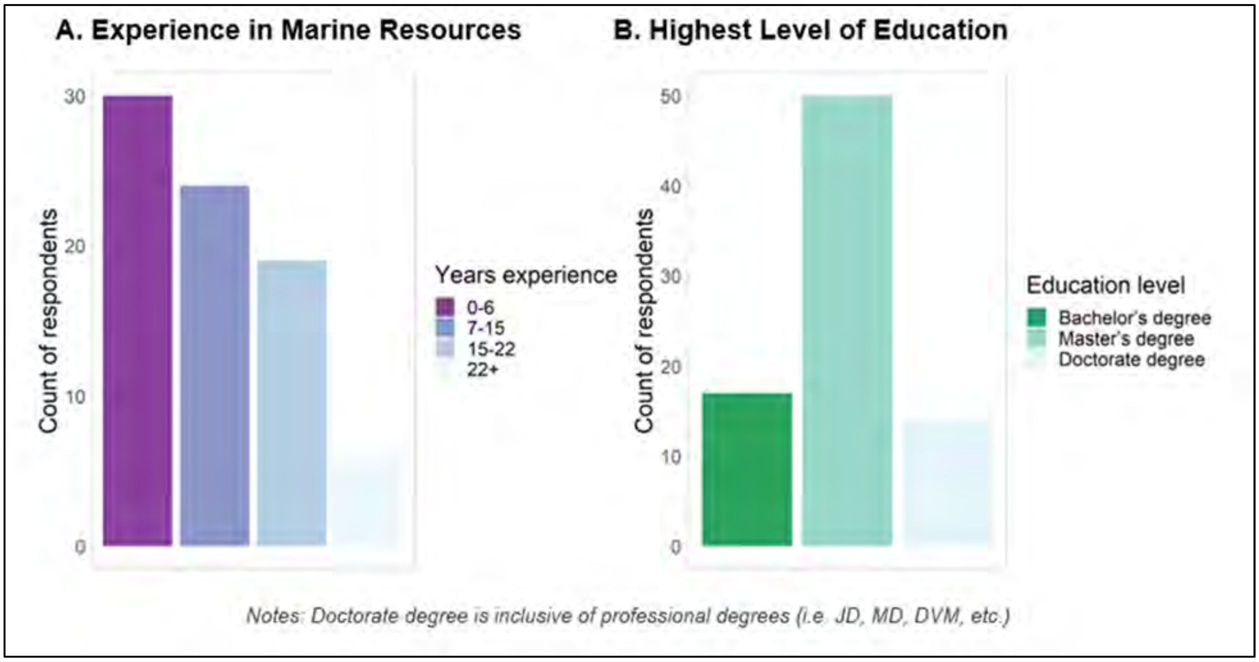


Figure 4.2. Canadian respondent experience in a marine resources agency (A) and education level (B).

Respondents were asked to identify the policies and programs that their work influences, with multiple responses allowed (Figure 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 as more non-regulatory options were provided and respondents were 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.

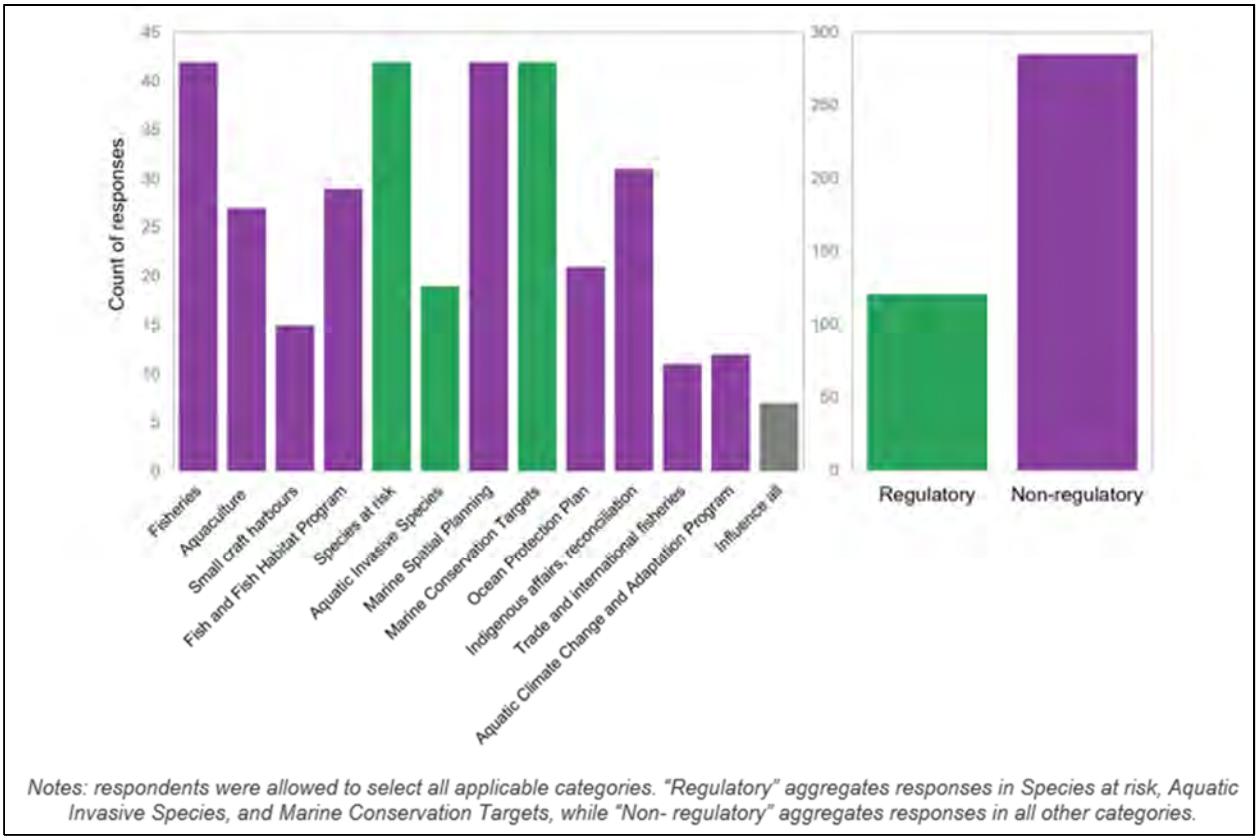


Figure 4.3. Canada: Policies or programs which respondents work influences.

4.2.4.2 Familiarity and Experience with ESV

Figure 4.4 summarizes respondent familiarity with the concept of ecosystem services and economic valuation of ecosystem services. The majority of respondents reported having a good prior knowledge of the concept of ecosystem services, 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 respondent's 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.

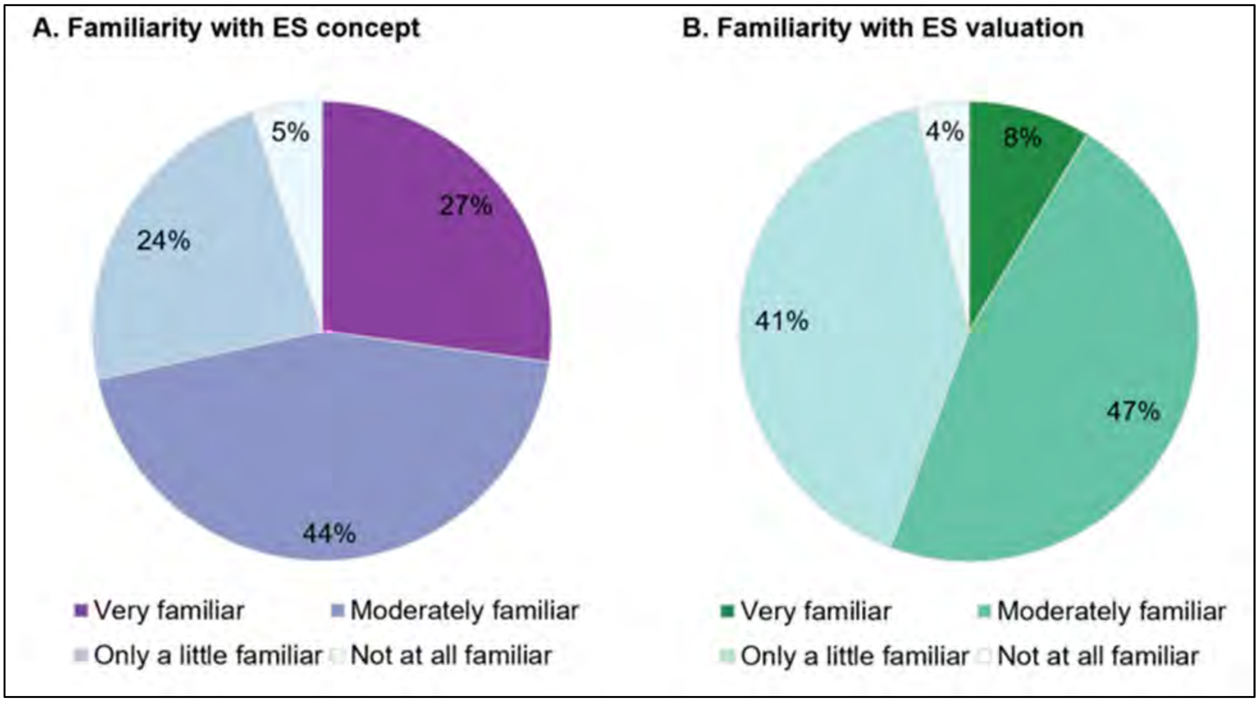


Figure 4.4. Canada: Respondents familiarity with the concept of ecosystem services (A) and ecosystem service valuation (B).

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.

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). ESVs 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 of the organization (5 respondents).

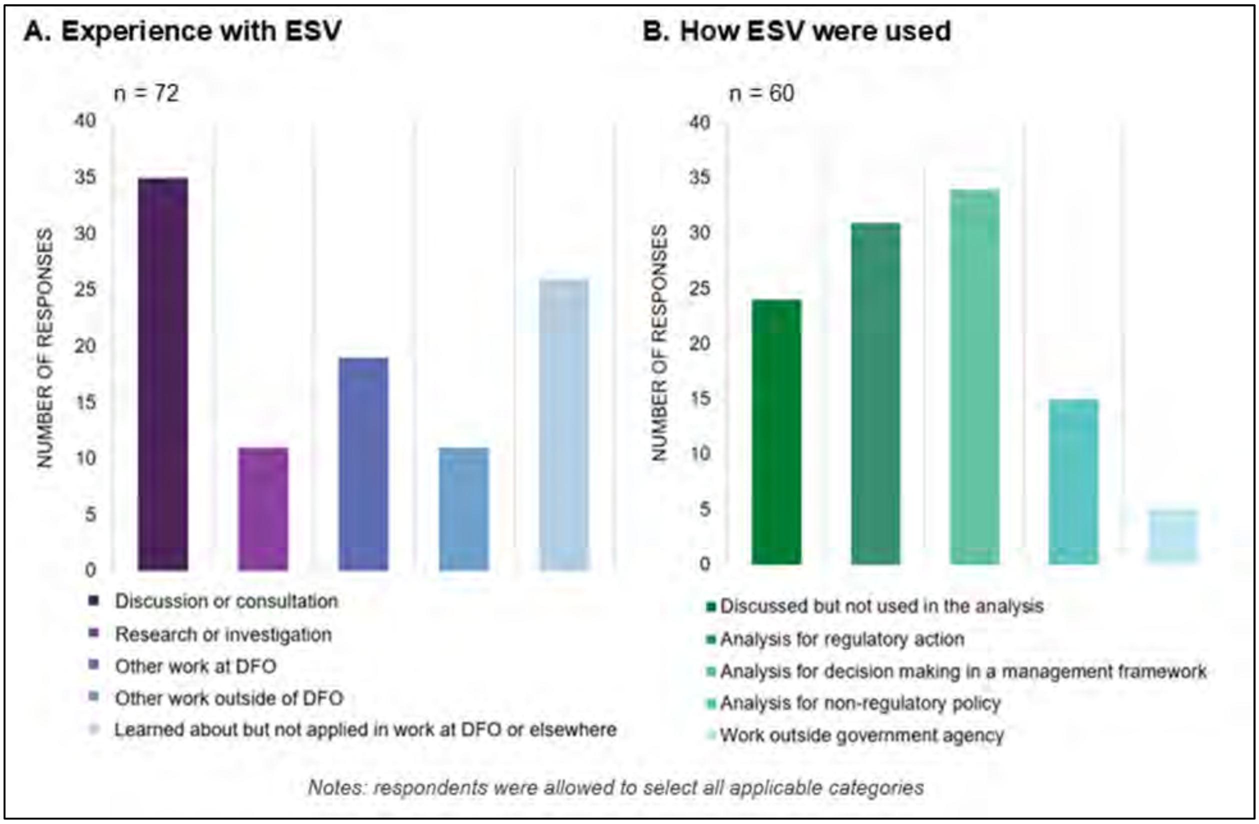


Figure 4.5. Canada: Respondent experience with ESV (A) and use of ESV in a professional context (B).

4.2.4.3 Importance of specific ESV to work

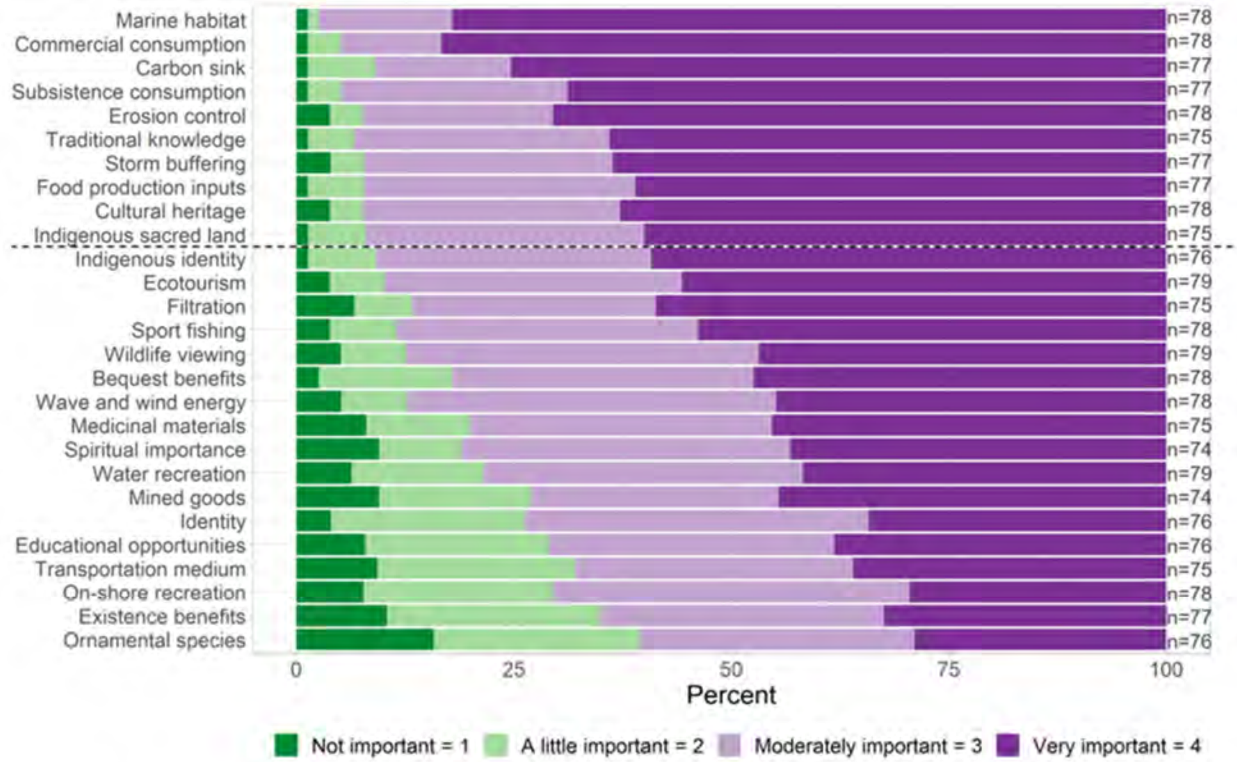
The survey included two slightly different questions to identify respondents' perceptions of the usefulness of economic values for different types of ES. First they were asked to identify the importance to DFO decision-makers in general, and second to their ability in their current role to provide useful 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 the list of 27 ES was presented was identical. For ease of presentation within each question, the list of provisioning and regulating ES were presented in one table and cultural ES in a different table.

Table 4.1: List and description of marine ecosystem services 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, etc.)
	Sport fishing	Sport fishing opportunities
	Wildlife viewing	Wildlife and scenic viewing opportunities (e.g. bird watching, whale watching, etc.)
	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 (Figure 4.6), and in respondents ability to provide information to decision makers (Figure 4.7). When compared to DFO management decisions in general (Figure 4.6), respondents appear to score the potential utility of ES valuation information lower for their individual work (Figure 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 A 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%.

Figure 4.6. Canada: Distribution of responses, indicating level of importance of ESV for DFO management decisions in general.

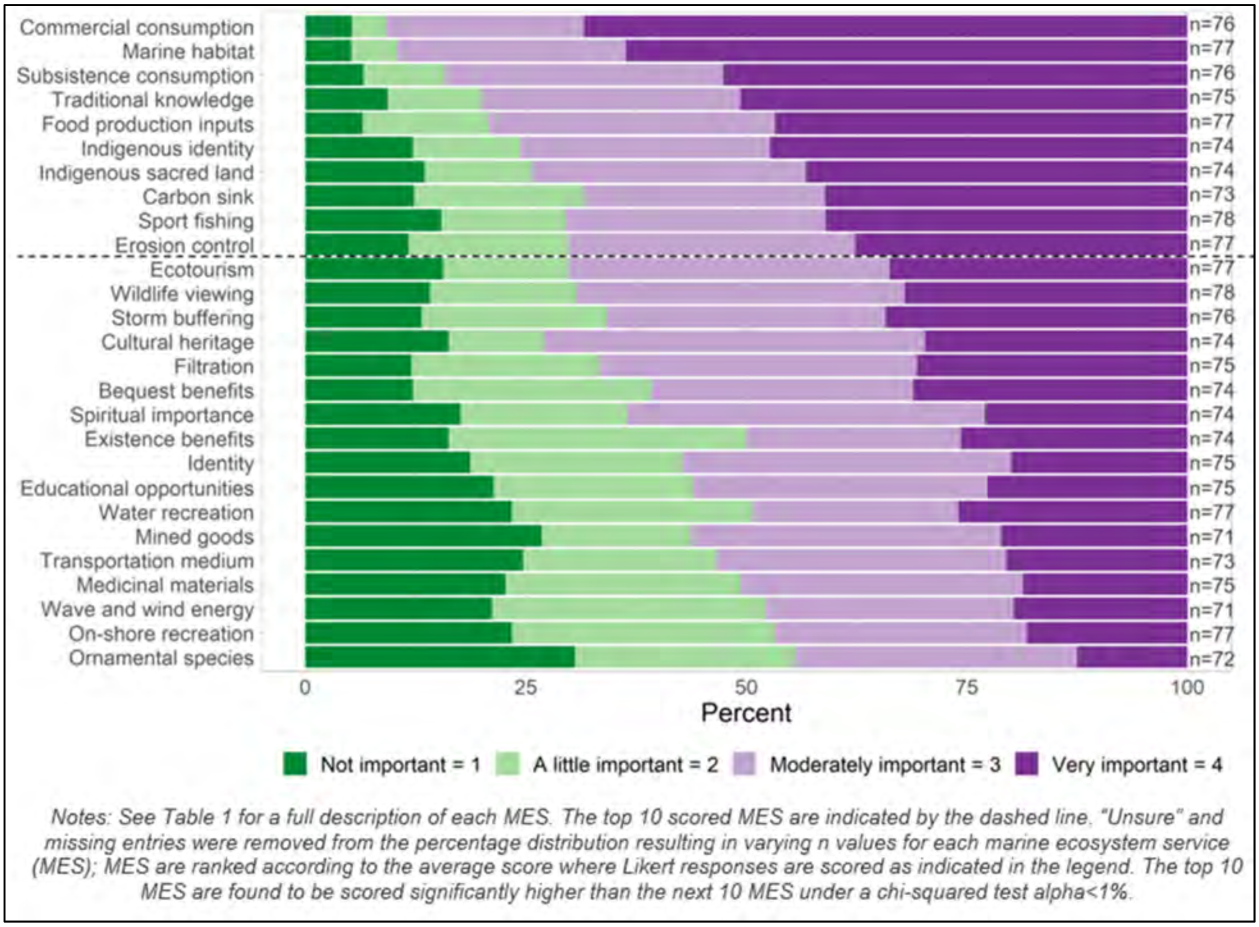


Figure 4.7. Canada: Distribution of responses, indicating perceived importance of ESV information for respondents' work at DFO.

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, policy development. Overall, respondents appear to perceive ESV information of similar value to regulatory and non-regulatory work (Figure 4.8). The majority of respondents believe ESV information would be very valuable to both regulatory and non-regulatory activities.

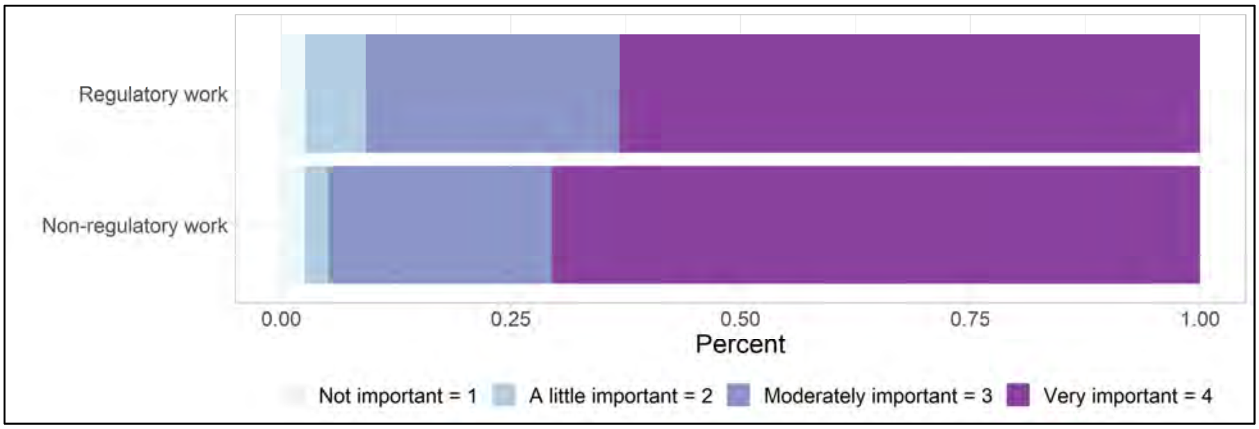


Figure 4.8. Canada: Respondents perceived utility of ESV information for regulatory and non-regulatory work.

4.2.4.4 Opinions related to ESV

The final section of the survey were 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.

Table 4.2: Canada: Distribution of opinions related to statements regarding 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.[26]	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%

[26] Note that this statement differs from that used in the US version of the survey, which used the term "human preferences."

	Statement	Strongly agree	Moderately agree	Neutral	Moderately disagree	Strongly disagree	Unsure/ no opinion
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%

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).

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 regions, with the work of respondents influencing most aspects of the work of DFO 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, and only 25% had actually used them in their work at DFO, suggesting potential constraints or lack of opportunity for ESV implementation within the department.

Respondents perceive economic valuation information for a wide range of ecosystem services as 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, and were of the opinion that ESV could be appropriate and useful and should be included in decision making despite potential costs, even with uncertainty with regard to 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 forwards the idea of "Clear waters and green mountains are as good as mountains of gold and silver", 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 pointed out that 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 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, requesting 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 ecosystem service values 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 section of the chapter provides a summary of 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 sections was designed to investigate coastal and marine environmental decision-makers. Annex B of this chapter provides an English translation of the survey instrument. The *first section* provides background including a definition and explanation of marine ecosystem services and the economic valuation of marine ecosystem services, as well as the objectives and potential value of the survey.

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

The *third and fourth sections* 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 marine ecosystem services. 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 were designed to investigate factors that limit the application of use and nonuse values in policy decisions.

The *fifth section* 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 (Figure 4.9 (1)). Fourteen percent of respondents identified their primary role in coastal and marine management decision-making as a top manager in coastal and marine management, 22 percent as a middle manager, 26 percent as a first-line manager and 38 percent as a researcher who played a role in decision-making (Figure 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 percent on marine ecological conservation and supervision, 26 percent on marine environmental impact assessment, 16 percent on marine development strategies, policies and regulations, 15 percent on marine resource investigation, registration and supervision, 10 percent on land-use planning and control, and 7 percent on marine disaster forecasting and monitoring (Figure 4.9 (3)). The majority of respondents (73 percent) had more than 10 years of experience in coastal and marine management decision-making (Figure 4.9 (4)). Additionally, approximately 70 percent of respondents reported they had a master's degree or above (Figure 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.

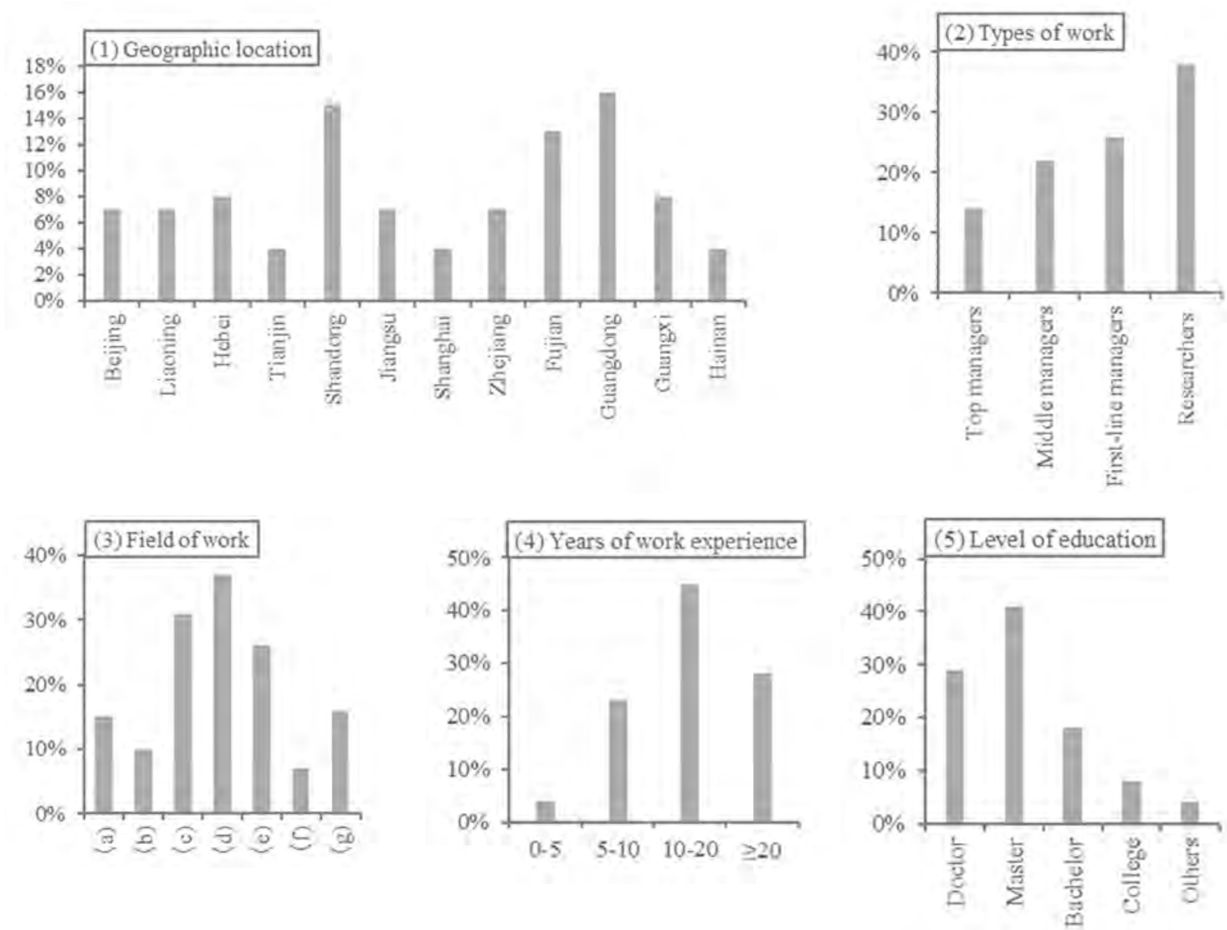


Figure 4.9. China: Characteristics and geographic location of the respondents (Source: Li and Wang, 2022: p. 5).

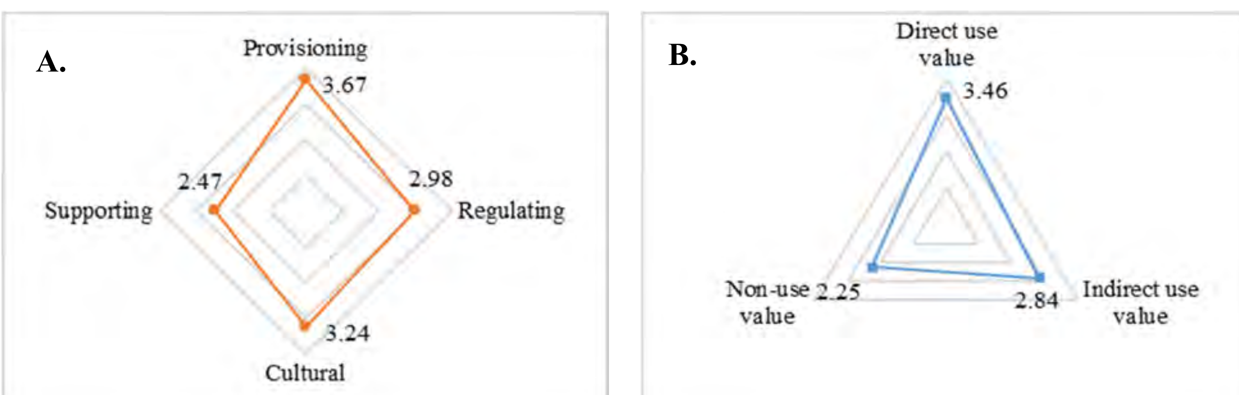


Figure 4.10. China: Average score of respondents' cognition of coastal and marine ecosystem services by classification and values by type (Source: Li and Wang, 2022: p. 5).

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 percent "Very necessary" and 26 percent "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 (Figure 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.

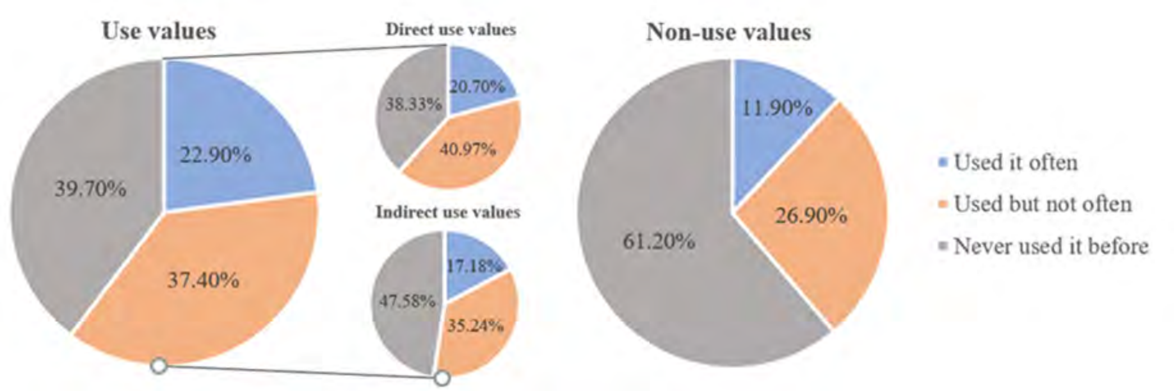


Figure 4.11. China: Share of respondents that applied direct or indirect use values and nonuse values of coastal and marine ecosystem services in China (Source: Li and Wang, 2022: p. 6).

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 EIA of sea-related engineering construction projects was higher than for several management areas where the application was "technical".

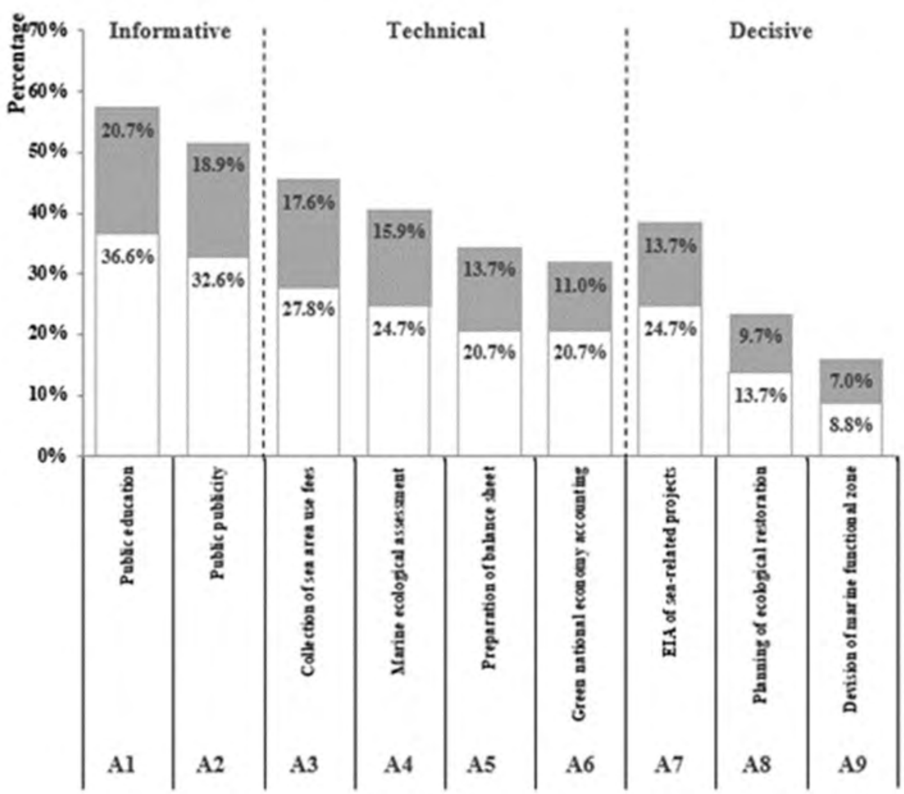


Figure 4.12. China: Application of use and nonuse values in the nine management areas. White bars refer to management areas of use value information; grey bars refer to management areas of nonuse value information (Source: Li and Wang, 2022: p. 7).

4.3.4.5 Factors limiting utilization of nonuse values

Given 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 showing 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" represents the science underlying economic valuation of nonuse value is too uncertain; "Accuracy" represents the valuation results of nonuse value are too often inaccurate; "Simplicity" represents economic valuation of nonuse value is too simplistic to give the complex interlinkages between ecosystems and humans; and "Definition" represents the definition and classification of ecosystem services for nonuse valuation are 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 in particular "Preference" and "Ethics" variables which reflect decision-makers' personal opinion of nonuse values, and the "Relevance" variable with 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 regarding 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 that 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 is too simplistic to reveal the complex interlinkages between ecosystems and humans, and the lack of clear and consistent definition and classification of ecosystem services 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 US the 2010 Executive Order 13547 (referred to as the National Ocean Policy) and the National Ocean Policy Implementation Plan (2013) both stress the need to further our understanding of ecosystem services provided by oceans and coasts. This was followed by the US 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 IEA), 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 (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 ecosystem service values as an organic and core part of NOAA's mission, and in what areas this is most appropriate (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 Marine 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 section 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 that was 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 of this chapter.

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 this 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 (WG41) for additional review. Feedback from PICES 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 has 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 has also worked on marine resource issues for 16.1 years (median = 16 years) and has 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). 71% 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. 23% of item respondents indicated being in coordination or planning roles, and 20% indicated working in communication, stakeholder facilitation, or outreach. 20% 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, Alaska, Pacific Islands, 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%). 16% of item respondents also indicated their work focuses on National issues, and 11% indicated working on international issues.

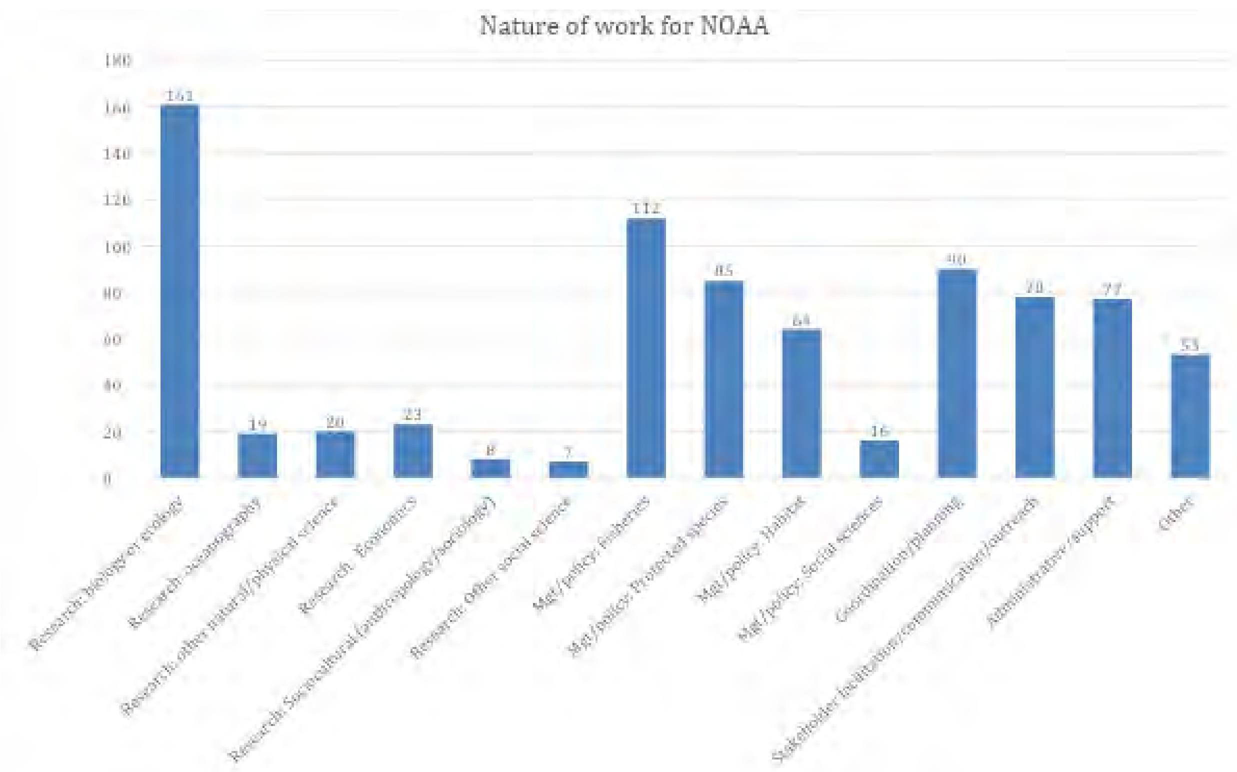


Figure 4.13. USA: Nature of survey respondents' work. Item respondents = 391. Respondents were able to select all relevant areas for which their work is focused, so the total responses exceeds the number of respondents.

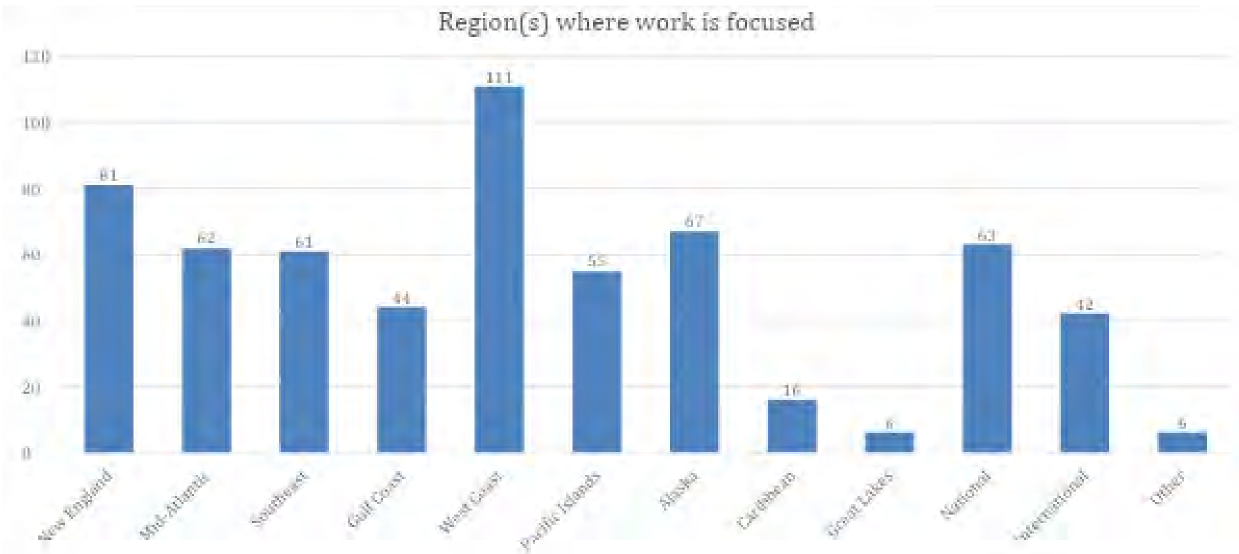


Figure 4.14. USA: Geographic regions in which respondents' work is focused. Item respondents = 387. Respondents were able to select all regions in which their work is focused, so the total responses exceeds the number of respondents.

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% (see Figure 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 (Figure 4.16).

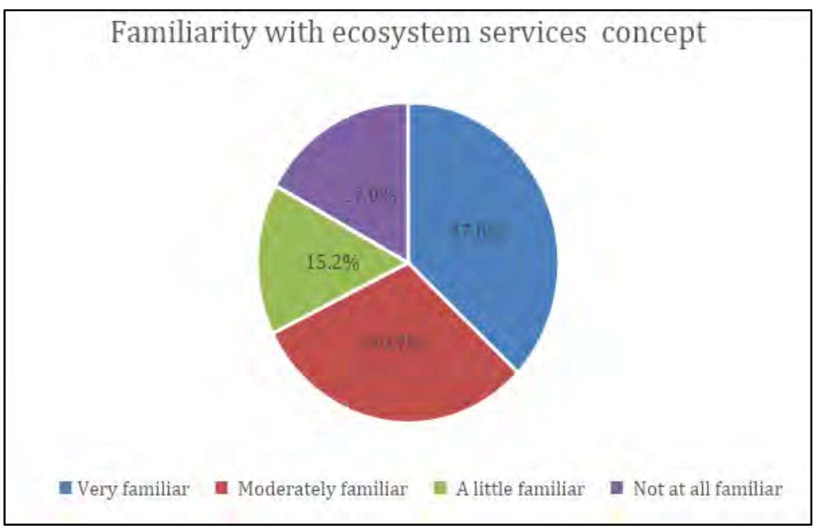


Figure 4.15. USA: Familiarity with the ecosystem services concept. Total item respondents = 505.

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) (Figure 4.17). About 39% indicate not having any experience with ESV information.

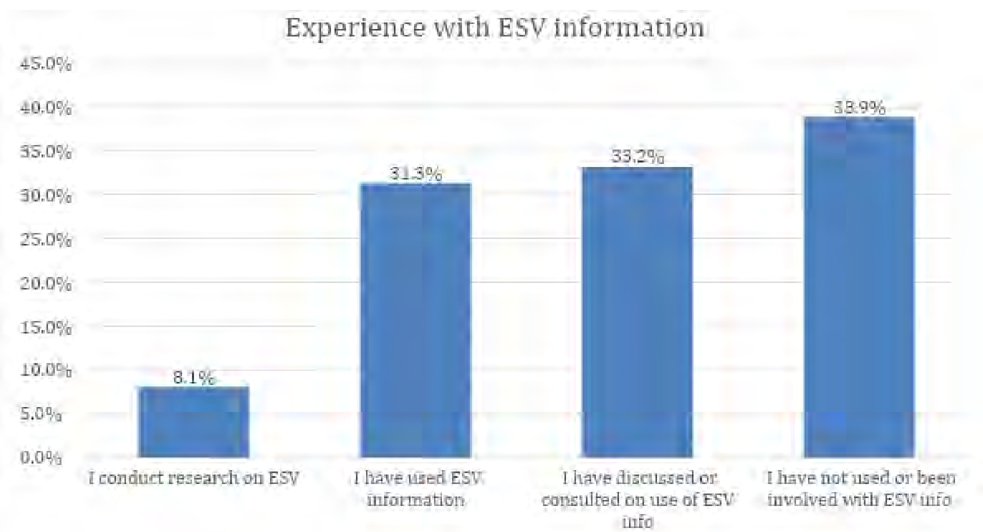


Figure 4.16. USA: Familiarity with the ecosystem service valuation and/or ecosystem service value concept. Total item respondents = 505.

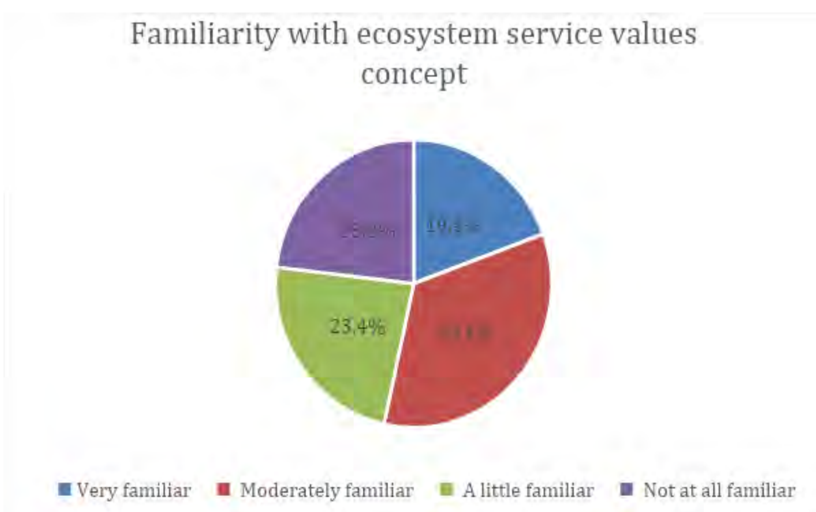


Figure 4.17. USA: Respondent experience with ESV information. Item respondents = 422.

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 (e.g., ecosystem based fisheries management, 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 (Figure 4.18).

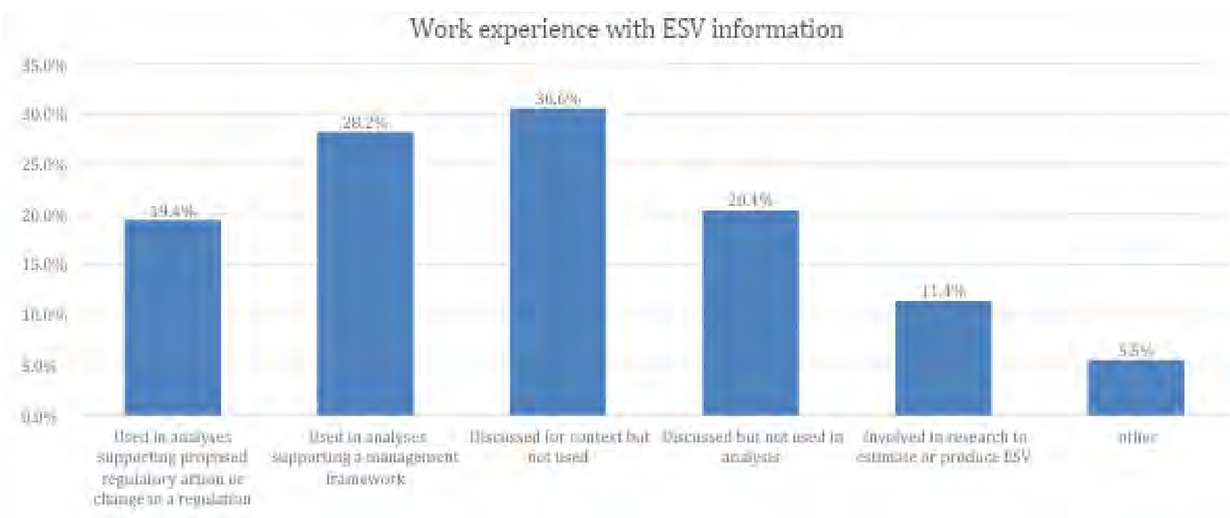


Figure 4.18. USA: Work experience with ESV information. As respondents were able to select multiple answers, the percentages do not add up to 100%. Item respondents = 422**.**

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 that information would be "very useful", with another 37% indicating it would be "moderately useful" (see Figure 4.19). Thus, almost 90% of respondents indicate ESV information would be at least moderately useful in their work.

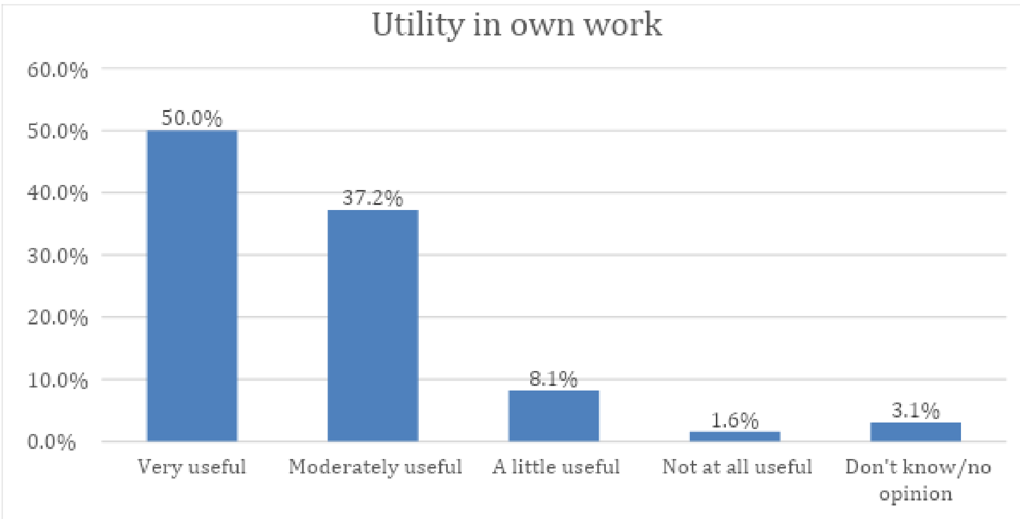


Figure 4.19. USA: Usefulness of ESV information in respondent's own work. Item respondents = 258.

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 indicate these values would be at least “moderately useful” for management and decision-making. 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%) indicate 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.”

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%

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%

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 amount of 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.

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%

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 >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, etc.), and environmental justice assessments. Of these, environmental justice assessments 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.

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%

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.

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%

Having ESV information available for different types of protected species analyses was viewed by a majority of respondents (item respondents = 335) 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 ESA-related analyses, other endangered and threatened species activities (e.g., international agreements), or MMPA-related activities.

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%

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 (item respondents = 335) as “very useful,” with about 85% of respondents generally indicating ESV information would be at least “moderately useful.”

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%

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 ESV 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.

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%

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 as 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.

The first group of statements generally address aspects of using ESV information in decision-making. The first statement related to the appropriateness of using ESV information to represent human preferences in decision-making. Over 68% of respondents indicated they agreed with the statement, "Using ecosystem service values is an appropriate way to include human preferences in decision-making." About 7% of respondents disagreed with the statement, indicating that they did not feel ESV information is the appropriate manner in which to account for human's preferences and values in policy and management. The second statement related to whether the use of ESV information should be evaluated on a case-by-case basis. About 42% agreed and 25% disagreed with the statement, "Including ecosystem service values is best done on a case-by-case basis," with an additional 19% being neither agreeing nor disagreeing and 14% being unsure or not having an opinion. The third statement related to whether ESV information should be considered to the maximum extent possible in marine management decisions. About 71% at least "moderately agreed" and 8% at least "moderately disagreed" with the statement, "Ecosystem service values should be included to the greatest extent possible when making decisions about the marine environment." 14% had no opinion or were unsure.

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. And 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. 59% 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. 72% disagreed with the statement, “It is unethical to put an economic value on ecosystem services,” while about 10% agreed with it. 13% 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, Himes-Cornell, and Lee 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. 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, analysis of the pattern 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 also 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 facilitates improved understanding of trade-offs. The results also 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 of, 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 Anderson and Plummer 2016; Lee, Steinback, and Wallmo 2017; Lew and Larson 2015; Carter, Lovell, and Liese 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, Layton, and Rowe 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 USA (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 USA (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 57% and 53% of respondents being at least moderately familiar with ESV in Canada and USA, respectively. In the China, the average level of familiarity 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 with 89%, 60% and 61% of respondents in Canada, China and USA 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 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 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 your current position at DFO, would information on economic values of the following ecosystem services improve your ability 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 opinion 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**

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

Annex B – English Translation of Survey used in China

The Questionnaire of 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

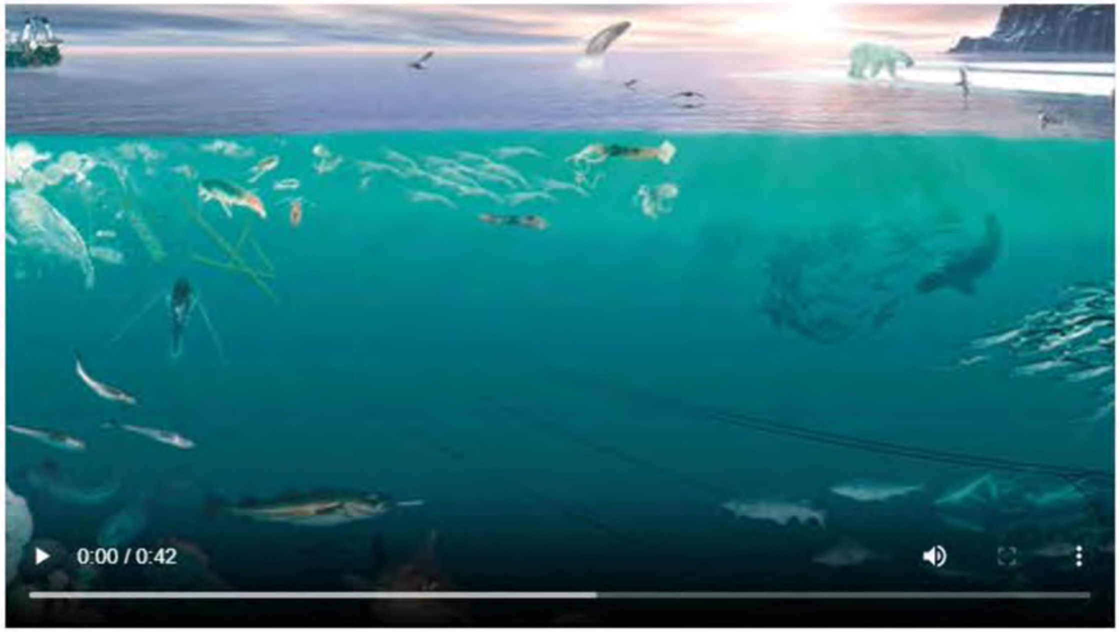
7、How long have you been working?			
Less than 5 years	6 to 10 years	11 to 20 years	More than 20 years

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

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10%

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)	○	○	○	○	○

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Ecosystem Services Valuation Survey

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

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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					

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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)	○	○	○	○	○

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44%

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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.	○	○	○	○	○	○

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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)

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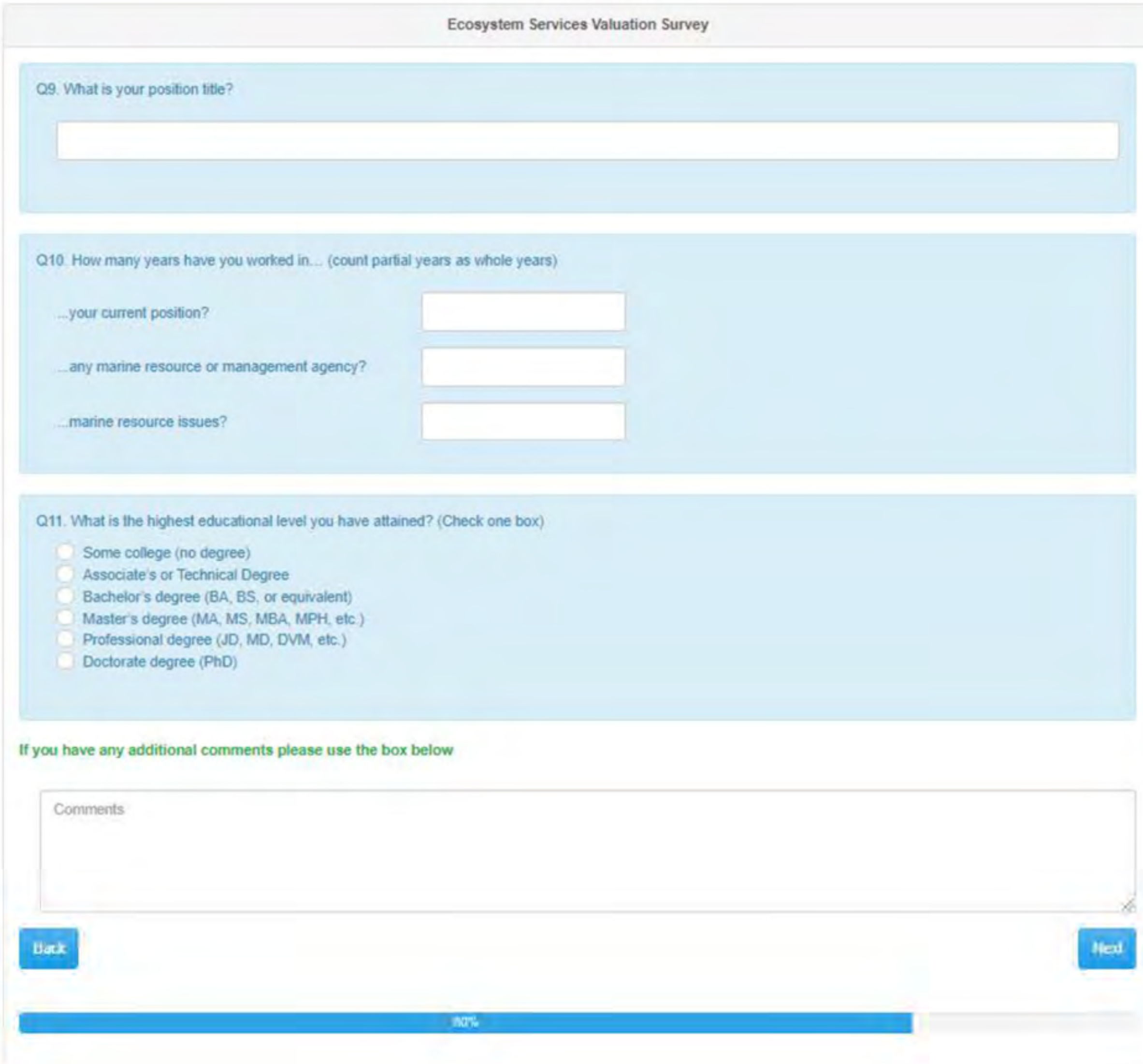
60%


Ecosystem Services Valuation Survey

Q9. What is your position title?

Q10. How many years have you worked in... (count partial years as whole years)

...your current position?

...any marine resource or management agency?

...marine resource issues?

Q11. What is the highest educational level you have attained? (Check one box)

- Some college (no degree)
- 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)

If you have any additional comments please use the box below

Comments

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Ecosystem Services Valuation Survey

Thank You for Completing This Survey!

Thank you for taking the time to complete this survey - your responses are appreciated.

100%