2023 Intersessional Science Board Meeting

Report

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

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Appendices

Agenda Item 1: Welcome, adoption of agenda

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

List of Participants

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
Xianshi Jin	FIS Chair
Mitsutaku Makino	HD Chair
Andrew Ross	MEQ Acting Chair
Lei Zhou	POC Chair
Jennifer Jackson	POC Vice-Chair
Sung Yong Kim	MONITOR Chair
Vladimir Kulik	Representing Russia (Igor Shevchenko's behalf)
*Governing Council	
Enrique Curchitser	PICES Chair
Tetsuo Fujii	PICES Vice-Chair
PICES Secretariat	
Sonia Batten	Executive Secretary
Sanae Chiba	Deputy Executive Secretary
Lori Waters	PICES Communications Officer
Alex Bychkov	Special Projects Coordinator
Invited Guests	
Vera Trainer	Former SB Chair
Raphaël Roman	AP-ECOP
Hana Matsubara	AP-ECOP
Minkyoung Kim	AP-ECOP
Taewon Kim	Project SEAturtle
Yutaka Hiroe	F&A
Tatsuki Oshima	F&A
Hitomi Kawahara	GC Advisor
Katsutoshi Ishikawa	GC member

*Note : GC members are regularly invited to participate in the Intersessional Science Board Meeting.

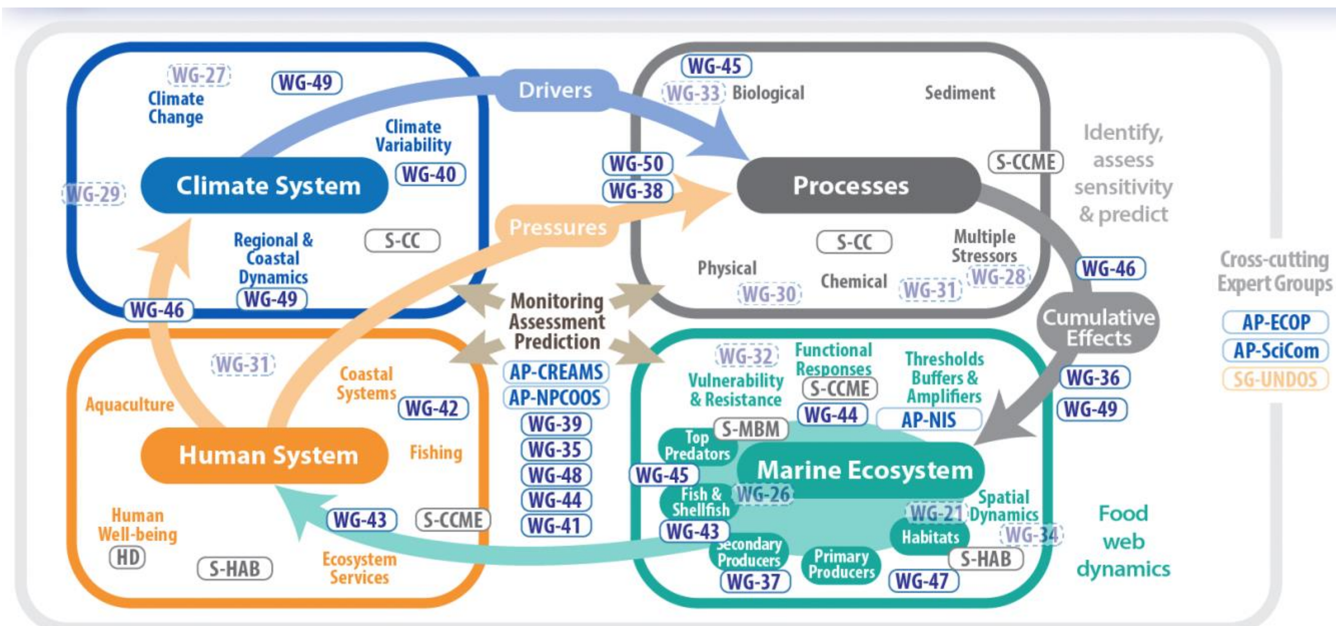
Agenda Item 2: FUTURE-SSC Report

FUTURE Co-chair, Dr. Steven Bograd, updated the activities and planning of FUTURE.

1. Report of FUTURE SSC meeting

FUTURE SSC held a one-day hybrid business meeting on April 27 (PST), 2023. They updated FUTURE Schematic (see below, not on the current website) and Liaison table in accordance with the establishment of new PICES Expert Groups and changes in its membership. They discussed the planning of FUTURE Workshop: Sharing Capacity and Promoting Solutions for Marine Ecosystem Sustainability within the UN Decade of Ocean Science at PICES-2023 and progress of the FUTURE products: FUTURE Phase II Final Report (due: December 2023), FUTURE Phase II Brochure, and FUTURE Product matrix Paper. They agreed to propose at SB-2023 to hold a 1-day FUTURE Open Science Meeting as its Phase II synthesis in conjunction with PICES-2024 when the logistics of PICES-2024 are determined at IGC in the end of May 2023.

Reference:
FUTURE Implementation Plan (Phase II) 2016-2020
FUTURE Implementation Plan (Phase III) 2021-2025
FUTURE Schematic (ver. April 2022)



2. Promotion of FUTURE ECOP Award

FUTURE Early Career Ocean Professional (ECOP) Award scheme was established at GC-2019 to provide full travel support for an ECOP who presents their study applying Social-Ecological-Environmental Systems (SEES) approaches (Bograd et al., 2019). However, there have been no applicants since then because the application procedure on the PICES website is not clear or visible. FUTURE SSC requested to change its online application procedure and website description. SB admitted the need for the proposed changes and requested Secretariat to modify its website information.

Current description:

To apply for this award, you must be a student or Early Career Ocean Professional (ECOP) in the beginning of your career, with ten years or less of professional experience, conducting inter-disciplinary research on marine ecosystems. Selections will be made based on:

1. submitted abstract.
2. a brief description (~1 page) of the proposed SEES approach
   - to be submitted to Sanae Chiba at the PICES Secretariat (Sanae.Chiba@pices.int) by the Annual Meeting abstract deadline.
   - Subject line to include your given name AND FUTURE ECOP Award (e.g. Smith-FUTURE ECOP Award)

Applicants should also complete an application for Financial Support during their online Annual Meeting Registration.

Proposed new description (updated on website after ISB-2023):
To apply for this award, you must be a student or Early Career Ocean Professional (ECOP) in the beginning of your career, with ten years or less of professional experience, conducting inter-disciplinary research on marine ecosystems. Selections will be made based on the submitted abstract to S1: Science Board Symposium. The abstract should describe **the** SEES approach taken for the study.
Applicants should also complete an application for Financial Support during their online Annual Meeting Registration.

3. ECOP member recruitment
FUTURE SSC requested each national delegate to nominate at least one ECOP to join FUTURE SSC to engage ECOPS in the planning and implementation of FUTURE and foster their experience in leadership of the next PICES Program. SB supported the request and ensured with Secretariat to have it informed to the national delegates. *
See Agenda Item 12 for membership requests

Agenda Item 3: SmartNet/IPOD Report

SmartNet co-chair and AP-UNDOS co-chair Dr. Steven Bograd, updated SmartNet activities in 2022 and planning for 2023.

2022 Accomplishments
SmartNet was very active in 2022, with a principal focus on IPOD ToR 1, i.e. beginning to build partnerships, both within and outside of ICES and PICES, and co-design of activities below.

Completed

1. Participation in UNDOS 'Blue Foods' Community of Practice (Jan 2022)
2. Submitted SRI Symposium & ECCWO Symposium session proposals (Feb 2022)
3. Participated in OSM-Ocean KAN Town Halls (Feb-Mar 2022)
4. Update IPOD/SmartNet material on ICES and PICES websites (Mar-Apr 2022)
5. Proposal for PICES AP-UNDOS (Apr 2022)
6. Coordination with Tula Foundation – Decade Collaborative Center (Apr 2022)
7. Participate in Consortium for Ocean Leadership 'Workshop to Coordinate Biological Observing Programs in UNDOS' in DC (Apr 2022)
8. Submitted UN Ocean Conference side event – with MPOWR and ECOP (May 2022)
9. Submitted SmartNet video with ECOPs (May 2022)
10. Submitted resource needs assessment (May 2022)

11. Prepared for, and conducted "Productive Ocean' Town Hall: invite participants, prepare agenda and materials (May-Jun 2022)
12. IPOD Chairs meeting: workshop planning; UNDOS program collaboration; survey update; funding (Sep 2022)
13. Organized & conducted PICES-2022 SmartNet Workshop (Sep 2022)
14. Participated in Ocean KAN 'network weaving' training session (Oct 2022)
15. 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
16. Conference call to discuss SmartNet-SIDS engagement with Khush Jhugroo and Daniel Marie of Mauritius Oceanographic Institute (Nov 2022)
17. Chairs coordination discussion with Ocean Visions DCC (Dec 2022)
18. End-of-year update e-mail to IPOD & partners (Dec 2022)
19. Conduct IPOD meeting; form sub-groups on priority actions (Feb 2023).
20. Conduct ECCWO UNDOS co-design workshop – build from satellite event, reach out to partners (Apr 2023).
21. Participate in Ocean Visions Summit in Atlanta (Apr 2023)

Among these activities, there are a few we want to highlight: SmartNet hosted a Town Hall virtual event on June 1st, 2022 associated with the UNDOS Satellite Event on 'A Productive Ocean' (**item 11**), which had nearly 50 international participants and presentations from panelists representing the Pacific Subregional Committee of the Asia Pacific Network for Global Change Research (APN); the Our Fish, Our Future project; the Blue Belt MPA project; capacity sharing with Small Island Developing States; the ECOP Programme in UNDOS, as well as the FishSCORE and SmartNet Programmes.

SmartNet also hosted a Workshop at the PICES 2022 Annual Meeting (**item 13**, photo next page), aiming to facilitate a broad discussion within the PICES community and amongst partners on methods and priorities for implementing SmartNet. We heard presentations from several UNDOS-endorsed Programmes in addition to SmartNet, including SUPREME, GEOS, BECI, DOOS and ECOPs. We also heard a presentation from Mitsutaku Makino on a project being led by his group at the University of Tokyo and collaborators to implement a global survey on general public perceptions about the 7 outcomes of UNDOS. These survey results can contribute to a better formulation and prioritization of UNDOS challenges, as well as to guide PICES' international science collaborations and provide policy recommendations. We also had an invited talk from Khush Jhugroo, an early career ocean professional from the University of British Columbia and the Hakai Institute, titled 'Early Career Ocean Professionals (ECOP) and Small Island Developing States (SIDS) engagement in the UN Decade of Ocean Science For Sustainable Development'. Khush reflected on the many challenges facing SIDS due to various anthropogenic and climate stressors, and as an example described the impacts of an oil spill in Mauritius, her home country. A review of the PICES-2022 SmartNet Workshop will be published in the Winter 2023 issue of *PICES Press*.

UNDOS Relationships

Another important SmartNet activity to highlight is our growing relationship with other UNDOS Actions. In the Fall 2022 UNDOS Call for Actions, we were open for proposed Projects to request affiliation with and be endorsed under the SmartNet umbrella. Seven proposed Projects requested affiliation with SmartNet, and we notified the Decade Coordination Unit that three of the proposed Projects - *The Ocean Matter; COST Action - Marine Animal Forest of the World; sustainMare* - would be well suited to be placed under the SmartNet umbrella. If these Projects receive final endorsement, we will want to engage with these Projects and co-design new activities. This will be an exciting new development in 2023.

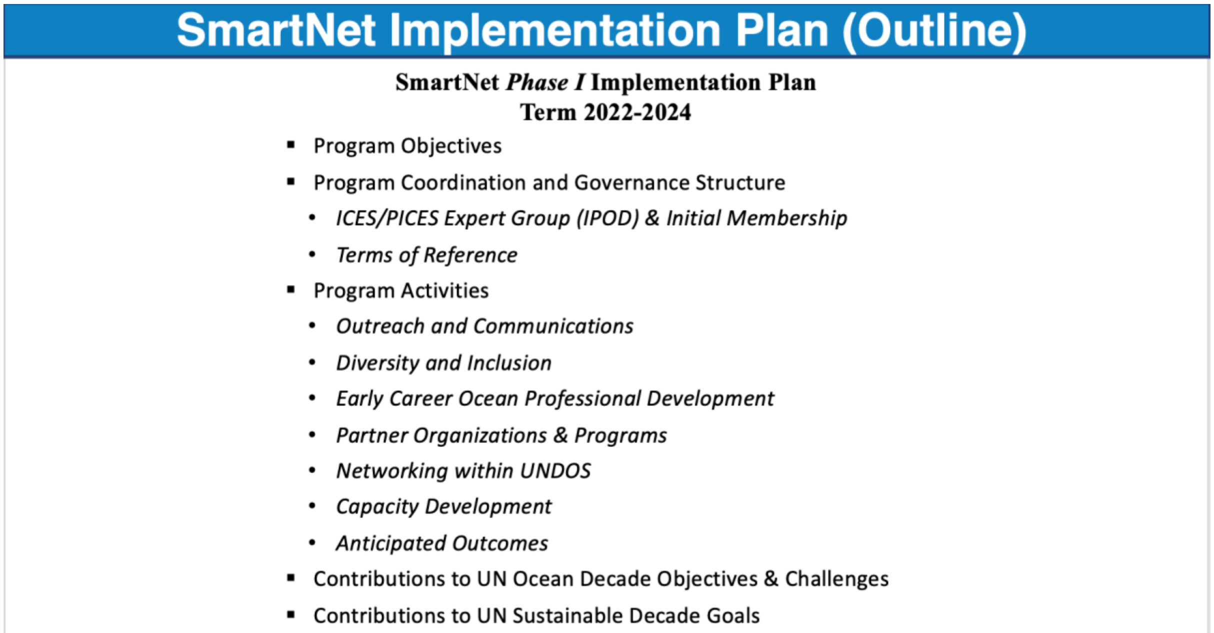
Finally, Steven, Jörn and Erin have had a discussion with Courtney McGeachy, the coordinator of the newly-formed Ocean Visions Decade Collaborative Center (OV-DCC), which is located at the Georgia Aquarium in Atlanta, GA. Each DCC will be a primary Center for a select group of UNDOS Programmes, and the OV-DCC has selected SmartNet as one of five UNDOS Programmes in its portfolio. The OV-DCC will help SmartNet with coordination and planning activities, which will be tremendously helpful in making SmartNet a success. We look forward to working closely with the OV-DCC and our umbrella Projects in the coming year.

Tasks for 2023
In addition to developing our partnerships with these UNDOS entities, we have a number of actions planned for the first half of 2023 . Please note item (3): we plan to conduct a virtual IPOD meeting in early 2023. A key aim of this meeting will be to develop sub-groups to take on the various tasks on our agenda. We welcome ideas and thoughts from all of you on how best to move SmartNet forward.

Upcoming Tasks

1. Update IPOD membership; ICES-PICES balance, ECOPs
2. Submit SmartNet Annual Report to IOC (May 2023)
3. Revise/maintain SmartNet web presence: https://forum.oceandecade.org/ventures?block-filters%5Bfulltext%5D=SMARTNET
4. Prepare contribution to 'Food for Thought' article for ICES Journal of Marine Science or other venue
5. Develop partnerships with 'Ocean Visions' Decade Collaborative Center and endorsed umbrella Projects
6. Follow up on SmartNet-SIDS engagement (Khush Jhugroo and Daniel Marie of Mauritius Oceanographic Institute)
7. Facilitate collaborative activities with Empowering Women for the UN Decade of Ocean Science for Sustainable Development (WMU)

8. Prepare SmartNet Implementation Plan (including Phase I action plan, products & deliverables)
9. Contribute to UNDOS National Surveys (Led by Makino)
10. Planning and organization of Workshops on community engagement (ITK; community-supported observation), with DCC support (incl. Workshop 9: "Indigenous and Community-Led Approaches to support climate change Adaptation and Ecosystem Resilience in the North Pacific and the Arctic" at PICES-2023)



Agenda Item 4: Special Project Updates

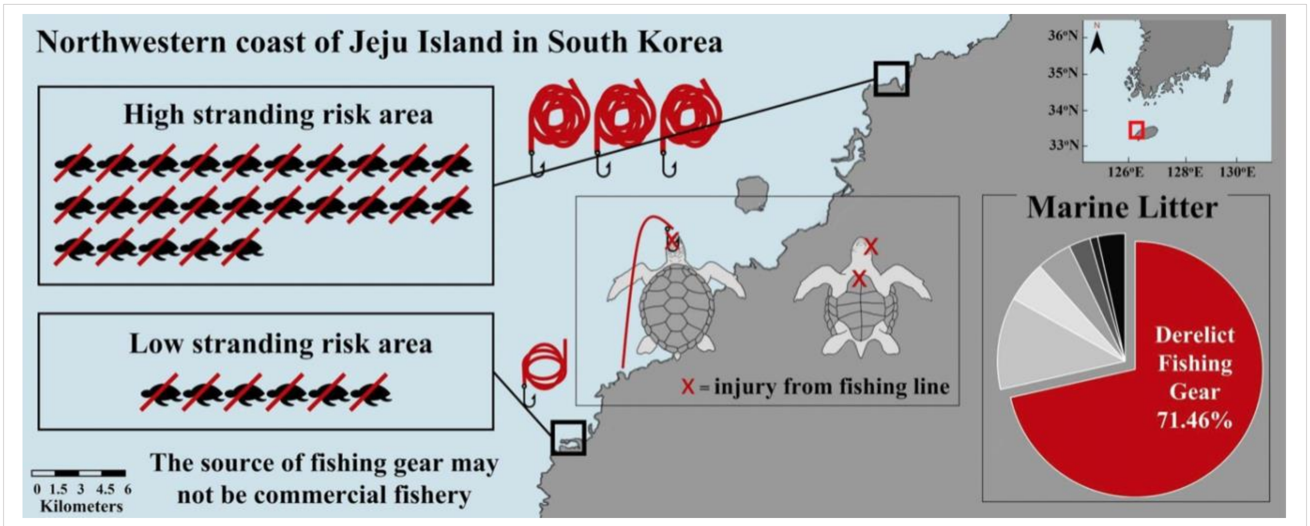
4.1. SEAturtle

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

- https://meetings.pices.int/projects/SEAturtle
- Term: December 2018 – November 30, 2023
- 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)

Dr. Taewon Kim, SEAturtle Science Team Co-chair, updated the progress of the project since SB-2022. The project will be completed in November 2023.

He summarized the major outcomes of the 5 year project which were achieved through tagging surveys, genetic survesy, stable isotope analysis, and the impact of marine plastic pollution on sea turtles around Jeju Island and the wider western North Pacific region. The project team also conducted an education campaign for local citizens to prevent the harmful impact of fishing gear on sea turtle ecology. The team published their scientific findings in a peer-reviewed journal*: Jo K et al. (2022) Possible link between derelict fishing gear and sea turtle strandings in coastal areas. Marine Pollution Bulletin. 185*, also reported in : *PICES SEAturtle researchers find clues linking derelict fishing lines of "Urban Fishermen" to sea turtle stranding.* SB members highly commended the accomplishments of the project.



Summary of study on fishing gear impacts on sea turtles.

4.2. PICES/MAFF Project

4.2.1.Ciguatera: Building local warning networks for the detection and human dimension of Ciguatera fish poisoning in Indonesian Communities

- https://meetings.pices.int/projects/Ciguatera
- Term: April 2020 – March 2023
- Project Science Team Co-Chairs:
  Mitsutaku Makino (The University of Tokyo, Japan), Mark Wells (University of Maine, USA)
- Funding Agency**:** Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan, through the Fisheries Agency of Japan (JFA)
- Project Coordinator: Alexander Bychkov (PICES)
- Parent PICES Committee: Human Dimensions Committee (HD)
- Objective: to build the capacity of local small-scale fishers and community members in Indonesia to monitor their coastal ecosystems and coastal fisheries.

The 3 year project "Ciguatera" was completed in March 2023. HD Chair and Project Science Team co-chair, Dr. Mitsutaku Makino presented the summary of the major outcome of the project. Local capacity development was achieved through activities in 5 components; 1. monitoring coastal water quality, 2. Monitoring Harmful Algae Bloom, 3, Catch estimate, 4. Reporting illegal, Unreported, Unregulated (IUU) fishing, and 5. Monitoring floating debris (including plastics). Although the Covid pandemic impacted the progress of the project, Dr. Makino reported the team successfully conducted seasonal field monitoring from May 2022 to Feb 2023 and implemented an MOU to facilitate the continuation of the project (photo). See **Appendix A1** Project Summary Report for the details.

SB asked about the long-term daa policy of the Ciguatera project, and Dr. Makino confirmed the project plans to store the data in the National Oceanographic Data Centre in Indonesia.

4.2.2. New PICES/MAFF Project: Creating a phytoplankton-fishery observing program for sustaining local communities in Indonesian coastal waters

Upon the successful completion of the predecessor projects, FishGIS and Ciguatera, PICES and MAFF planned the following 3 yr project on "phytoplankton-fishery observing for sustaining local communities in Indonesian coastal waters". Dr. Makino and PICES/MAFF project coordinator, Dr. Alex Bychkov introduced the background and implementation plan and asked SB to recommend GC approve the launch of the new project. Dr. Bychkov explained that upon the GC approval, two co-chairs would be selected: one from HD and one from S-HAB, and that Project Science Team (PST) members would be appointed from several standing Committees. See **Appendix A2** for Project Principles (already reviewed and supported by MAFF/JFA) and Project Profile.

Background and Objective
In December 2022, The Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan offered to provide funding for a new 3-year PICES project for 2023-2026 following the Ciguatera project. The ideas of the proposal for the new project were discussed during the final Ciguatera PST meeting held in mid-March in Yokohama, Japan.

The objective of this project is to establish, in collaboration with local fishermen and research institutes and universities, a phytoplankton-fishery observing program in coastal Indonesia by integrating the FishGIS application, developed and refined during the previous two PICES/MAFF projects (2017–2023) with existing automated technologies for detection of toxic benthic Harmful Algal Bloom (HAB) species. The longer-term goal is to provide local communities with the capacity and knowledge to sustainably manage their fisheries resources and ensure seafood safety. The project also aims to identify potential research needs for deploying the FishGIS application in PICES member countries.

SB recommended GC approve the implementation of the new project.

Agenda Item 5: PICES 2023 and upcoming PICES Annual Meeting

5.1. PICES-2023

PICES Executive Secretary, Dr. Sanae Chiba updated the schedule of PICES-2023. She clarified with SB members the new protocol of EGs and Committee business meetings: All EG are to hold one online business meeting before PICES-2023 as a default but could hold one additional in-person meeting during the annual meeting upon making a request, and Committees hold one online pre-PICES-2023 business meeting and one in-person meeting at PICES-2023 as a default. ***SB reviewed the proposed in-person business meetings from EGs (see the table next page) and recommended GC for approval.***

Date: Oct 20-27, 2023,
Location: Seattle, USA, Venue: The Westin Seattle

PICES-2023 Schedule

Pre-meeting timeline (tentative)	
April 22 – June 15	Abstract submission & Financial support application
July - August	Confirmation of speakers, Finalization of Sessions / Workshop schedule
Mid-August – Sept. 15	**Online** EG Business meetings to prepare; Activity Reports & Requests for SB-2023 & Session/WS proposal for PICES-2024
Sept. 20 – Oct. 10	**Online** Committee/FUTURE business meeting to review; EGs Activity Reports & Requests for SB-2023 and Session/WS proposal for PICES-2024

PICES-2023 schedule			
Oct 20 (Fri)	Day	4 Parallel Workshops	in-person EG business meetings (1-2 per day)
Oct 21 (Sat)	Day	4 Parallel Workshops IPHC Special Session	
	Evening	Committee Business Meetings x 3 (hybrid)	
Oct 22 (Sun)	Day	5 Parallel Workshops	
	Evening	Committee Business Meetings x 4 (hybrid)	
Oct 23 (Mon)	AM	Opening Ceremony & Keynote talk (s)	
	11AM-	S1: Science Board Symposium	
	Evening	Welcome reception	
Oct 24 (Tue)	Day	4 Parallel Topic Sessions,	in-person EG business meetings (1-2 per day) F&A meeting Day 1&2 (0.5 day) on Oct 24 and 25 (hybrid)
	Evening	Sports event (TBA)	
Oct 25 (Wed)	Day	4 Parallel Topic / Paper Sessions	
Oct 26 (Thu)	Day	4 Parallel Topic Sessions	
	Evening	Poster Session	
Oct 27 (Fri)	AM	4 Parallel Topic / Paper Sessions	
	Noon	Closing Ceremony	

	PM	SB Meeting Day 1 (hybrid)	
	Evening	Chair's reception	
Oct 28 (Sat)	Day	SB Meeting Day 2, GC Meeting Day 1 (hybrid)	
Oct 29 (Sun)	Day	GC Meeting Day 2 (hybrid)	

Requests of in-person EG Business Meetings

EGs	Date	Duration (day)	Rationale for having an on-site meeting
AP-ECOP	Oct 22	0.5 or less	Provide us with an opportunity to meet each other in person and coordinate on the group logistics for our ECOP engagement(s) at PICES 2023 (mentorship, joint workshops, communication platform between ECOPs, networking session, etc.)
AP-UNDOS	Except Oct 21	1.0	Coordinate activities for the upcoming year
SG-ARC	Oct 20 or 21 or 22	1.0	WGICA* Annual (hybrid) meeting in cooperation with SG-ARC and WG44 on 20-22, October 2023, Seattle, USA. *WGICA: ICES/PICES Joint working group on Integrated Ecosystem Assessment of the Central Arctic Ocean
WG47	Oct 24 or 25	0.5	WG47 began during the COVID-19 pandemic and relative few members participated in PICES 2022. So, an in-person business meeting is important for WG47 to be connected.
WG44	flexible	1.0	Important for finalizing complicated conceptual models and agreeing on next steps and responsibilities for completing work
AP-NIS	Oct 24	1.0	AP-NIS has some technical issues to discuss that are complex and will take longer than typical virtual meeting allows.
WG46	Oct 24	0.5-1.0	A face to face meeting should be organized at the end of 2023 to take stock of what WG 46 has accomplished over the past three years and discuss future activities which contribute to completing the Terms of Reference (ToR).
New PICES/MAFF project	Oct 20	1.0	Kick-off meeting of the new projects (upon GC approval at IGC-2023).
FUTURE	flexible	1.0	
WG49	flexible	0.5	
AP-CREAMS	Oct 22	0.5 or 1.0	

5.2. PICES-2024

Dr. Chiba updated the progress in PICES-2024 planning. She explained that GC would discuss the best option and decide on the location and style (in-person, online etc.) at the IGC meeting held online on May 30/31, 2023.

The expected rough timeline is as follows:

- May 2023: GC decides the location and style of PICES-2024
- Jun-July 2023: PICES-2024 basic plan will be announced.
- Aug 2023: Call for Session and Workshop proposal

5.3. PICES-2025

Dr. Chiba noted that Japan has confirmed to host PICES-2025. Meeting details will be updated in due course.

Agenda Item 6: PICES External Review

PICES Executive Secretary, Dr. Sonia Batten, provided a brief overview of the PICES External Review panel process.

Background
In January 2022, Study Group: External Review of PICES (SG-ER) was established with the consideration of GC on the need to commission a review of PICES to ensure that it is evolving in line with global marine science priorities and to give confidence to Contracting Parties that their resources are effectively used (2021/A/10). The SG members consist of PICES Chair, PICES Executive Secretary and one member from each member country.

Update
SG is nominating the candidates of the External Review Committee members, and once GC agrees on the list and procedure, the members will be invited and the review will take place, later in 2023 and in 2024. PICES Executive Secretary will update the information in due course.

Agenda Item 7: Awards

PICES Award Selection Committee, which consists of PICES Chair and SB members chose the award recipients for the Wooster, POMA and the Zhu-Peterson awards. The awardees will be recognized during the awards ceremony to take place during the opening ceremony of PICES-2023. Note: Information on the awardees is confidential until PICES-2023.

Agenda Item 8: Basin Events to Coastal Impacts (BECI) Project update

Dr. Batten provided a briefing and update of progress in the BECI Project. SB members asked about possible BECI and SmartNet relevance, and Dr. Batten responded that, though highly relevant, it would need more time to figure out how SmartNet and BECI could effectively synergise the activities of these two programs.

Background:
At SB 2021, Science Board Recommends that PICES support the continued development of the BECI project proposal and that NPAFC/BECI be requested to submit a full proposal for PICES consideration as a PICES Special Project.
Council approved continued development of the NPAFC/BECI program, and that NPAFC/BECI be requested to submit a full proposal for consideration as a PICES Special Project (GC 2021/S/5). Once approved as the Special Project, it would last for the duration of the UNDOS.

Update:
The Basin Events to Coastal Impacts (BECI) project, an endorsed project of the UN Decade of Ocean Science was

co-proposed by North Pacific Anadromous Fish Commission (NPAFC) and PICES Presentations were given to many PICES expert groups and Governing Council at PICES-2022 about the project and received endorsement to continue its development.

In March 2023 the coordinating team convened a science plan development workshop in Victoria, BC, with over 25 people participating in-person and online to collaborate for several days on this task. Although visa processing delays and other travel challenges prevented some invitees from participating at the last-minute PICES member countries were well represented and specialists in disciplines covering modelling and observations, in physical oceanography through lower trophic levels to salmon, were present.

The workshop was supported by many organizations and PICES is very grateful to the following for their support: The Columbia River Inter-Tribal Fish Commission (CRITFC), Fisheries and Oceans Canada (DFO), NOAA Fisheries, the North Pacific Fisheries Research Board (NPRB), the North Pacific Anadromous Fish Commission (NPAFC), the Pacific States Marine Fisheries Commission (PSMFC) and the Tula Foundation.

Significant progress was made on the format and content of the Science Plan during the week, to connect state of the art climate and oceanographic models to fisheries management, with special reference to Salmon, in the NE Pacific. Work is ongoing to revise the text and will be sent out for review by the participants shortly, before wider circulation to the community to obtain feedback. <u>A proposal for initial funding submitted to the BC Salmon Restoration and Innovation Fund was approved just before ISB-2023</u>. The fund may help the process for BECI to become a PICES Special Project, but more discussion will be needed for determining the details.

Participants of the BECI science plan development workshop, March 2023.

Agenda Item 9: Scientific and Technical Mid-Year Reports

Science Board, FUTURE and Committees reported scientific achievements and progress of TOR of their respective Children Expert Groups since PICES 2022 (~5 min for each EG). Committees also updated their specific achievements if applicable.

Notes and Discussion on some EGs Reports

AP-SciCom

SB members asked Secretariat about the progress of the PICES website renewal. Dr. Batten answered the planning was in progress but there were issues to sort out, including resources and time of the staff.

AP-ECOP

AP-ECOP co-chair, Dr. Raphael Roman introduced the recently launched online demographic survey of ECOPs who attend the PICES Annual Meeting and PICES-sponsored international conferences. The survey data will be shared in the PICES community.

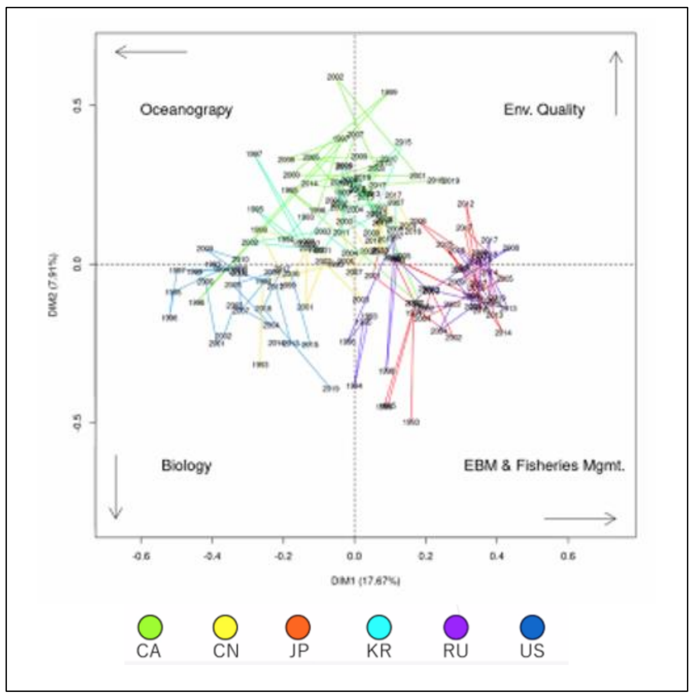
AP-NIS

TCODE Chair, Ms. Jeanette Gann asked about the data policy of AP-NIS. TCODE will ask AP-NIS to include their database in the TCODE database directory.

WG51: Exploring Human Networks to Power Sustainability

During Agenda Item 9, Dr. Makino, the Chair of HD (Parent Committee of WG51) presented the recent study result of WG51 on an analysis of PICES research topics and its variation among member countries (figure right) and decadal transition in a collaboration network of organizations in the PICES community. The study showed clear international differences in popular disciplines and a distinctive trend in the formation of more complex and denser networks from the 1990s to the 2010s.

He noted that the results help identify gaps and bridges for future collaboration among the PICES community and suggested it would lead to useful discussion for the development of the next (post-FUTURE) integrated science program. WG51 was still recruiting its membership, and SB members agreed to help to find the members.



WG42: Indicators of Marine Plastic Pollution
WG43: PICES/ICES Small Pelagic Fish
WG48: Towards best practices using Imaging Systems for Monitoring Plankton

These 3 WGs have been very productive but will end their terms at PICES-2023. SB members asked their respective parent Committees to ensure the timely delivery of WG Final Reports and confirm whether they will plan to develop new EGs builing upon the accomplishments of the present WGs.

SG-DATA

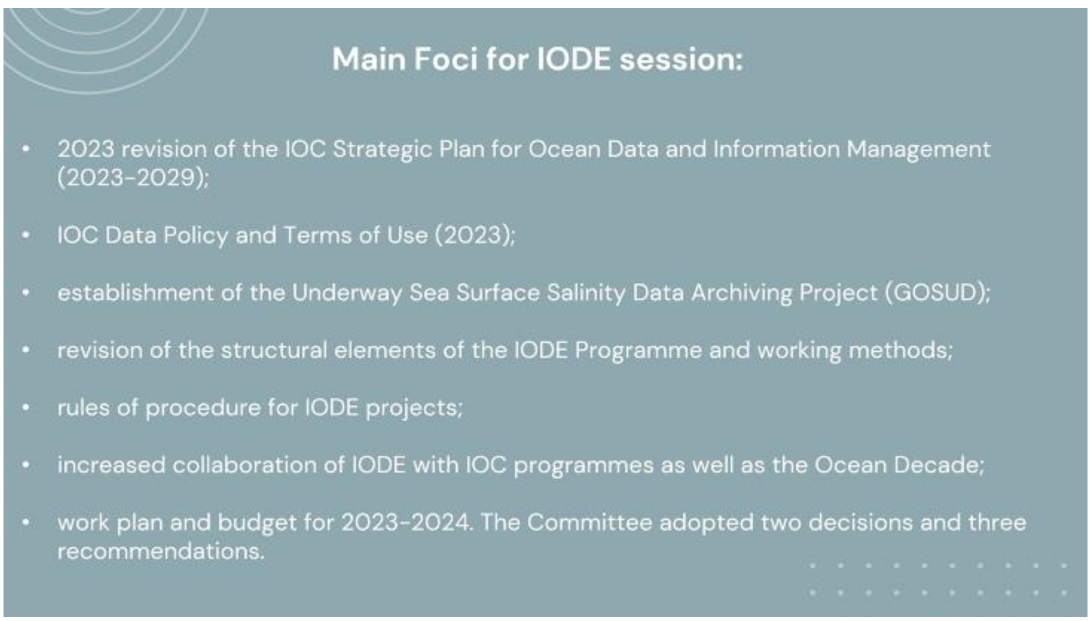
SB members asked for clarification of the PICES data policy. Ms. Gann answered that SG-DATA was considering tracking, pooling, and managing “PICES-specific” data collected by PICES member countries, to make data findable and accessible among PICES Community even if not available publicly.

Agenda Item 10: PICES data issues

10. 1. IODE Workshop Report

TCODE Chair, Ms. Jeanette Gann reported on the IODE Workshop she attended in late March 2023.

Background:
PICES was invited to the 27th Session of the IOC Committee on International Oceanographic Data and Information Exchange (IODE), from 22 to 24 March 2023 at UNESCO/IOC Headquarters (Paris, France). The Session focused on new developments in the field of oceanographic data and information management and exchange. Ms. Gann attended the Session representing PICES. The official meeting report is found here.



Report:
IODE invites all IOC programmes, IOC regional subsidiary bodies and partner organizations to collaborate by mobilizing their stakeholder communities to enter information into the IOC Ocean Data Information System (ODISCat) and to participate in ODIS Projects. Ms. Gann reported this would provide PICES with an opportunity to make PICES data more findable and accessible to the global community and suggested PICES add any projects to ODISCat. IOC/IODE Joint Open Access repository “Aquadocs” is becoming the official literature repository system for UNDOS, and PICES publications have been routinely input to Aquadocs.

10. 2. Proposal of introducing DOI to PICES publication

Ms. Gann presented the proposal for introducing DOI to PICES publications. Given the affordable cost of joining the scheme of Datacite Canada Consortium and the benefits in effectively discemінating ICES scientific accomplishment among wider communities, ***SB recommended GC approve the proposal*.**

Background:
During Dr. Batten's recent discussions with the Chair of the ICES Science Committee, it was suggested that there would be value in PICES issuing DOIs for its publications, to ensure the persistence of publication links. Secretariat asked TCODE to discuss on this issue during its business meeting and, if agreed, propose the introduction of DOI to PICES publication at ISB-2023.

What is a DOI?
DOIs provide a unique, persistent string of characters that identifies a specific publication and its location, in perpetuity. DOIs are created through a registration process, according to ISO standards, by Registering Agencies (RA's), who may be individual organizations, or consortia. The value of DOIs is that the "home address" of a DOI-issued publication remains constant over time. Citing a publication using its DOI should never result in a broken link. For PICES, this would mean that our publications would be "findable" over the long term.

How are DOIs registered?
To issue DOIs, Registering Agencies pay a fee to the *International DOI Foundation*, and are assigned batches of DOIs which can then be issued by the RA for specific publications.

In Canada, there are several RA's which provide DOIs, however, this can be costly, were PICES to directly purchase a block of DOIs to issue for its publications, as DOI blocks cost a minimum of €2000.00. However, a cost-effective solution exists in Canada: Datacite Canada Consortium organizes bulk purchases of DOIs, and then apportions smaller amounts of DOIs to consortium members, for a pro-rated fee, based on the quantity of DOIs to be registered. The purchase of DOIs is subsidized both through membership and by the data alliance.

Datacite: criteria, costs.
According to its website, www.crkn-rcdr.ca, the DataCite Canada Consortium is managed by the Canadian Research Knowledge Network (CRKN) and the Digital Research Alliance of Canada (the Alliance) as a global non-profit organization dedicated to making data and scholarly content more accessible and citable. This collective of organizations and institutions register DOIs in Canada via DataCite as its central RA.
PICES qualifies for membership in the consortium, as DataCite Canada is open *to "**all Canadian institutions** of higher education, **non-profit organizations**, and government research and funding agencies."* We have confirmed for DataCite that PICES has legal status in Canada. As a result, we would qualify to become a member of the consortium. Based on the number of DOIs we would require, PICES could become a member under Tier 1 membership of the DataCite consortium structure, able to issue up to **99 DOIs per year**, for an **annual fee of €60**, billable in Canadian Funds, based on current foreign exchange rates.

Joining DataCite may be one of the most cost-effective ways for PICES to be able to issue DOIs, as the consortium structure would allow us to save up to 90% on normal DOI costs by benefiting from subsidies provided by the Digital Research Alliance of Canada, as well as funding from the consortium fee model. Conversely, as noted above, if PICES wanted to instead purchase direct membership to be able to issue larger numbers of DOIs, the required annual fees of > €2,500 would be quite cost-prohibitive (i.e., *membership* fee of €2,000; *organization* fee of €500; *plus* DOI usage fees, based on quantity).

DataCite Structure and Subsidies:

Membership in a consortium such as DataCite Canada includes fewer fees because the entire consortium pays the ***annual membership*** fee of € 2,000, which is charged once to the entire consortium (rather than per member) and is fully covered by funds from the Alliance. Further to this, the annual *organization fee* and the *DOI* usage fees are combined into a (subsidized) capped fee per member.

What happens if PICES issues too many DOIs?
In the highly unlikely event that PICES were to issue >10,000 DOIs in one year, we would be directly billed €2,000, for our additional DOI usage.

How does PICES join the DataCite Consortium, and when would PICES be able to issue DOIs?
To join, PICES Executive Secretary would need to fill out the DataCite membership form, and, once approved, PICES would simply pay its Tier 1 invoice.

DataCite representatives would follow up with the PICES Executive upon joining to ensure that PICES has a robust stewardship plan for its DOIs, based on a proven ability to maintain an ongoing membership, or, to have a transfer plan in place for our DOIs in the unlikely event that the organization was no longer able to sustain our members and our DOIs.

Once PICES Membership in DataCite was approved and paid, this would allow PICES to initially issue DOIs for all of our back-catalogue publications (currently about 71 publications in all, including: Scientific Reports, Technical Reports, Special Publications). Once this back-catalogue work is completed, PICES could issue DOIs on an ongoing as-needed basis for PICES publications.

Agenda Item 11: EG Proposals for SB Recommendation with Funding Request

Dr. Chiba with respective Parent Committees Chairs reported EGs' proposals for SB recommendations.

11.1. Proposal for Travel Support

Note: Travel funding support for PICES scientist(s) to convene or attend international meeting(s) etc. Priority is given to ECOPs. PICES has a limited fund for travel support of ECOPs.

Because the date was too close for GC to make its decision, *TCODE withdrew the proposal.*

EG (reporting parent Committee): SG-DATA (TCODE)		
Conference title / Date / Location	Recipient name / organization / country / contact	Amount and rational of fund request
2023 Oceans Conference Limerick, Ireland 5-8 June 2023	Erin Satterthwaite, USA, UCSD, (esatterthwaite@ucsd.edu) *Upon her official membership and co-chairpersonship approval	(USD$4632) To support data management training at conference in partnership with CIOOS. US$1665 Air travel, $1400 Lodging, $920 Per diem, $357 conference reg., $300 ground transportation

11. 2. Proposal for Open Access Fee

SB recommended GC approve the paper as a PICES publication, WG38 Final Report and support Open Access Fee for its publication.

EG (reporting parent Committee): WG38 (POC)		
Paper Title	Note	Amount to request
Ueno et al. (2023) Review of oceanic mesoscale processes in the North Pacific: Physical and biogeochemical impacts. Progress in Oceanography 212. doi.org/10.1016/j.pocean.2022.102955	Upon GC approval as a PICES publication (see Agenda 15.1: Journal paper) POC reviewed and approved this review paper as the WG38 Final Report (see Agenda 15.2: Final Report) WG38 and PICES are acknowledged. "*This review is the outcome of the work of the Working Group 38 (Mesoscale and Submesoscale Processes) of the North Pacific Marine Science Organization (PICES)*"	US$ 3300

Reference: PICES 2016/A/13: Policy regarding funding support for Open Access Publication.

11. 3. Proposal for PICES Promotion Video Production

SB reviewed the proposal and valued the benefits of the proposal as a cost-effective method for PICES promotion and requested AP-SciCom to allow input from SB when designing the video contents, for example, SB wanted to include scenes (photos etc) with field observations.
SB recommended GC approve the production of PICES promotion video.

EG (Parent)	Proposal	Amount and rational of fund requested
AP-SciCom (SB)	Proposal to fund a videographer/filmmaker to attend PICES 2023, Seattle. See below for the details.	(CA$) 6000 See below for breakdown

Proposal to fund a videographer/filmmaker to attend PICES 2023

The Advisory Panel on Science Communication proposes to fund a videographer/filmmaker to attend PICES 2023 annual meeting. The objective of this contract is to produce three short videos (2-3 minutes long) that highlight PICES science and serve as a tool to educate, inform, and inspire a broader community.

Examples of the videos could include showcasing one or two of the workshops, highlighting the work of ECOPS, or showcasing a unique story that occurs when PICES membership comes together. We are open to the videographer's unique suggestions on what types of films would be engaging.

To cover the necessary expenses associated with producing these videos, we have proposed a budget in Canadian dollars. The proposed budget includes **$350 for transportation**, **$1,250 for accommodation** (at a rate of $250 per night for five nights), **$500 for food per diem** (at a rate of $100 per day for five days), and **$1,300 per film for production costs** (shooting, post-production, equipment rentals, etc.), totaling **$3,900** for 3 films.

In total, the budget for this project is **$6,000**. The resulting videos will serve as a powerful tool to promote PICES science, and we are confident that this initiative will yield significant benefits for PICES.

Agenda Item 12: EG Proposals for SB Recommendation without Funding Request

Dr. Chiba with respective Parent Committees Chairs reported EGs' proposals for SB acknowledgement or recommendations.

12. 1. Membership Needs/Changes

SB acknowledged the membership requests of all EGs. SB is concerned about the delay in the membership appointment which has seriously been hindering the EG activities and urges the national delegates to consider the appointment of new members at an appropriate time. There were still confusion and complaint among SB, Committees and EGs on the procedure of membership appointment, and Dr. Batten clarified the procedure.

EG (Parent)	Country	Names, Organizations if identified *Names in red: previously requested at PICES-2022 *Green: Added during IBS-2023	e-mail
AP-SciCom (SB)	Russia	1-2 members	-
AP-UNDOS (SB)	Korea Canada Russia Ex-Officio	Sukyung Kang (NIFS) Hanna Na (SNU) Sinjae Yoo (KIOST) Raphael Roman (IOC) ECOP Khush Jhugroo (Hakai Institute) ECOP Evgenia Kostianaia (UNDOS) ECOP 1 from Asia-Pacific Network TBD	sukyungkang@korea.kr hanna.ocean@snu.ac.kr sinjae.yoo@gmail.com raphael@ecopdecade.org khush.jhugroo@hakai.org e.kostianaia@unesco.org
AP-ECOP (FUTURE)	Russia	Nikita Aleksandrovich Chikanov (St. Petersburg State University)	erjey_nik@mail.ru
WG49 (FUTURE)	Ex-Officio Canada	Shoshiro Minobe (Hokkaido Unv) As ex-officio member of WCRP's Light House Activity (LHA), Explaining and Predicting Earth System Change (EPESC). Jennifer Jackson, DFO (Canada)	minobe@sci.hokudai.ac.jp Jennifer.Jackson@dfo-mpo.gc.ca
S-CCME (FIS)	Canada	A member to replace Jackie King * Patrick O'Hara agreed	-
WG43 (FIS)	Ex-Officio	Dr. Kazuhiro Oshima, NPFC representative, replacing Oleg Katugin (based on NPFC request Nov. 2022).	oshima_kazuhiro28@fra.go.jp

WG50 (POC)	Russia Canada Japan	Nikita Aleksandrovich Chikanov (St. Petersburg State University) Sergey Prants (Pacific Oceanological Institute, Department of the Ocean and Atmosphere Physics) Jody Klymak (Unv Victoria) Takeyoshi Nagai (Tokyo Univ of Marine Sci & Tech)	erjey_nik@mail.ru prants@poi.dvo.ru jklymak@uvic.ca tnagai@kaiyodai.ac.jp
SG-DATA	USA Russia Canada Korea	Hernan Garcia (NOAA) Jeanette Gann (NOAA) Jill Prewitt (AOOS) Erin Satterthwaite (UCSD) ECOP Igor Shevchenko (TINRO) and 1 more member Tim van der Stap (Hakai Institute) Brett Johnson (Hakai Institute) ECOP Shelee Hamilton (DFO) Trajce Alcinov (DFO) 2 members	Hernan.Garcia@noaa.gov jeanette.gann@noaa.gov prewitt@aoos.org esatterthwaite@ucsd.edu igor.shevchenko@tinro-center.ru tim.vanderstap@hakai.org brett.johnson@hakai.org Shelee.Hamilton@dfo-mpo.gc.ca trajce.alcinov@dfo-mpo.gc.ca
FUTURE	All Canada	1 ECOP from each member country. Mackenzie Mazur (DFO)(ECOP) Philina English (DFO)(ECOP)	
SG-GREEN	China Russia USA	1-2 members 1-2 members Jeanette Gann	 jeanette.gann@noaa.gov
WG51	Canada	Raphael Roman (IOC) ECOP	raphael@ecopdecade.org
TCODE	Ex-Officio	Toru Suzuki (IODE) replacing Yutaka Michida. *Toru Suzuki is stepping down as TCODE Japanese member upon his appointment as the IODE ex-officio,	suzuki@mirc.jha.jp

12. 2. Change of EG Chairs

SB reviewed the requests and recommended GC approve the changes.

EG (Reporting Committee)	Current Chair to replace	New Chair Name/Country/Organization
SG-ARC (SB)	Alison Deary (*officially not approved by US delegates)	Zack Oyafuso, USA, NOAA, Zack.Oyafuso@noaa.gov
SG-GREEN (SB)	New (2nd chair)	Hiroya Sugisaki, Japan, FRA, sugisaki_hiroya13@fra.go.jp
SG-DATA (TCODE)	New	Herman Garcia, USA, NOAA (Hernan.Garcia@noaa.gov) Erin Satterthwaite, USA, UCSD (ECOP) (esatterthwaite@ucsd.edu) * Herman and Satterthwaite regularly outside of larger group meetings to discuss direction and logistics for the group. *upon membership approval

Note: Selection and approval of EG Chairs (PICES Rules and Procedures: Rule 17)
WG Co-Chairs are selected from the membership by SB for approval by GC to serve for the life of the group.

SG Chair(s) are selected by Council if the group reports directly to the Council, or nominated by an executive committee and approved by the Council if the group reports to an executive committee. The Chair or Co-Chairs serve for the life of the group (typically one year);

AP Chair(s) are selected from the membership by SB, for approval by GC to serve for a period to be determined by SB

12. 3. Change of TOR

SB reviewed the changes of TORs and recommends GC approve them.

EG (Reporting Committee)	TOR, Action Plan or Term	Note
WG49 (FUTURE)	TOR	**No. 5 (old)** Identify a set of social, economic, and cultural indicators that account for the suite of human dimension impacts from climate extremes. **No. 5 (Revised)** Evaluate tools that relate climate extremes to impacts on ecosystem services and human communities, and, encourage the development of such models in member countries.
WG44 (HD)	Deliverables:	**Old** Year 1 Deliverables: • Inventory of metadata, knowledge, institutions and programs relevant to the Northern Bering Sea-Chukchi Sea LME. PICES or ICES Report. Web-based repository. Year 3 Deliverables: • Integrated Ecosystem Assessment for the Northern Bering Sea-Chukchi Sea LME. PICES or ICES Report. Contribution to NPESR. PAME-AMAP-CAFF Report. Contribution to Arctic Report Card. • Journal articles • Outreach activities • Knowledge Gap and Next Steps Report. PICES or ICES Report. **New** 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. Knowledge Gap and Next Steps Report. PICES Report and/or Journal article.

12. 4. Extension of WG term

SB reviewed the rationale of extension needs and recommended GC approve the requests.

EG (Parent)	Duration	Rationale
SG-GREEN (SG)	1 year (to ISB-2024)	SG has not met TOR. This SG has been slow to find members. Also the Chair, Trainer has started a new job with the University of Washington (1 Jan 2023) and hasn't had time to assemble the members for discussion. We request an extension of this study group.
WG47 (BIO)	1 year (to PICES-2024)	We anticipate a short delay (1-2 years) in completing all tasks outlined in WG47's TOR due to delays associated with the COVID-19 pandemic.
WG45 (FIS)	1 year (to PICES-2024)	ICES approved the new resolution to allow the next three years activity of WGGRAFY. Because of the effects of COVID-19, WG-45 in PICES needs one-year extension to accomplish the TORs.

12. 5. New Expert Group Idea

SB acknowledged the planning of the new Expert Group ideas which are expected to be proposed at PICES-2023.

Name of EG	Parent Committee	Background and Goals
Advisory Panel Study on the Arctic Ocean and the Pacific Gateways (AP-ARC)	TBD	Develop from WG39 and WG44 based on the recommendation to be made by SG-ARC. Chairs: Sei-Ichi Saitoh (WG39) (Japan), Hyoung Chul Shin (WG39) (Korea), Zack Oyafuso (USA) and Sarah Wise (WG44) (USA)
TBD Post-WG43 EG	TBD	The extended term of WG43 is coming to a close in fall of 2023. Members of the working group are discussing the advantages of forming a new group to continue to build upon the inter-basing collaboration with ICES (and potentially other organizations), and discussions are already underway for a potential small pelagic fish symposium. However, the discussions have not yet reached the point where we are yet able to offer a proposal for another expert group. We plan to do so before the fall Annual Meeting.

Agenda Item 13: PICES Sponsoring Conference/Symposia

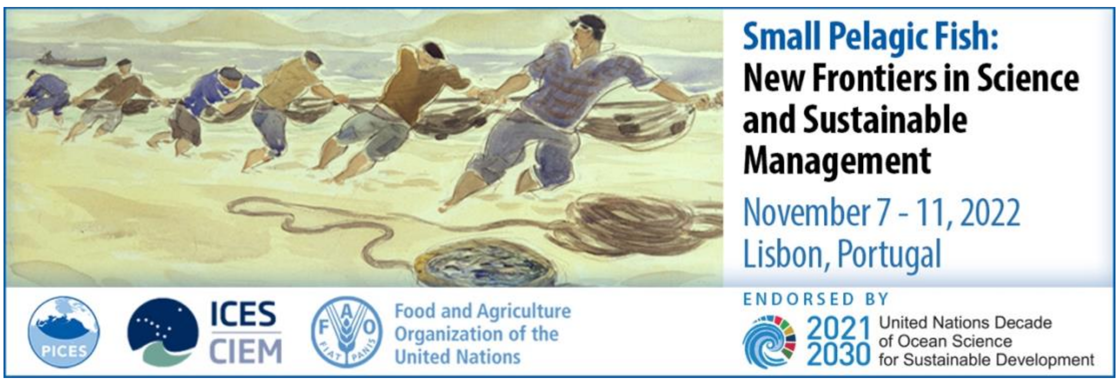
Dr. Chiba updated information on PICES-Sponsored International Conferences and Symposia which took place or are upcoming from 2022 to 2025. The symposium coordinator of Small Pelagic Fish 2022, Dr. Bychkov, presented the proposal for the next Small Pelagic Fish Symposium to be hosted by Mexico in 2026 (13.8).
SB reviewed the proposal and recommended GC approve the plan and PICES's sponsorship of the SPF-

2026 symposium.

List of International Symposia

1. International Symposium on Small Pelagic Fish, **Nov. 2022** Lisbon, Portugal
2. Effects of Climate Change on the World's Ocean (ECCWO), **Apr. 2023**, Bergen, Norway
3. ICES Annual Science Meeting, **Sept 2023**, Bilbao, Spain
4. Ocean Sciences Meeting (OSM) 2024, **Feb 2024,** New Orleans, USA
5. 9th World Fisheries Congress **Mar 2024**, Seattle, USA
6. 7th International Zooplankton Production Symposium, **Mar 2024**, Hobart, Australia.
7. MSEAS: Marine Socio-Ecological Systems Symposium, **June 2024**, Yokoyama, Japan
8. International Symposium on Small Pelagic Fish, **2026**
9. 5th Early Career Scientists Conference, **2027**

13. 1. ICES/PICES/FAO International Symposium on Small Pelagic Fish (SPF) 2022



- Local Organizer: Portuguese Institute of Sea and Atmosphere (IPMA), Calouste Gulbenkian Foundation
- Venue: Calouste Gulbenkian Foundation

PICES Member involvement:

WGSPF/WG43**:** ICES/PICES Working Group on Small Pelagic Fish (WGSPF/WG 43)

** 3-day meeting of WGSPF is planned immediately after the symposium*

Symposium Convenor: Ryan Rykaczewski (USA), Akinori Takasuka (JPN)

SSC: many PICES Scientists

Coordinator: Alexander Bychkov

See **Appendix B1** and articles in PICES Press Vol.3.1. No. 1 for the details.

13. 2. ECCWO5

- Primary Sponsor: ICES, PICES, IOC, FAO,
- Venue: Radisson Blu Royal Hotel
- Local host: Institute of Marine Research, Norway
- Session/Workshop information (link)
- SCOR supported the travel of ECSs (US$ 5000).
- Conference Style: Hybrid

PICES Member involvement:
Symposium Convenors: Sonia Batten (Executive Secretary)
SSC: Emanuel Di Lorenzo (USA), Mitsutaku Makino (Japan), Tsuneo Ono (Japan), Erin Satterthwaite (USA)

Conference Statistics
19 Theme Sessions, 4 Workshops, 9 Plenary talks, 186 Posters
Total attendees registered: 716 (in-person: 462, online: 254)
Female attendees: 55 %
Total number of countries represented: 71
(top 3 countries: USA: ca. 25%, Norway: ca. 15%, Canada ca. 7%)
* Detailed Report will be published in the coming PICES Press issue.

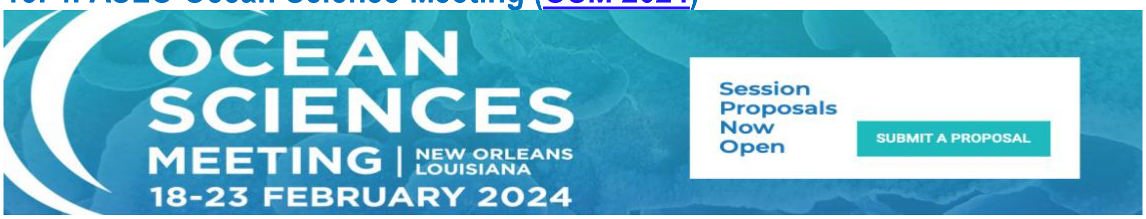
Conference Organisers at the symposium dinner venue, Haakon's Hall.

13. 3. 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)

13. 4. 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.
* Libby Logerwell (WG44 Chair) was a member at OSM-2022

- PICES will be provided with complimentary registration for the full Ocean Sciences Meeting for one person.
- Business meetings or space needs for PICES will be executed through the auxiliary events submission process.PICES would bear the cost of any AV or catering expenses and fees.
- If PICES produces an electronic ad or short presentation on its presence at the meeting, OSM24 will consider placement at the meeting of that piece.

13. 5. 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
- Abstract submission deadline: June 2023

PICES engagement: TBDUTAS

13. 6. 7th ICES/PICES Zooplankton Production Symposium 2024

- Date & Location: March 16-21, 2024, Hobart, Australia
- Venue: Hotel Grand Chancellor, Hobart
- Local organizer: University of Tasmania
- Sessions/Workshops under selection, call for abstracts: TBA

PICES Member involvement:
Organizing Committee: Batten, Chiba (Secretariat), Sastri (BIO)
SSC: Bi (WG48), Kobari (WG37),

13. 7. 2nd MSEAS Symposium

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

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

- Date & location: June 3-7, 2024, Yokohama, Japan
- Venue: Pacifico Yokohama North
- Primary Sponsors: PICES, ICES, NOAA Fisheries, FRA
- Local Organizer: FRA
- Sessions under revision, call for additional abstracts: TBA
  * Sessions and abstracts previously approved for MSEAS-2020 are regarded as placeholders.

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

13. 8. ICES/PICES/FAO International Symposium on Small Pelagic Fish (SPF) 2026

Proposed Plan

- Date: March or April 2026
- Location: La Paz, Mexico
- Venue: TBD (for ~400 participants)
- Local logistic support: CICIMAR, CIBNOR, CICESE, UABCS, etc.
- Local sponsors: National Science Council (CONACYT), the National Fisheries and Aquaculture Institute (INAPESCA) National Fisheries Management Body (CONAPESCA), etc.
- Local organizing committee: multi-institutional, TBA

See **Appendix B2**: Proposal to host SPF-2026 for the details, and Support letter from the ICES Co-Chairs of the ICES-PICES Working Group on Small Pelagic Fish.

13. 9. 5th ICES/PICES Early Career Scientists Conference (ECS) 2027

ICES and PICES are the main organisers of ECS, taking 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 14: Capacity Development Events

Dr. Chiba updated information on Capacity Building Events organized by PICES partner organizations upcoming from 2023 to 2025. . ***SB reviewed the information and recommended GC approve fund 14.3. IMBeR ClimEco8 Summer School for travel support of participants from PICES countries.***

14. 1. SCOR Capacity Development (link)

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 Organization)
  - Funded US$ 6K for participants of the 2022 International ECS Conference (July 2022)
  - Funded US$ 5K for participants of 5th ECCWO (Apr. 2023)

14. 2. SOLAS Summer School 2023

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

NOTE: The travel support for SOLAS Summer School 2021 was approved at GC2020, and GC approved to defer the funding support to 2023 at IGC 2022.

14. 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 funds CA$ 5000 for travel support of 2 participants from PICES countries (Canada and China).

14. 4. ICTP/CLIVAR Summer School on Marine Heatwaves: Global Phenomena with Regional Impacts (Link)

Date and Location: July 24-29, 2023, Trieste, Italy
Abstract: closed
PICES funds: TBD

14. 5. GOOD-OARS Summer School

November 6 – 12, 2023, Coquimbo-La Serena, Chile
OARS (Global Acidification Research for Sustainability), GOOD (Global Ocean Oxygen Decade)
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.

Agenda Item 15: Publications update (Chiba, 20 mins)

15. 1. Peer Reviewed Journal Papers (published)

SB reviewed the papers and recommended GC approve these papers as PICES EGs' products to be posted on the PICES website.

EG (Parent)	Citation
WG44 (HD)	Datsky A.V., Sheybak A.Yu., Chikilev V.G. Chukchi Sea — new walleye pollock fishing area. Trudy VNIRO. 2022;189:162-179. (In Russ.) doi: 10.36038/2307-3497-2022-189-162-179
S-HAB	Boivin-Rioux A et al. Harmful algae and climate change on the Canadian East Coast: Exploring occurrence predictions of Dinophysis acuminata, D. norvegica, and Pseudo-nitzschia seriata. Harmful Algae. 2022 Feb 1;112:102183. DOI: 10.1016/j.hal.2022.102183
	Emam M et al. Gill and Liver Transcript Expression Changes Associated With Gill Damage in Atlantic Salmon (Salmo salar). Frontiers in Immunology. 2022;13. doi.org/10.3389/fimmu.2022.806484
	Esenkulova S et al. Indications that algal blooms may affect wild salmon in a similar way as farmed salmon. Harmful Algae. 2022 Oct 1;118:102310. DOI: 10.1016/j.hal.2022.102310

	Esenkulova S et al. Harmful Algae and Oceanographic Conditions in the Strait of Georgia, Canada Based on Citizen Science Monitoring. Frontiers in Marine Science. 2021:1193. doi.org/10.3389/fmars.2021.725092
	McIntyre L, Miller A, Kosatsky T. Changing trends in paralytic shellfish poisonings reflect increasing sea surface temperatures and practices of Indigenous and recreational harvesters in British Columbia, Canada. Marine Drugs. 2021 Oct 14;19(10):568. doi.org/10.3390/md19100568
	McKenzie CH et al. Three decades of Canadian marine harmful algal events: Phytoplankton and phycotoxins of concern to human and ecosystem health. Harmful Algae. 2021 Feb 1;102:101852. DOI: 10.1016/j.hal.2020.101852
	Rashidi H et al. Monitoring, managing, and communicating risk of harmful algal blooms (HABs) in recreational resources across Canada. Environmental Health Insights. 2021 May;15. DOI: 10.1177/11786302211014401
WG38	Ueno et al. (2023) Review of oceanic mesoscale processes in the North Pacific: Physical and biogeochemical impacts. Progress in Oceanography 212. doi.org/10.1016/j.pocean.2022.102955 *Upon CG approval, proposed as WG Final Report (see 15. 2)
FIS	Planas et al. (2022) Integrating biological research, fisheries science and management of Pacific halibut (*Hippoglossus stenolepis*) across the North Pacific Ocean. https://doi.org/10.1016/j.fishres.2022.106559
SEATurtle	Jo K et al. (2022) Possible link between derelict fishing gear and sea turtle strandings in coastal areas. Marine Pollution Bulletin. 185. doi.org/10.1016/j.marpolbul.2022.114240

15. 2. WG Final Report

SB reviewed and evaluated these papers, and recommended GC approve them as Final Reports of their respective WGs.

EG (Parent)	Type of publication & Title	Note
WG36 (FUTURE) Common Ecosystem Reference Points across PICES Member Countries	**PICES Science Report** Common Ecosystem Reference Points across PICES Member Countries **Appendix C**	Recommended at SB-2022 with GC approval pending. Under final editing by Secretariat.
WG38 (POC) Mesoscale and Submesoscale Processes	**Journal Review Paper** Ueno et al. (2023) Review of oceanic mesoscale processes in the North Pacific: Physical and biogeochemical impacts. Progress in Oceanography 212. doi.org/10.1016/j.pocean.2022.102955	WG38 and PICES are acknowledged. "*This review is the outcome of the work of the Working Group 38 (Mesoscale and Submesoscale Processes) of the North Pacific Marine Science Organization (PICES)*"
WG40 (FUTURE, POC) Climate and Ecosystem Predictability	**Journal Special Issue** North Pacific Climate and Ecosystem Predictability on Seasonal to Decadal Timescales. Ed: Minobe s. et. Al. Frontiers in Marine Science. Comprised of 15 contributed papers. (Approved as PICES publication at GC-2020) Editorial article: Minobe S. et al. (2022) https://doi.org/10.3389/fmars.2022.1111272	WG40 and PICES are acknowledged in Editorial: *"This Research Topic is organized by the Working Group on "Climate and Ecosystem Predictability", a joint working group between the North Pacific Marine Science Organization (PICES) and Climate and Oceans, Variability, Predictability and Change (CLIVAR)"*

15. 3. EG Final Report in Progress

SB acknowledged the status of WG Final Reports under progress and urged the respective parent Committees to ensure the WGs deliver their final reports without delay.

These Final Reports are in various stages (1. In preparation, 2. Being reviewed by parent Committee, 3. submitted to Secretariat, 4. previously approved by SB and nearly completed, 5. Published)

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 Under editing & formatting (except R19)	R11, R15, R16, R18, R20, R22, R23, R24 published online
WG37 (BIO) disbanded	**PICES Science Report No 63, 2022** Zooplankton Production Methodologies, Applications and Measurements in PICES Region	**Published** (task completed)	
WG36 (FUTURE) disbanded	**PICES Science Report** Common Ecosystem Reference Points across PICES Member Countries	3.5 **SB recommended**, need GC approval (See 15.3)	
WG38 (POC) To be disbanded	**Journal Review Paper** WG synthesis paper, Progress in Oceanography	**Published**, need GC approval (See 15.3)	
WG40 (POC/FUTURE) To be disbanded	**Journal Review Paper** WG Topic Issue, Frontiers in Marine Science	**Published**, need GC approval (See 15.3)	
WG41 (HD/FUTURE)	**PICES Science Report** Marine Ecosystem Services	1. In preparation	Draft submission by Feb 2023 => postponed
WG39 (SB)	**PICES Science Report**	1. In preparation	

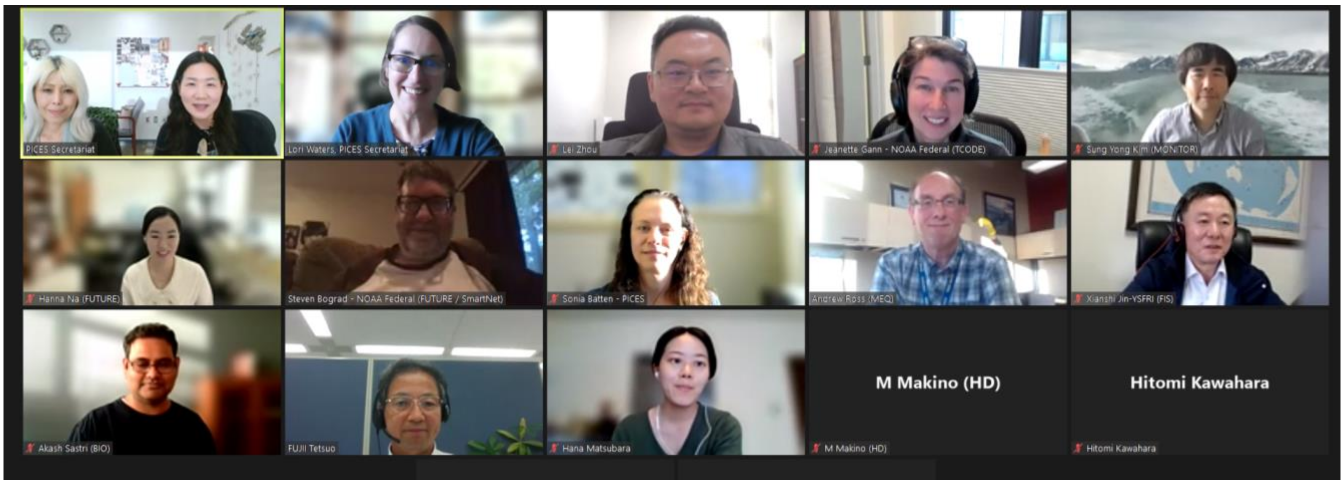
Note on the Protocol of WG Final Report Submission and the Timing of Disbandment of WG.
(agreed at ISB-2022)

- WGs are due to submit their final reports to the Parent Committees upon the end of the term. Science Board members wish to gently remind EG's that final reports are expected – particularly for those groups where GC has already extended their terms to complete their reports.
- The format of the final report will be typically a PICES Science / Technical Report (PICES Rule) but also could be in various formats such as Peer-reviewed Journal Special Issue, Peer-reviewed Journal Review Paper, etc.
- Definition: WG disbands upon the submission of its Final Report to the Secretariat after review and approval of Parent Committee(s).
  PICES Rule of Procedure 13: A WG shall be disbanded either after the preparation of its final report or as determined by the SB, for inadequate progress in achieving its tasks.

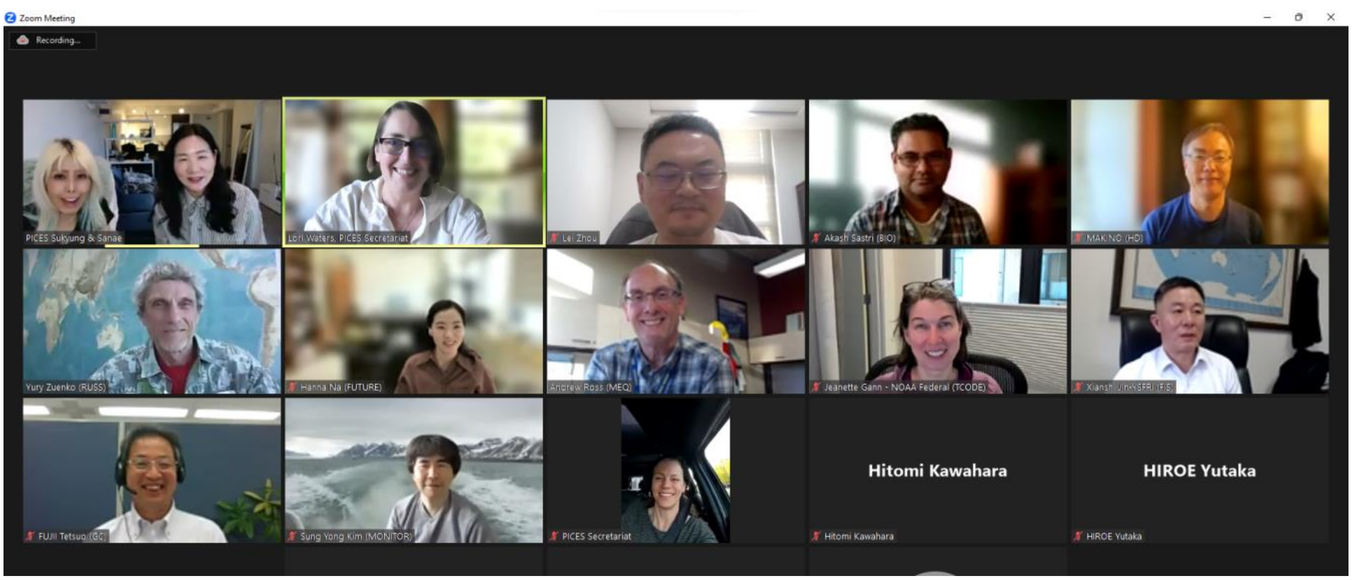
Agenda Item 16: Other Issue (Kang, 10 mins)

SB members to discuss the ideas of the structure and invited speakers for the Science Board Symposium (S1) to be held at PICES-2023.

//End of ISB-2023



Day 2 attendants (partial)



Day 3 attendants (partial)

Appendix A1

SUMMARY OF ACTIVITIES

The request from the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan to undertake the project "*Building local warning networks for the detection and human dimension of Ciguatera Fish Poisoning in Indonesian communities*" (a.k.a. Ciguatera) was approved by PICES Governing Council in February 2020.

Project background

Benthic HAB species, such as the causative organism underlying *Ciguatera Fish Poisoning* (CFP), arguably have the greatest human health and economic impacts of any algal-based poisoning syndromes. CFP stems from the human consumption of fish containing toxins produced by benthic microalgae of the dinoflagellate genera *Gambierdiscus* and *Fukuyoa*, which are the initial sources of ciguatoxin. The impact of CFP on the human dimension extends far beyond the proximate health and economic outcomes. Chronically impacted communities become fearful of local and other fish sources and transition from these traditional ways of life to one where protein is imported from foreign sources. CFP is endemic in many tropical Pacific regions. Although ciguatera and other toxin producing benthic HABs occur in pristine environments, anthropogenic pressures and climate change are leading to its emergence in new regions, and intensification in others. The expansion of dead corals and eel-grass habitats that replace healthy corals facilitates intrusion and establishment of toxin-producing benthic algae. Currently the health and socioeconomic effects of benthic HABs are poorly understood.

Indonesia was chosen as a developing Pacific Rim country to implement the project. Indonesia is part of the Coral Triangle, the most biodiverse marine area on earth, and these extensive reefs are key to maintaining the ecological products that contribute to fisheries in this region. However, presently only about 7% of these coral reefs are in excellent condition, while anthropogenic stressors have left more than 35% in poor condition. Decreasing coral health in Indonesia is a relatively new phenomenon comparative to other areas of the world, and the human populations living adjacent to the deteriorating corals are not yet fully aware of the consequences of this change. Current reports of benthic HAB occurrences such as CFP are low in Indonesia, almost certainly because diagnosis is difficult without proper training and experience.

Project objective and initiatives

The overall objective of the project was to build the capacity of local small-scale fishers and community members to monitor their coastal ecosystems and coastal fisheries to benefit human health in Pacific Rim developing countries. The project' focus was to detect and monitor benthic HAB species in tropical reef fisheries to ensure seafood safety.

Consistent with the directives of the United Nations Decade of Ocean Sciences for Sustainable Development (UNDOS), the project included three major initiatives:

1. Coastal ecosystem monitoring activities by local small-scale fishers and other community members to detect ecosystem changes (*e.g.*, changes in water quality and the presence and changes in the spatial distribution of dead coral and eel-grass benthic environments) using smartphone-based technology developed during the 2017–2020 PICES/MAFF project on "*Building capacity for coastal monitoring by local small-scale fishers*" (a.k.a. FishGIS);
2. Detection of CFP toxin-containing dinoflagellates in the reef environment using two approaches: (a) implementation of smartphone-based tools developed during the FishGIS project, and (b) employing internationally-standardized sampling protocols for toxic benthic algae.
3. Training of local fishers and community members to utilize these tools for generating citizen-science data available for local decision-making on coastal fisheries to avoid the transfer of contaminated fish to the tables of families until the presence of CFP toxin-containing dinoflagellates is minimized.

In addition to the primary initiatives, early steps have been taken to explore two secondary initiatives: modifying the FishGIS application to incorporate (1) artificial intelligence-based assessment of fish stocks from the collective catch data reported by the local fishers, and (2) a tsunami early warning notification for remote fishing communities, with the goal of laying the foundation for future full development of these capabilities.

Project funding

This 3-year (April 2020 – March 2023) project was funded by MAFF, through the Fisheries Agency of Japan (JFA), from the Official Development Assistance (ODA) Fund. A total MAFF contribution was $292,653 CAD.

Project organization in PICES

The project had strong connections and interactions with the PICES Scientific Committees on Human Dimensions (HD), Marine Environmental Quality (MEQ) (through the Section on Ecology of Harmful Algal Blooms in the North Pacific – S-HAB) and Fishery Science (FIS), PICES Technical Committees on Data Exchange (TCODE) and on Monitoring (MONITOR), and the PICES FUTURE Science Program (Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems) Science Program. The HD Committee was the parent committee for the project.

To direct the project, a Project Science Team (PST) was formed by PICES Science Board based on principles and procedures detailed in the PICES Policy for approval and management of special projects (Decision 2017/A/7).. All PICES member countries and were represented on the PST, co-chaired by Drs. Mitsutaku Makino (HD Committee Chair; Atmosphere and Ocean Research Institute, University of Tokyo, Japan) and Mark Wells (S-HAB Chair; University of Maine, USA). The PST Co-Chairs were responsible for the detailed planning and execution of the project, and annual reporting on scientific progress to MAFF/JFA and to Science Board through the HD Committee. During the lifetime of the project, the PST had seven formal meetings. Due to the COVID-19 pandemic, the first five meetings (all meetings in Year 1 and Year 2) were held online, and only the last two meetings in Year 3 (September 2022 in Busan, Korea and March 2023 in Yokohama, Japan) were in-person.

Dr. Alexander Bychkov was appointed to serve as the Project Coordinator and was responsible for fund management, and for the annual reporting to MAFF/JFA and to PICES Finance and Administration Committee.

Project support in Indonesia

The Ciguatera project was the fourth PICES project in Indonesia funded by MAFF, with its foundation being the strong collaborations with the Indonesian Agency for the Assessment and Application of Technology (BPPT) and the Indonesian Institute of Sciences (LIPI) (now reorganized into BRIN) developed over the previous three PICES/MAFF projects – "*Development of the prevention systems for harmful organisms' expansion in the Pacific Rim*" (2007–2012), "*Marine ecosystem health and human well-being*" (2012–2017; MarWeB), and "*Building capacity for coastal monitoring by local small-scale fishers* (2017–2020; FishGIS). Project activities also were supported through the Memorandum of Understanding between PICES and the Indonesian Institute of Technology (ITI) (signed in March 2022), and by the Provincial Government of West Nusa Tenggara, which provided invaluable assistance in organizing a training workshop in Lombok.

Activities and outputs

Project Design Matrix: A Project Design Matrix (PDM) and a Plan for Operation (PO) were developed by the PST to effectively manage the project. The PDM describes the logical structure of the project (the links between activities and objectives) as well as the quantitative data that will be obtained. This framework assists in the planning process, facilitates communication of the "why" and "how" of the project, and provides a basis for assessing the project progression. It is structured to list the *Project Goals* (to codify the overriding objectives), the *Project Purpose* (the intended impacts and anticipated benefits), the *Results/Outputs* (the objectives the project management must achieve and sustain), and the *Activities* (steps taken to achieve the desired results/outputs). However, due to COVID-19, we were unable to take full benefits from this approach as the pandemic seriously affected the flow and progress of this project, especially by limiting the opportunity for PST members to visit field sites and organize meetings and training workshops with local people. Only one training workshop was held close to end of the project, in January 2023 in Lombok. This successful workshop was attended by more than 90 researchers from BRIN, ITI, University of Indonesia, Mataran University and provincial institutions, and coastal community participants.

Observation tools: The 2017–2020 FishGIS project led to the development and implementation of smartphone tools (FishGIS application) for fisheries and environmental observations, such as water quality aspects, phytoplankton, fish catch, floating garbage (plastics) and Illegal Unregulated and Unreported (IUU) fishing, by local small-scale fishers and community members in Indonesia. The Ciguatera project was expected to adapt and refine these smartphone capabilities for measurement and automated reporting and combine them with new automated technologies for plankton species identification.

The updated version of the FishGIS application is now available on Apple Store and Google Play and can be installed on iOS 10 and Android 7 or later smartphone devices. The major modifications include:

- a reporting scheme that is consistent with ABS (Access to genetic resource and Benefit Sharing) rules of the UN Convention of Biological Diversity;
- an improved user interface;
- a function allowing direct launch the HydroColor water quality application;
- a function allowing to directly launch the Info BMKG application (officially provided by BMKG – Indonesian government agency for Meteorology, Climatology, and Geophysics) to better incorporate a tsunami early warning notification for remote fishing communities;
- a function to map Ciguatera field survey data and to accumulate fisheries-related data (as photos of fish species in local fish markets);
- a dashboard for data management.

Planktoscope is a low-cost microscope platform that allows automated image collection of phytopolankton cells in a simple flow-through system. These images are uploaded to a dedicated server where artificial intelligence software can be trained to identify and quantify the composition of the phytoplankton assemblage. This tool will revolutionize plankton monitoring and is particularly suited to this project. A successful pilot deployment of several Planktoscopes took place in the Gili Islands region during the January 2023 training workshop.

Field sampling program: Based on recommendations from our Indonesian colleagues, Gili islands region (West Nusa Tenggara Province) was selected as a case study site. The two criteria for selecting this site were the existence of a well-established local fishing community and an active BRIN research station in the area.

The field observation was to be carried out by local small-scale fishers and community members. However, the pandemic-related delays to the planned on-site training workshops led to augmenting and expanding BRIN-planned surveys of waters surrounding the Gili Island region (Gili Trawangan, Gili Meno, and Gili Air) to facilitate data collection. The initial survey design was shared with the PST, and modifications were jointly decided. A portion of Ciguatera project funds were re-directed to support a total of five extended surveys conducted in different seasons: May 23–28, 2022 (Transition I), August 1–5, 2022 (Dry Season), October 10–16, 2022 (Transition II), December 12–18, 2022 (Rainy Season) and February 20– 25, 2023 (end of Rainy Season). The smartphone-based FishGIS and HydroColor tools were actively used in these observations. In addition to water column and benthic samples, fish caught around Gili islands or Lombok were purchased for ciguatoxin analysis. Researchers from BRIN and Mataran University also collected the basic socio-economic information in the area using the same methodology as in the previous PICES/MAFF projects (on-site surveys, questionnaires, and focus group discussions). Analysis of samples is still ongoing, but preliminary results indicate that the threat of CFP in this area is low. These activities in Lombok area were widely reported by the Indonesian mass media. Two talks by Indonesian researchers were presented at the 2022 PICES Annual Meeting in Busan.

Considering that one of the main goals of the project is capacity building, the PST has agreed to support six undergraduate students from the University of Indonesia, Mataran University and ITI (two from each) to participate in the field sampling program by providing them partial tuition.

Risk assessment model: Finally, a bow-tie risk assessment model was constructed. This model summarizes the connections among coastal environment, ciguatoxins, human exposure to these toxins and the CFP risk, and demonstrates how the project's activities can prevent, adapt, and mitigate the risks.

Next step

Due to the COVID pandemic not all of the originally planned activities for the Ciguatera project have been implemented. Fortunately, a new 3-year project has been approved by MAFF, with expectation that one of major case study sites will be in Gili islands region, where a field sampling protocol has been already developed, preliminary network of local people and researchers has been set, and basic knowledge and technologies have been disseminated among the key people. The Provincial Government of West Nusa Tenggara has indicated strong interest and political will to assist to support activities of the new project.

Appendix A2

PRINCIPLES

1. A 3-year (April 1, 2023 – March 31, 2026) project, entitled "*Creating a phytoplankton-fishery observing program for sustaining local communities in Indonesian coastal waters*", is funded by the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan, through the Fisheries Agency of Japan (JFA), from the Official Development Assistance (ODA) Fund. The objective of the project is to build, in collaboration with local fishermen and research institutes and universities, a phytoplankton-fishery observing program in Lombok island region (Indonesia) using tools developed in the 2017–2020 PICES/MAFF project "*Building capacity for coastal monitoring by local small-scale fishers*" (a.k.a. FishGIS) and refined during the 2020–2023 PICES/MAFF project "*Building local warning networks for the detection and human dimension of Ciguatera Fish Poisoning in Indonesian communities*" (a.k.a. Ciguatera), to enable the detection of toxic benthic Harmful Algal Bloom (HAB) species that can threaten tropical reef fisheries. The long-term goal is to provide local communities with the capacity and knowledge to sustainably manage their fisheries resources and ensure seafood safety, and to identify research needs for deploying these tools in PICES member countries.

2. The maximum duration of the project is 3 years, with the ending date set as March 31, 2026.

3. The following organizational principles agreed to by MAFF/JFA and PICES apply to the project:
   - The project will have strong connections and interactions with, and support relevant activities of, the PICES Scientific Committees on Human Dimensions – HD, Marine Environmental Quality – MEQ (through the Section on *Ecology of Harmful Algal Blooms in the North Pacific* – S-HAB) and Fishery Science – FIS, PICES Technical Committees on Data Exchange – TCODE and on Monitoring – MONITOR, and the PICES FUTURE (Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems) Science Program (specifically, Research Theme 3 on "*How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?*"). The HD Committee will serve as the parent committee for the project.
   - The project will be directed by a Project Science Team (PST) formed based on principles and procedures detailed the PICES Policy for approval and management of special projects (Decision 2017/A/7). All PICES member countries and the above-mentioned groups are expected to be represented on PST.
   - The PST will be co-chaired by PICES members, with one Co-Chair from Japan, representing the Human Dimensions Committee, and another from the USA, representing the Section on *Ecology of Harmful Algal Blooms in the North Pacific*. These Co-Chairs will provide the geographical balance and the balance of expertise between the human dimension and harmful algal bloom components of the project. The PST Co-Chairs are responsible for the scientific implementation of the project and for the annual reporting to MAFF/JFA and to PICES Science Board through the HD Committee. This report should be submitted to JFA within 90 days after the close of each project year ending March 31, and include a summary of the activities carried out for the year, with an evaluation on the progress made, and a workplan for the next year.

4. The following financial principles agreed to by MAFF/JFA and PICES apply to the project:
   - A separate bank account shall be established to deposit the remitted funds.
   - The PICES Executive Secretary, or a Project Coordinator designated by the Executive Secretary, is responsible for the management of the fund and for the annual reporting on its disposition to MAFF/JFA and PICES Governing Council, through the Finance and Administration Committee, within 90 days after the close of each project year ending March 31.

- The main elements of the budget are organized into the following categories:
  - Travel and meetings – this category covers travel costs associated with project activities such as field studies, organizational trips, project meetings, workshops, scientific sessions and public events.
  - Contracts – this category covers grants/fees to be paid to consultants and experts employed to implement the project. Tasks and deliverables for contractors are to be determined by the PST Co-Chairs. To support the objectives of the project and to ensure that its activities have minimal impact on the workload of the existing staff of the PICES Secretariat, the Project Coordinator can employ additional staff as required.
  - Publications – this category covers costs associated with publishing findings of the project in special issues of peer-reviewed journals, reports and brochures, and dissemination of these materials.
  - Equipment – this category covers purchases and shipment of equipment for laboratory/field data/sampling processing/analysis, computer hardware/software for the development of database(s) and the project website.
  - Miscellaneous – this category covers expenses associated with the project (mail and phone charges, bank charges, *etc*.) and includes contingencies such as fluctuations in currency exchange rates.
- Transfers of up to 10% of allocations between the budget categories are allowed based solely on the decision by the PICES Executive Secretary or the Projects Coordinator. In special cases, transfers up to 20% between the budget categories can be authorized by JFA. All transfers shall be reported at the end of the fiscal year.
- A 13% overhead on the annual budget shall be retained by PICES to offset expenses related to the Secretariat's involvement in the project.
- The interest earned by the fund shall be credited to the project and used in consultation with JFA.
- Any funds remaining after the completion of every fiscal year of the project shall be reported and disposed of in consultation with JFA.

5. Ownership of the outcomes of the project, including materials, data, copyright and intellectual property rights, will be vested to PICES and the Government of Japan. Either Party may use those outcomes but will give full credit to their source.

North Pacific marine Science Organization (PICES)

Project "*Creating a phytoplankton-fishery observing program for sustaining local communities in Indonesian coastal waters*"

The Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan has requested PICES to undertake a project entitled as "*Creating a phytoplankton-fishery observing program for sustaining local communities in Indonesian coastal waters*". The profile of the project is as follows.

Project objectives

This project will establish, in collaboration with local fishermen and research institutes and universities, a phytoplankton-fishery observing program in Lombok island region (Indonesia) using tools developed and refined during the previous two PICES/MAFF projects (2017–2023), to enable the detection of toxic benthic Harmful Algal Bloom (HAB) species that can threaten tropical reef fisheries. The long-term goal is to provide local communities with the capacity and knowledge to sustainably manage their fisheries resources and ensure seafood safety, and to identify research needs for deploying these tools in PICES member countries.

Project funding and duration

MAFF will provide funding for the project through the Fisheries Agency of Japan (JFA). This financial contribution is from the Official Development Assistance (ODA) Fund and thus, involvement of developing Pacific Rim countries in project activities is required.

The maximum expected project lifetime is 3 years: from the starting date of the project in 2023 to March 31, 2026. Funding for Year 1, ending March 31, 2024, is set at 7,750,000 JPY (~$76,000 CAD).

Connection to the previous PICES/MAFF projects

Two previous PICES/MAFF projects, "*Building capacity for coastal monitoring by local small-scale fishers*" (a.k.a. FishGIS; 2017–2020) and *"Building local warning networks for the detection and human dimension of Ciguatera Fish Poisoning in Indonesian communities"* (a.k.a. Ciguatera; 2020–2023), have led to the development and implementation of smartphone technology (FishGIS app) for fisheries and environmental observations, such as water quality aspects, phytoplankton, fish catch, floating garbage (plastics) and Illegal Unregulated and Unreported (IUU) fishing, by local small-scale fishers and community members in Indonesia. These smartphone capabilities for measurement and automated reporting, combined with new automated technologies for plankton species identification, are the foundation for the new MAFF project.

Project background and structure

Benthic HAB species, such as the causative organism underlying *Ciguatera Fish Poisoning* (CFP), arguably have the greatest human health and economic impacts of any algal-based poisoning syndromes. CFP stems from the human consumption of fish containing toxins produced by benthic microalgae of the dinoflagellate genera *Gambierdiscus* and *Fukuyoa*, which are the initial sources of ciguatoxin. The impact of CFP on the human dimension extends far beyond the proximate health and economic outcomes. Chronically impacted communities tend to become fearful of local and other fish sources and transition from these traditional ways of life to one where all protein is imported from foreign sources. CFP is endemic in many tropical Pacific regions. Although ciguatera and other toxin producing benthic HABs occur in pristine environments, anthropogenic pressures and climate change are leading to its emergence in new regions, and intensification in others. The expansion of dead corals and eel-grass habitats that replace healthy corals facilitates intrusion and establishment of exotic populations of toxin-producing benthic algae. Currently the health and socioeconomic effects of benthic HABs are poorly understood.

Indonesia is part of the Coral Triangle, the most biodiverse marine area on earth, and these extensive reefs are key to maintaining the ecological products that contribute to fisheries in this region. However, presently only about 7% of these coral reefs are in excellent condition, while anthropogenic stressors have left more than 35% in poor condition. Decreasing coral health in Indonesia is a relatively new phenomenon comparative to other areas of the world, and the human populations living adjacent to the deteriorating corals are not yet fully aware of the consequences of this change. Current reports of benthic HAB occurrences such as CFP are low in Indonesia, almost certainly because diagnosis is difficult without proper training and experience.

Communities must understand the risks of exposure to keep the impact of benthic HABs to a minimum. The highest risk is when the reefs, that communities depend on for fish, have large patches of dead coral or large seagrass mats, as these surfaces are ideal for the growth of benthic algal cells. The proposed project will offer technology-assisted, community-based training that drives community awareness of emerging problems, and will foster surveillance and management skills that can reduce the incidence of illness. Three levels of surveillance can engage communities in the maintenance of a healthy environment: the health of the corals, the biology of the benthic species, and the harvesting of potentially contaminated fish to the community.

The project strategy builds on successes of the 2020-2023 PICES/MAFF Ciguatera project and continues. The project foundation would be the robust collaborations developed over the previous four PICES/MAFF projects (conducted in the period from 2007 to 2023) with two Indonesian research institutions, now integrated into the Indonesian National Research and Innovation Agency (BRIN). Project activities also will be supported through the Memorandum of Understanding between PICES and the Indonesian Institute of Technology (ITI) (signed in March 2022), and by the Provincial Government of West Nusa Tenggara, which has demonstrated strong interest and political will to assist in project implementation. Potentially, the project will attract involvement of the Ministry of Marine Affairs and Fisheries, Ministry of Environment and Ministry of Culture and Tourism of the Republic of Indonesia.

Major initiatives

Four long-term goals guide this MAFF-funded initiative. First, consumers will come to rely on information from local communities and researchers about benthic HABs when purchasing marine goods or services. Secondly, the socio-economic basis of local communities will gain resilience by not depending on products with CFP risks. Thirdly, coral reef health, and signals of declining health, are better understood by developing nations. Through these capacity-building goals, coastal Indonesian communities can be sustainably improved, with less uncertainties and risks from CFP and degradation of coral ecosystems. The fourth long-term goal, and most directly relevant to PICES, is that lessons learned in this project inform and benefit PICES nations facing the emergence of climate-driven benthic range extension of HAB species into their marine systems.

The project is proposed to focus on the following major initiatives:

1. Provide a scientific basis to inform local communities about the influence of benthic HABs on their sustainable use of marine resources. This will be underpinned by developing a database from coastal ecosystem monitoring activities by local fishers and community members to detect ecosystems changes.
2. Develop automated image analysis strategies for quantifying fisheries-relevant information from image analysis of the smartphone application data collections. These data will be combined with known benthic HAB toxin vectors to inform risk assessments.
3. Detect the presence of toxin-containing dinoflagellates in the reef environment using two approaches: (a) implementation of smartphone and internet-capable automated microscope and species identification tools developed during the previous PICES/MAFF project, and (b) employing internationally-standardized sampling protocols for toxic benthic algae.
4. Training of community members to utilize these tools and collected data in local decision-making on coastal fisheries regions to avoid the transfer of contaminated fish from the damaged environment to the tables of families until the presence of CFP toxin-containing dinoflagellates is minimized.

Briefly, the project activities are expected to encompass conducting adequate surveys to obtain sufficient benthic HAB-related data/information, using these data to test multiple hypothesis regarding potential benthic HAB impacts and related marine environmental conditions (*e.g.*, locations, timings, particular fishes and syndromes in records of human health issues and local knowledges), and conducting background studies in the mechanisms of CFP and other benthic HAB syndromes to better risks associated with specific vectors (*e.g.*, fish species). We also plan to investigate alternatives for locals to sell/use fish with reduced risks, and to disseminate knowledge about CFP and related benthic HAB risks for local stakeholders along local supply chains. More broadly, we will attempt to co-create and visualize mitigation strategies with local community stakeholders to minimize negative impacts when they arise. Finally, we will help to design a benthic HAB warning strategy and provide technical guidance to local stakeholders to maximize the efficiency of economic activities.

To support these primary initiatives, annual capacity building workshops, led by scientists from PICES member countries, will be held in Indonesia. The purpose of the workshops is to work with local communities to increase the sustainability of their fishing resources by providing them with CFP information. The combination of training and citizen-science contributions in the project is expected to: (1) generate the needed capacity for monitoring CFP hotspots in Indonesian waters, (2) provide valuable datasets for the study of *Gambierdiscus, Fukuyoa* and other toxic benthic algae, along with the factors controlling its abundance in reef systems, and (3) increase human wellness by identifying fishing regions where the health of community members is at risk.

Besides the primary initiatives, four secondary initiatives will be explored during the project: (1) deploying several new low-cost compact, internet-capable flow-through microscope systems for rapid detection and quantification of pelagic and benthic phytoplankton, (2) developing image analysis libraries for rapid automated identification of toxic species within the generated datasets, (3) modifying the FishGIS smartphone application with preliminary steps towards artificial intelligence-based assessment of fish stock from the collective fish catch data reported by community members, and (4) refining the incorporation of the tsunami early warning notification component of the smartphone application to better communicate the relevant dangers to these remote fishing communities.

Anticipated publications and products

- A report will be published in the PICES Scientific Report Series that is built based on the results from the project including lessons learned.
- A summary of the report will be published as a brochure highlighting the project's purpose and findings for the general public;
- Several newsletter (PICES Press) articles will be contributed during the project period.
- Project training materials will be translated into Bahasa language to enhance sustained ongoing training activities by Indonesian government personnel and community leaders beyond the term of this project.
- The electronic database generated by these citizen-science data collection activities will be automatically uploaded to the Indonesian National Ocean Data Center.

Linkages within PICES and project organization

The project is expected to have strong connections and interactions with the PICES Scientific Committees on Human Dimensions (HD), Fishery Science (FIS), and Marine Environmental Quality (MEQ) (through the Section on *Ecology of Harmful Algal Blooms in the North Pacific* — S-HAB), PICES Technical Committee on Data Exchange (TCODE) and on Monitoring (MONITOR), and the PICES FUTURE (Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Ecosystems) Program (specifically, Research Theme 3 on "*How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?*"). The HD Committee is suggested as the parent committee for the project.

To direct the project, a Project Science Team (PST) will be formed based on principles and procedures detailed in the PICES Policy for approval and management of special projects (Decision 2017/A/7). It is anticipated that all PICES member countries and all the above-mentioned groups will be represented on the PST. Dr. Mitsutaku Makino (HD Committee Chair; Atmosphere and Ocean Research Institute, The University of Tokyo, Japan; mmakino@aori.u-tokyo.ac.jp) and Dr. Mark Wells (S-HAB Chair; University of Maine, USA; mlwells@maine.edu) are recommended to serve as PST Co-Chairs. This will provide the desirable geographical balance and the balance of expertise between the human dimension and harmful algal bloom components of the project. The PST Co-Chairs will be responsible for the scientific implementation of the project and annual reporting to MAFF/JFA and to PICES Science Board through the HD Committee. Within PICES, Science Board takes the task of reporting to Governing Council on the progress and achievements of the project.

The PICES Executive Secretary or a designated Project Coordinator will be responsible for the management of the fund and annual reporting on its disposition to MAFF/JFA and to Governing Council, through the Finance and Administration Committee. It would be advisable to retain Dr. Alexander Bychkov as the Project Coordinator as he has been integral to the organization and implementation of the previous three PICES/MAFF projects which have generated the key products that form the foundation for the proposed project.

Appendix B1

2022 International Symposium
on "Small Pelagic Fish: New Frontiers in Science and Sustainable Management"

http:/www.pices.int/smallpelagics2022

Dates and Venue

The international symposium "Small Pelagic Fish: New Frontiers in Science and Sustainable Management" was held November 7–11, 2022, at the Calouste Gulbenkian Foundation's Conference Center in Lisbon, Portugal.

Background/Purpose

Small pelagic fish (SPF) account for more than 30% by weight of the total landings of capture fisheries around the world. SPF populations of both marine and inland ecosystems are crucial for ensuring global food security. SPF also play an important role in the transfer of energy in food webs, so understanding processes affecting the dynamics of their populations, their role in marine ecosystems and how these shape robust management practices continues to be a high priority.

Research concerning SPF populations has flourished, in part, due to the history of comparisons among ecosystems from around the world. The 2022 SPF symposium was a cherished opportunity to advance that theme of international collaboration, particularly given the challenges to travel and social interactions that we have faced in the last several years. The symposium re-united a community of scientists and managers who aim to improve the ecological understanding, management, and future status of these critical populations in marine and inland systems, and who last gathered in 2017, in Victoria, Canada. Lisbon could not have been a better setting for a meeting of forage fish fanatics, as the interests of the symposium's participants were matched by the prominence of sardine in the culture of Portugal. The artwork, cuisine, and history of the region served as persistent reminders of the significant role that SPF can play in ecological and socioeconomic communities.

The symposium complemented collaborative research conducted by the joint ICES/PICES Working Group on Small Pelagic Fish and was endorsed as one of activities relevant to the goals of the UN Decade of Ocean Science for Sustainable Development, particularly "to bolster scientific research for a sustainably harvested ocean ensuring the provision of food supply."

Symposium Program

The symposium scientific program was composed of six half-day workshops held on the first day of the event (November 7) and seven theme sessions on a wide range of topics addressing the science and management of SPF. Morning plenary sessions on November 8–10 provided overarching keynote presentations and introduced topics for the concurrent sessions that were convened that day. A final plenary session on November 11 included talks outlining the history of international collaboration on SPF and emerging topics. A panel discussion and symposium summary presentation identified key research themes to be addressed in the future.

The following set of topic sessions was identified by the Scientific Steering Committee:

S1 – Trophodynamic processes,
S2 – Life cycle closure: Advances in process understanding,
S3 – Understanding population- and ecosystem-level shifts: From seasonal timing to tipping points,
S4 – Responses to climate variability and change at decadal to centennial scales,
S5 – Progress in pelagic surveys: From biomass estimates to monitoring ecosystems,
S6 – Reconciling ecological rules and harvest goals: Development and testing management strategies to enhance marine ecosystem services,
S7 – Advancing social-ecological analyses and sustainable policies for human SPF-dependent communities.

The following set of pre-symposium workshops was selected by the Scientific Steering Committee based on the proposals from the scientific community:

W1 – Application of genetics to SPF,

W2 – The devil is in the details of using species distribution models to inform multispecies and ecosystem models,
W3 – SPF for whom? Challenges and opportunities for the equitable distribution of nutritional benefits,
W4 – Evaluating inter-sectoral tradeoffs and community-level response to spatio-temporal changes in forage distribution and abundance,
W5 – Recent advances in the Daily Egg Production Method (DEPM): Challenges and opportunities,
W6 – SPF reproductive resilience

A summary of the key research themes discussed at the symposium, including recommendations for future work. and the summaries from all six workshops have been published in the winter 2023 issue of PICES Press.

Evening networking events included: a welcome reception in an 18th century manor house in Monsanto Forest Park (November 7); a mentoring event for early career scientists that was structured around techniques, topics and regions of interest vital to SPF science and management (November 8); a poster session (November 9); and a symposium dinner at Pátio da Galé located in the historical center of Lisbon on Praça do Comércio where the Royal Palace stood when the 1755 earthquake struck (November 10).

Other activities at the symposium venue comprised: a display with photographs of the Horácio Novais Collection from the Art Library of the Calouste Gulbenkian Foundation, exhibiting historical scenes from traditional Portuguese SPF markets and fisheries, and demonstration (throughout the symposium) of the documentary "Portuguese Sardine – A Natural Wealth" that was produced for the National TV (RTP) in 2022.

Symposium Organizers

- Primary International Organizers: PICES, ICES and FAO
- Local Organizer: IPMA (Portuguese Institute of Sea and Atmosphere)
- Co-organizers:
  - DPPO (Danish Pelagic Producers Organization)
  - DFO (Fisheries and Oceans Canada)
  - FCG (Calouste Gulbenkian Foundation) – donated the use of their fabulous conference center in the heart of Lisbon and the support of their Public Relations and Audiovisual teams
  - GFCM (General Fisheries Commission for the Mediterranean)
  - IMBER (Integrated Marine Biogeochemistry and Ecosystem Research)
  - IRD (French National Research Institute for Sustainable Development, France)
  - MOF (Ministry of Oceans and Fisheries, Republic of Korea) through KIOST (Korea Institute of Ocean Science and Technology)
  - NSF (National Science Foundation, USA) through WHOI (Woods Hole Oceanographic Institution)
  - NIOZ (Royal Netherlands Institute for Sea Research, Department of Coastal Systems, The Netherlands)
  - NOAA-Fisheries (National Marine Fisheries Service, USA)
  - NPAFC (North Pacific Anadromous Fish Commission)
  - NPFC (North Pacific Fisheries Commission)
  - NPRB (North Pacific Research Board, USA)
  - PFA (Pelagic Freezer-trawler Association)
  - SCOR (Scientific Committee on Oceanic Research)
  - IFFO (The Marine Ingredient Organization)
- Symposium Convenors: Ryan Rykaczewski (PICES, USA), Akinori Takasuka (PICES, Japan), Ignacio Catalán (ICES, Spain), Myron Peck (ICES, Netherlands) and Susana Garrido (Portugal)
- Symposium Coordinator: Alexander Bychkov (PICES) and Julie Kellner (ICES)
- Scientific Steering Committee: In addition to the symposium convenors, SSC included:
  - PICES: Jennifer Boldt (Canada), Noelle Bowlin (USA) and Yongiun Tian (China)
  - ICES: Rebecca Asch (USA) and Arnaud Bertrand (France)
  - FAO: Tarub Bahri and Miguel Bernal (GFCM)

- Other: Jana del Favero (Brazil), Toshihige Kidakato (NPFC, Japan), Joel Llopiz (IMBER/CLIOTOP, USA), Salvador Lluch-Cota (Mexico) and Martin Pastoors (PFA)

- Session Convenors: Convenors represented 13 countries (Australia – 1, Brazil – 1, Canada – 3, France – 1, Germany – 2, Japan – 4, Netherlands – 1, Norway – 1, Peru – 1, Portugal – 2, Spain – 1, UK – 2 and USA – 7) and FAO. Of 28 convenors, 11 were members of PICES expert groups (10 from WG 43).
- Plenary/Invited Speakers: Speakers represented 12 countries (Australia – 1, France – 2, Germany – 2, Japan – 3, Mexico – 1, Norway – 1, Peru – 1, Portugal – 1, South Africa – 2, Spain – 3, Tanzania – 1 and USA – 4) and industry (PFA – 1). Of 23 speakers, 3 were members of PICES expert groups (2 from WG 43).

Participation and Presentations

The symposium attracted 288 participants hailing from 39 countries and 4 international organizations (PICES, ICES, FAO and NPFC). Scientists came from six continents: Australia – 5, Africa – 18, Europe – 168, Asia – 36, North America – 47, and South America – 15, with 47 participants being from developing countries. Participation of experts in climate, physical oceanography, zooplankton, fisheries biology, and socioeconomics clearly indicated the interdisciplinary nature of research on SPF. The group was nearly gender-balanced (47% female, 53% male), with a substantial portion of the attendees identifying as early career scientists (44%).

In total, there were 278 presentations at the symposium: 14 plenary talks, 7 invited and 173 contributed talks, and 84 posters, which were discussed thoroughly during an evening poster-viewing session. All presentations, for which we have permission from authors, will be posted at the symposium website.

Publications

Two publications stemming from oral and poster presentations made at the symposium are expected to emerge in 2023. Selected papers from Topic Sessions 1–4 and Workshops 1, 2 and 4 will be published in a special issues of *Marine Ecology Progress Series* (MEPS), and selected papers from Topic Sessions 5–7 and Workshops 3, 5 and 6 will be included in a special issue of *Canadian Journal of Fisheries and Aquatic Science* (CJFAS). April 30, 2023, was set as the due date for manuscript submissions to both special issues.

ECS at Symposium

The generous support of symposium sponsors facilitated the participation of many early career scientists (ECS) from around the world – a total of 126 ECS (or 44% of all attendees) presented their talks and posters in Lisbon. For comparison – at the 2017 SPF symposium in Victoria, only 18% of all attendees were ECS (43 of 237).

To recognize and encourage excellence in science, the awards were given to ECS for best oral presentations (5) and best posters (4). The award recipients came from nine different countries.

A mentoring session for ECS, structured around techniques, topics and regions of interest vital to SPF science and management was held on the evening of November 8. During this event, more than 60 ECS had the opportunity to interact with 23 mentors who have expertise across diverse geographic regions, research disciplines, and career-related areas. Mentors included members of the symposium's organizing and scientific steering committees, plenary and invited speakers, and topic session and workshop conveners.

ICES-PICES Working Group on Small Pelagic Fish

The symposium was a Term-of-Reference of the joint ICES-PICES Working Group on Small Pelagic Fish and was directly followed by a two-day (November 12–13) in-person meeting of this group where about 60 participants discussed products closely aligned to symposium topics such as the compilation of world-wide data sets, integrative analyses, and peer-reviewed manuscripts. The meeting also provided an opportunity to broaden the working group network by welcoming new members, including many early career scientists.

Appendix B2

In order to maintain exchange of information and cooperation among scientists working on small pelagics around the world, which was successfully re-started during the 2017 Small Pelagic Fish symposium (SPF-2017), PICES and ICES have agreed of having symposia on this topic on a regular basis.

Request to Science Board:

- To consider the possibility of holding, jointly with ICES and FAO, the next Small Pelagic Fish symposium in the spring 2026 in La Paz, Mexico

Proposal to host SPF-2026 in La Paz, Mexico

Motivation

In 2026 it will be 50 years since arguably the most significant and best documented North Pacific climate regime shift (1976-77), one that ignited most of the research on decadal and multidecadal variability and that is strongly linked to small pelagics dynamics. We find it exciting that same year coincides with some events of local interest to Mexico, especially the ~50th anniversary of CICIMAR, CIBNOR, and UABCS, and the 35th meeting of Mexico´s Small Pelagics Technical Committee.

Since their foundation about half a century ago, some of the institutions based in La Paz have maintained an interest in the study of small pelagics and their fisheries. During the 1970s, some of the most influential researchers on fish recruitment trained Mexican scientists in ichthyoplankton research. In the late 1980s and early 1990s, La Paz hosted the Regime Problem Group (later SCOR WG98 on “Worldwide Large-scale Fluctuations of Sardine and Anchovy”) and the team who formulated the SPACC (Small Pelagics and Climate Change project of GLOBEC) science plan. This is not by chance - these fisheries have represented around 70% of the national fishing production in some periods and occur practically entirely in the northwestern region of Mexico. Enthusiasm for the issue has not waned. Today, many of the researchers of that time are giving way to a generation of passionate young scientists.

We envision that hosting a 2026 Small Pelagic Fish symposium would help us expose those early career scientists to the international community, hopefully developing a generation of academics better prepared for the challenges represented by the management of these resources in times of climate change.

Suggested dates

Based on the most recent experience, we support the model adopted in Lisbon, consisting of four days for the main program plus one or more days for workshops. As tentative dates, we propose the second week of March (Sunday 8th to Saturday 14th) or the second half of April (Sunday 19th to Saturday 25th), but we will remain flexible to accommodate other PICES needs. Due to the climate of La Paz, we suggest that the meeting not be held after mid-May (too hot). From March 29 to April 13 is also a period to avoid (the Holy Week holiday period).

Venue

Once the dates are decided, we can identify and try to book the venue. Based on the comfort for the attendees and the quality of the facilities, we consider the Hotel Araiza Palmira as the first option; it has 2 rooms for 50, 1 room for 100, 1 large room for 350 that can be divided in two, and an executive meeting room. The second option would be CIBNOR located 15km far from the city (bus transport needed), but with all the auditorium (400 seats), smaller rooms for parallel sessions (3 x 50 seats, 1 x 100 seats), office space, and an entire team for tech and logistics support (and the least expensive).

Local support

CICIMAR, CIBNOR, CICESE, and UABCS are local institutions where fisheries science is part of the core scientific agenda. We can count on support in aspects such as informatics, transport, office space and equipment, and administration through the direct involvement of institutions' personnel and volunteering young scientists. We expect important involvement of Mexico´s Small Pelagics Technical Committee, a permanent scientific forum where 20-30 researchers meet annually with the industry and NGOs.

Potential local sponsorship

It is hard to commit local and national sponsorship at this time, but based on our experience in organizing other fisheries-related international meetings in the past, the National Science Council (CONACYT), the National Fisheries and Aquaculture Institute (INAPESCA), and the National Fisheries Management Body (CONAPESCA) are federal entities that have partially supported this kind of events. Research institutions, such as CICIMAR, CIBNOR, CICESE, and the local University also usually support these events and frequently provide in-kind support. In case La Paz is chosen as the symposium venue, we would search for complementary funding through direct support contributions and grants.

Directly involved individuals

If La Paz is selected as the venue for the event, we would form a multi-institutional local organizing committee and provide a short list of experienced local scientists who could serve as members of the Scientific Steering Committee. Meanwhile, we can volunteer to serve as the head of the Local Organizing Committee (Romeo Saldivar), Symposium Co-convener (Salvador Lluch-Cota), and member of the Scientific Steering Committee (Rubén Rodríguez-Sanchez).

April 24th, 2023

To whom it may concern,

We, Dr. Myron Peck and Dr. Ignacio Catalán, co-chairs for ICES of the ICES-PICES Working Group on Small Pelagic Fish (WGSPF) and co-conveners of the "International Symposium on Small Pelagic Fish: New Frontiers in Science for Sustainable Management", are writing to express our enthusiastic support for Mexico's candidacy to host the next symposium in the spring of 2026.

As experts in the field of small pelagic fish, we believe that Mexico would be an excellent host for this important event. The country has a highly reputed scientific community, a proven track record in organizing large-scale scientific events, and a strong commitment to sustainable fisheries management. We are confident that Mexico's expertise and dedication will create a stimulating and productive environment for scientists, researchers, and policymakers from around the world to exchange knowledge and expertise on small pelagic fish.

We are convinced that hosting this symposium in Mexico will make a significant contribution to the advancement of scientific understanding and management of small pelagic fish. We urge the international community to support Mexico's candidacy and look forward to the opportunity to participate in a productive and enlightening symposium.

Thank you for your consideration.

Sincerely,

Dr. Myron Peck and Dr. Ignacio Catalán Co-chairs for ICES of the ICES-PICES Working Group on Small Pelagic Fish and co-conveners of the "International Symposium on Small Pelagic Fish: New Frontiers in Science for Sustainable Management"

CATALAN ALEMANY IGNACIO ALBERTO - DNI 43088173L

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Appendix C

REPORT ON WORKING GROUP 36

On

COMMON ECOSYSTEM REFERENCE POINTS

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Executive Summary

Overview

PICES Working Group 36 (WG36) on Common Ecosystem Reference points was established under PICES's main science program Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems (FUTURE). FUTURE was organized around three research themes, each with several objectives (https://meetings.pices.int/Members/Scientific-Programs/FUTURE#objectives). WG36 addressed FUTURE's research theme questions #1: "What determines an ecosystem's intrinsic resilience and vulnerability to natural and anthropogenic forcing?" and #2: "How do ecosystems respond to natural and anthropogenic forcing, and how might they change in the future?". Analyses and results for TOR 4 and TOR 6 address several of FUTURE's Objectives, particularly Objective 1.4: "How might changes in ecosystem structure and function affect an ecosystem's resilience or vulnerability to natural and anthropogenic forcing." In addition, results from analyses help address FUTURE's Objectives 1.2, 1.5, 2.1, 2.2, 2.3, 2.4 and 2.6 (Appendix 5).

Strong nonlinearities in marine ecosystems indicate the existence of thresholds beyond which small changes in pressure variables can cause large responses in other ecosystem components. Better knowledge of where thresholds occur can advance our ability to anticipate future conditions and critically inform what management actions can maximize ecological, social or economic benefits. Moreover, thresholds common across analogous systems can be used to develop robust sets of reference points to prevent ecosystems from shifting into undesirable states.

WG36's Terms of Reference (TOR) were to:

1. Outline each country's mission, goals, and governmental science plans that point to the establishment of reference points across PICES member nations, and identify those that are comparable.
2. Summarize previous efforts identifying data availability for geographic areas and time periods of particularly strong climate influence and dependence on marine systems within specific North Pacific ecosystems, fish stocks, and fishing communities. This will build upon indicators identified via WG-19, WG-28, S-HD and WG-35 (NPESR-3). Determine a subset (or not) of ecosystems and indicators that will be the focus of WG activities.
3. Summarize and select previous methods for determining thresholds (both non-linear and societal limits) in ecosystem indicators. This would include statistical and objective-based approaches.
4. Determine shapes or functional forms of driver - response relationships from available datasets, and quantify thresholds to identify potential ecosystem reference points.

5. Identify ecosystem components that respond earliest to changes in biophysical drivers and could potentially serve as leading indicators of loss of resilience and ecosystem change.
6. Develop a “heuristic model” to examine drivers (climate forcing, fishing) and ecosystem response using selected ecosystem reference points for member nations.
7. Publish final report

WG36 conducted the following activities to address their TORs:

1. Convened a Topic Session: S3, Below and beyond maximum sustainable yield: Ecosystem reference points, PICES annual meeting, Sept. 22- Oct. 1, 2017, Vladivostok, Russia.
2. Convened a workshop: W11, Quantifying thresholds in driver-response relationships to identify reference points, PICES/ICES/IOC/FAO 4th Symposium on Effects of climate change on the world's oceans”, June 2–3, 2018, Washington, DC.
3. Published an article in PICES Press Summer 2018, Vol. 26, No. 2 ECCWO-4 Workshop on Quantifying thresholds in driver-response relationships to identify reference points.
4. Convened a workshop: W5, Identifying common reference points and leading indicators of ecosystem change. PICES annual meeting, Oct 25 – Nov. 4, 2018, Yokohama, Japan.
5. Convened a Topic Session: S6, Identifying thresholds and potential leading indicators of ecosystem change: The role of ecosystem indicators in ecosystem-based management, Oct. 16-27, 2019, Victoria, BC, Canada.
6. Convened a workshop: W13, Common ecosystem reference points. PICES annual meeting, Oct. 16-27, 2019, Victoria, BC, Canada.
7. Convened annual and intersessional business meetings each year, 2017-2020, and published three reports summarizing WG36 activities and progress: 2020, 2019, 2018, 2017.
8. Completed analyses outlined in this report
9. Published two manuscripts (Boldt et al. 2021, Hunsicker et al. 2022) and drafted another (Hunsicker et al. in prep).

Main findings and conclusions by TOR

TOR 1

Reference points are commonly used for single-species fisheries management across multiple PICES member nations. However, there is increasing attention on the development and implementation of ecosystem-level reference points (ELRPs) in marine resource management. To address TOR 1, WG36 summarized if and how PICES member nations are incorporating ELRPs in their management and science plans.

The main findings for TOR 1 included:

1. All member nations are required to use single species reference points in fisheries management.
2. Member nations point to the establishment of ELRPs in their science and management plans, however they are not yet commonly required across PICES member nations.
3. Most member nations point to the inclusion of ecosystem information in government science and management plans.
4. A few member nations include the establishment of ELRPs as an important priority in government science and management plans.

TOR 2

WG36 summarizes previous efforts that identified data availability for marine systems within North Pacific ecosystems, fish stocks, and fishing communities and determined a subset of ecosystems and indicators to focus on for WG36 activities.

The main findings for TOR 2 included:

5. WG36 members selected indicators from a toolbox of recommended indicators for each region of study.
6. Many of the recommended core indicators were selected in all ecosystems to reflect environmental and human pressures and ecosystem responses; however, not all core indicators could be examined (because, for example, data were not available or to maximize the length of the time series examined). Member nations had different priorities for their recommended core indicators that influence their data collection and sharing protocols.
7. In addition to core indicators, some additional, ecosystem-specific indicators were included.
8. For analyses, a data-based approach was used (time series of data to calculate indicators) and indicators were selected to address ecosystem-based management objectives, where possible.

TOR 3

Over the past few decades, there have been many advancements in statistical methods for detecting thresholds in time series data (Andersen et al. 2009). WG36 summarized methods used to quantify nonlinearities and thresholds in pressure-response relationships in marine ecosystems with an emphasis on those methodologies used for case studies presented in TOR 4.

The main findings for TOR 3 included:

9. We provided an overview of a suite of quantitative methods that are more commonly used to detect thresholds in pressure-response relationships in marine ecosystems, as well as methods to detect thresholds in single time series and common trends in multivariate time series.

10. All of the methods reviewed have advantages and drawbacks. For example, some can handle multiple pressures and multiple responses, but are not easily interpretable while others are easily interpretable, but require long time series and cannot handle missing data.
11. There are additional advanced statistical methods for threshold detection that we did not review here because either (1) to the best of our knowledge there are no existing applications to marine ecosystems, or (2) the methodology (e.g., R code) is not easily accessible.
12. To address TOR 4, we selected Generalized Additive Models with derivative analysis, gradient forest analysis, and Dynamic Factor Analysis for our working group activities. These analyses were selected because (1) the methods have been thoroughly vetted by ecologists and fisheries scientists, (2) multiple working group members had prior knowledge of and experience working with these methods, (3) as part of a workshop, we built reproducible R code associated with the analyses, which are well documented and readily available for our working group and other PICES needs.

TOR 4

WG36 developed several regional case studies to determine the shapes or functional forms of pressure-response relationships and quantify thresholds to identify potential ecosystem reference points.

The main findings for TOR 4 included:

13. We characterized key pressure-response relationships and examined evidence of ecosystem thresholds in the pressure-response relationships. We used Dynamic Factor Analyses to identify common trends, gradient forest analyses to identify important pressures on ecosystem responses and thresholds, and general additive models to examine nonlinearities in pressure-response relationships.
14. Where significant single pressure-response relationships were found, about >50% were linear and <10% were nonlinear. The nonlinear relationships may provide leading indicators with thresholds.
15. Dimension-reducing analyses, such as Dynamic Factor Analysis, can simplify a suite of indicators to a few important trends. For example, for most of the case studies the pressures and ecosystem responses loaded on single trends. This was especially true for those models based on a small number of time series, e.g., less than 10 (Japan), and those that demonstrated strong coherence among the time series (U.S.A). In some cases, correlations among DFA trends can be used to provide evidence of structural or functional relationships between pressures and responses (e.g., Korea). Future analyses could be aimed at combining human pressures, environmental pressures, and ecosystem responses within the same model to evaluate potential associations among the time series.

16. A case study off the west of Vancouver Island (WCVI) in Canada applied both gradient forest and GAM analyses to environmental and biological time series. The Gradient Forest analysis identified similar nonlinearities as the single pressure-response GAM models, and additional nonlinearities as well. These findings support the use of a multi-model approach to detect nonlinearities and thresholds in marine ecosystems.
17. Top pressures include both basin and regional scale environmental pressures. Human pressures were not identified as important in the WCVI or U.S. case studies. However, human pressures were important in the Samhouri et al. (2017) U.S. study, especially in the gradient forest analysis.
18. Identification of pressure-response relationships likely depends on the length of time series, frequency of measurements (seasonal vs annual), spatial scale of indicators analyzed, as well as the ecosystem being examined. A recent update of the Samhouri et al. (2017) analyses using a longer time series resulted in the identification of fewer nonlinearities (M. Hunsicker et al., unpublished).
19. Future studies could take into account more proximate pressures of ecological responses. For example, changes in predator abundances could be evaluated with respect to prey abundance and condition rather than using environmental pressures as a proxy. The potential for nonstationarity in pressure-response relationships also deserves consideration in future efforts to quantify nonlinearities and threshold locations in those relationships.

TOR 5

The development and testing of methodological approaches for detecting early warning signs of loss of resilience and ecosystem change has been the focus of myriad research efforts over the past few decades.

The main findings for TOR 5 included:

20. While the pursuit of effective leading indicators or early detection of ecosystem change is ongoing, there are management-relevant indicators that have already been derived from significant pressure-response relationships (both linear and nonlinear), including anthropogenic and environmental pressures.
21. The characteristics that define reliable leading indicators of ecosystem change will depend on the ecosystem process and timescale of interest.
22. Indicators investigated to date depend on time series availability of the data.
23. Results may change with the length of time series or spatial scale of the data. Simulation studies, sensitivity analyses, and the use of ecosystem models could help address this challenge.
24. There is a potential for nonstationarity in pressure-response relationships, which could change the usefulness of leading indicators, as well as forecasting abilities. This

highlights the importance of monitoring and developing a process-based understanding of pressure-response relationships.

TOR 6

Heuristic models can be a useful tool for increasing understanding of complex relationships between pressures and ecosystem responses and how they might inform management actions or outcomes. Such models are simplified representations of ecosystem structure and functioning and are constructed based on hypotheses about the causal relationships among several variables

The main findings for TOR 6 included:

25. The outcome of our analyses from TOR 4 precluded us from developing heuristic models for all ecosystems examined. For example, (1) single pressure-response relationships were not examined in all ecosystems, (2) of those where single pressure-response relationships were examined, a small number resulted in defined thresholds, and (3) the identified pressure-response relationships with defined thresholds did not always have clear links to management actions.
26. We provided two examples of heuristic models, for coastal waters off the U.S. west coast and waters around the Korean Peninsula, to illustrate how such models could be constructed and how they might be useful for making management decisions.

Recommendations for future research related to TOR 6

As environmental, human and ecological time series lengthen and become more readily available, continued efforts to examine pressure-response relationships will enable the development of similar types of heuristic models presented here. Those relationships that may have clear links to management actions should be prioritized. These efforts would help support the development of heuristic models, regardless if the identified relationships are linear or nonlinear. In addition, this information could be used to develop and inform other types of models not explored here (e.g., qualitative or quantitative network models) and to assess ecosystem linkages and dynamics. For example, qualitative networks models are a useful tool for conducting dynamic simulations of conceptual models and evaluating how perturbations might affect different components of an ecosystem as well as management strategies (Harvey et al. 2016, Sobocinski et al. 2018, Forget et al. 2020). They are also well suited for data poor systems where precise quantitative relationships among different stressors and ecological components are unknown (Reum et al. 2015). All of these modeling approaches may serve as valuable tools for supporting ecosystem-based approaches to the management of marine resources in PICES member nations.

1. Introduction

Projected impacts of climate change and anthropogenic drivers in ocean ecosystems create uncertainty in ecological responses and can cause major shifts in ecosystem states or regimes (Biggs et al. 2018, Heinze et al. 2020, Figure 1-1). These shifts can occur gradually and continuously along a gradient of environmental and anthropogenic pressures (Hillebrand 2020). Alternatively, they can be dramatic and abrupt, such as when single populations, species interactions, or whole ecosystems cross a tipping point and rapidly change or reorganize (Selkoe et al. 2015, Heinze et al. 2020, Turner et al. 2020). Restoring a system from an altered state to its original state may be difficult or even impossible once a critical threshold is crossed because the pathway of recovery of an ecosystem may be different from the pathway leading to the state change (Suding and Hobbs 2009, Selkoe et al. 2015).

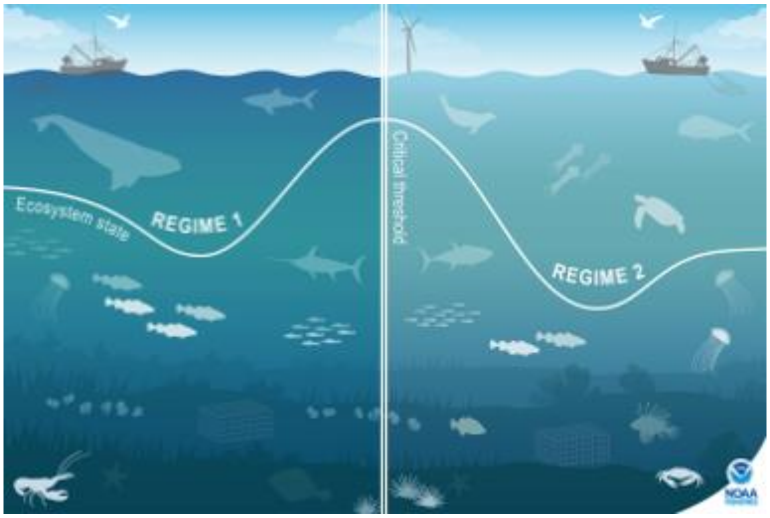

Figure 1-1. Conceptual figure of regime shift in ocean ecosystems. Credit: NOAA Fisheries

Large and abrupt changes in marine populations or ecosystem functioning potentially result in losses of valuable ecosystems benefits, which can have important consequences for coastal communities and economies. Therefore, there is much interest among scientists, resource managers, and stakeholders in anticipating these changes before they occur. Identifying and monitoring indicators of resilience, species or system traits that might provide advanced warning of tipping points may be useful for avoiding or mitigating ecosystem shifts (Scheffer et al. 2015, Selkoe et al. 2015, Mahli et al. 2020). Identifying strong nonlinearities and thresholds in relationships between environmental and anthropogenic pressures and ecosystem indicators can also be valuable for identifying targets or reference points for triggering management actions to prevent or mitigate the impacts of such shifts (Figure 1-2, Samhouri et al. 2010, 2011, Large et al. 2013). Over the past two decades, multiple research efforts have been aimed at detecting ecological thresholds that could help determine ecosystem-level reference points for managing natural resources. However, more research is needed to detect robust, management-relevant thresholds in north Pacific Ocean ecosystems and beyond. Pathways for the uptake of ecosystem-level reference points in the management process also need to be identified.

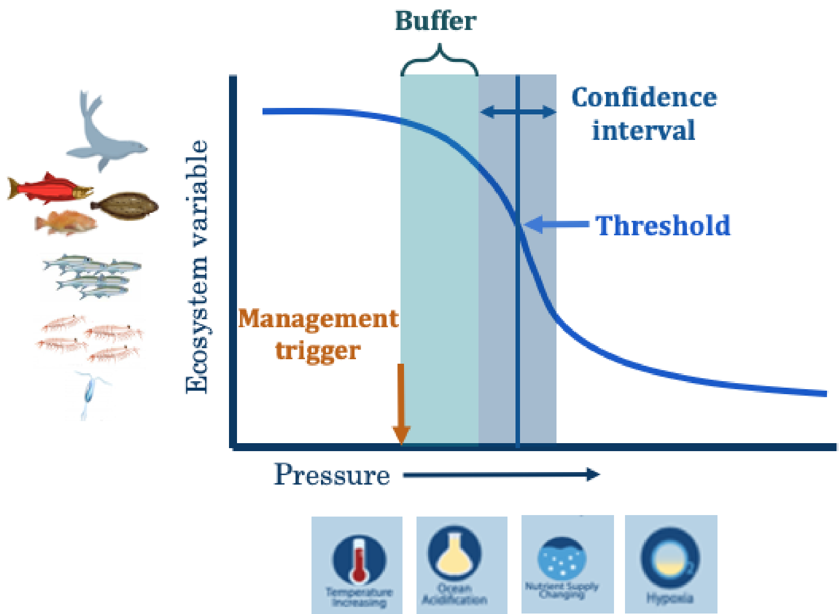

Figure 1-2. Conceptual figure showing nonlinearity and a defined threshold in the response of an ecosystem variable to an environmental pressure. It also denotes a target or reference point for triggering management action. Here, and throughout the report, we define nonlinear relationships as those pressure-response relationships '*having one or more curves or points of rapid change*' and thresholds are defined as a '*relatively rapid change from one ecological condition to another'* as per Selkoe et al. 2015.

1.1 Guide to the report

Here, we present the efforts of WG36 to address six TORs and to contribute to the broader efforts of identifying ecosystem-level reference points for the management of marine resources in PICES member nations and elsewhere. For TOR 1, we identified if and how PICES member nations are incorporating ELRPs in their management and science plans. For TORs 2 and 4, we developed nation-specific case studies and (1) identified the status and trends of key climate and biological variables in member nation coastal ecosystems, (2) characterized key pressure-response relationships using those variables, and (3) determined whether there was evidence of ecosystem thresholds in the pressure-response relationships examined. For TOR 3, we summarized methods used to quantify nonlinearities and thresholds in pressure-response relationships in marine ecosystems with an emphasis on the methodologies that we selected for the member nation case studies. For TOR 5, we provided a discussion on leading indicators of ecosystem change and the challenges associated with identifying reliable indicators. Finally, for TOR 6, we reviewed the value in developing heuristic pressure-response models using thresholds or reference points for making management decisions.

We note that for nation-specific case studies, we refer to the study systems according to the PICES bioregions (Figure 1-3): Canada, waters on the west coast of Vancouver Island that fall within the northern area of bioregion #11; China, waters on the east coast of Mainland China in the northern area of bioregion #20; Japan, waters around the Shiretoko Peninsula, Hokkaido in bioregions #17 and 18; Korea, waters around the Korean Peninsula in bioregions #19, 20, and 21; Russia, Exclusive Economic Zone of Russia in bioregion #19; U.S.A., waters off the U.S. west coast (California, Oregon, Washington) that fall within the southern area of bioregion #11.

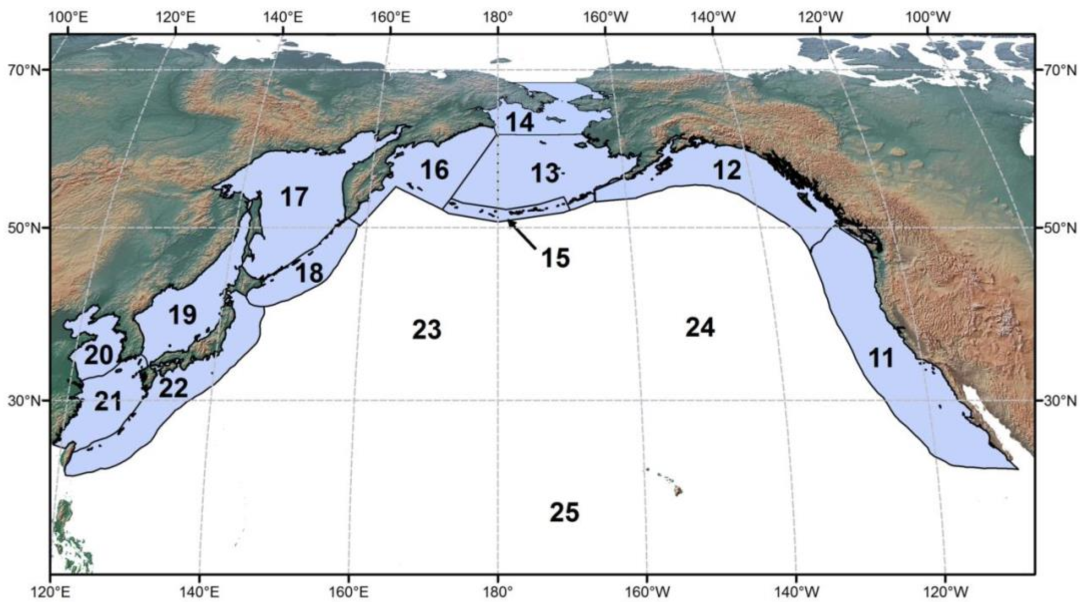

Figure 1-3. Map and numbering of PICES bioregions. Study systems for WG36 nation-specific case studies include PICES bioregions #11 and #17-20.

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2 Mission, goals, and governmental science plans that point to the establishment of ecosystem reference points across PICES member nations

2.1 Introduction

Reference points are commonly used for single-species fisheries management across multiple PICES member nations. For example, Maximum Sustainable Yield (MSY), the maximum catch that can be continuously removed without causing long-term stock depletion, has been used for decades as a target, and more recently, a limit on fishing mortality and biomass removal. However, it has become widely recognized that inclusion of broader ecosystem information is necessary to sustainably manage marine resources particularly in a variable climate. In turn, there is increasing attention on the development and implementation of ecosystem-level reference points (ELRPs) in marine resource management.

In 2015-16, PICES established a study group on common ecosystem reference points across PICES member nations (SG-CERP), which led to the formation of Working Group 36 (WG CERP) to support the need for ELRPs in north Pacific Ocean ecosystems. The first Terms of Reference (TOR) for WG CERP was to identify if and how PICES member nations are incorporating ELRPs in their management and science plans. Here, we provide summaries of the current status of ELRPs in marine resource management in Canada (Fisheries and Ocean Canada, Federal), China (Bureau of Fisheries, Federal), Japan (Fisheries Agency, Federal), Korea (Ministry of Oceans and Fisheries), Russia (The Pacific branch (TINRO) of Russian Federal Research Institute of Fisheries and Oceanography (VNIRO)), and the United States (NOAA Fisheries, Federal).

2.2 Nation-specific summaries

2.2.1 Canada

Mission

Fisheries and Oceans Canada (DFO) has the lead federal role in managing Canada's fisheries and safeguarding its waters. DFO works toward the following three strategic outcomes: Economically Prosperous Maritime Sectors and Fisheries, Sustainable Aquatic Ecosystems, Safe and Secure Waters (https://www.dfo-mpo.gc.ca/about-notre-sujet/mandate-mandat-eng.htm DFO’s vision is to advance sustainable aquatic ecosystems and support safe and secure Canadian waters while fostering economic prosperity across maritime sectors and fisheries. The

Department supports strong economic growth in Canada's marine and fisheries sectors by supporting exports and advancing safe maritime trade; supports innovation through research in expanding sectors such as aquaculture and biotechnology; and contributes to a clean and healthy environment and sustainable aquatic ecosystems through habitat protection, oceans management, and ecosystems research. DFO's work is guided by five key pieces of legislation: the Oceans Act; the Fisheries Act; the Species at Risk Act; the Coastal Fisheries Protection Act; and the Canada Shipping Act, 2001 (Transport Canada-led). In addition to these Acts, there are other Acts, such as the Canada National Marine Conservation Areas Act and the Canada Environmental Protection Act (for a list of all Acts, see: https://www.dfo-mpo.gc.ca/acts-lois/regulations-reglements-eng.htm), as well as several policies that guide the management of fisheries resources in the Pacific (http://www.dfo-mpo.gc.ca/reports-rapports/regs/policies-politiques-eng.htm), including: the Sustainable Fisheries Framework (SFF) which incorporates the precautionary approach (http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/overview-cadre-eng.htm). Other policies and initiatives under the SFF include the Wild Salmon Policy (http://waves-vagues.dfo-mpo.gc.ca/Library/285006.pdf), a Forage Species policy, a Sensitive Benthic Areas policy, and others that factor in ecosystem considerations and precaution providing a more rigorous and comprehensive approach to managing Canada's fisheries.

Goals

The overarching goal of Fisheries and Oceans Canada is to protect its three oceans, coasts, waterways and fisheries and ensure that they remain healthy for future generations. The SFF provides the basis for ensuring Canadian fisheries are conducted in a manner which supports conservation and sustainable use. It incorporates existing fisheries management policies with new and evolving policies. The SFF comprises: 1) conservation and sustainable use policies that include principles of ecosystem-based fisheries management and 2) planning and monitoring tools, such as Integrated Fisheries Management Plans (IFMPs; http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/index-eng.htm), to monitor and assess those initiatives geared towards ensuring an environmentally sustainable fishery, and to identify areas that may need improvement. Overall, the Sustainable Fisheries Framework provides the foundation of an ecosystem-based and precautionary approach to fisheries management in Canada.

Government science and strategic plans relevant to reference points

The Sustainable Fisheries Framework (SFF) and some policies, such as the Wild Salmon Policy (WSP), require the establishment of 'reference points' or, in the case of the WSP, 'benchmarks' (that do not prescribe specific restrictions). The SFF applies to specific and intended targets of a commercial, recreational, or subsistence fishery, requires a harvest strategy be incorporated into respective fisheries management plans to keep the removal rate moderate when stock status is healthy, promotes rebuilding when stock status is low, ensures a low risk of serious or irreversible harm to the stock, and requires a rebuilding plan when a stock reaches low levels. A fishery decision-making framework includes: 1) reference points and stock status zones

(Healthy, Cautious and Critical); 2) harvest strategy and harvest decision rules; 3) the need to take into account uncertainty and risk when developing reference points and developing and implementing decision rules (http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precaution-eng.htm).

Under the SFF, stock status zones are created by defining the Limit Reference Point (LRP) at the Critical: Cautious zone boundary, and an Upper Stock Reference Point (USR) at the Cautious: Healthy zone boundary and the Removal Reference for each of the three zones. LRPs are based on biological criteria through a scientific peer-reviewed process, and USRs are developed by fishery managers, based on science advice and consultations with First Nations and users. The scientific information available to define reference points may vary among stocks; therefore, different approaches must be used for calculating LRPs and defining harvest rules. A harvest rate strategy is used to manage the harvest of a stock with pre-agreed-upon harvest decision rules and management actions for each zone.

The WSP requires the identification of upper and lower benchmarks to delimit population status as well as habitat status zones (green, amber, red) (DFO 2004). For example, a low spawner abundance may be associated with the red zone and increased management actions (DFO 2004). Upper and lower benchmarks are also used to evaluate the status and aggregate risk rating of salmon habitat (green/low risk, amber/moderate risk, red/high risk). The identification of benchmarks is determined on a case-by-case basis with consultation with First Nations and resource users and with consideration for a variety of information. Population or habitat status relative to benchmarks and zones do not result in specific prescribed restrictions; instead, management responses vary with species, region, and causes (DFO 2004).

See Table 2-1 for full definitions of reference points and benchmarks.

Single species reference points are required in current DFO fisheries management; however, ecosystem reference points are not commonly required. Canada's Oceans Strategy promotes an ecosystem-based approach to management (DFO 2002) and there has been considerable research into identifying ecosystem indicators (e.g., Boldt et al. 2014, Bundy et al. 2017), assessing the state of marine ecosystems (e.g., Chandler et al. 2017), identifying regime shifts in indicators (e.g., Perry and Mason 2013), and incorporating ecosystem considerations in fisheries and oceans management (e.g., DFO 2016). In 2000, DFO's National Policy Committee proposed a framework for setting ecosystem objectives that included developing a suite of objectives, indicators and reference points for the maintenance of biodiversity, productivity, and water quality within coastal ecosystems of concern (DFO 2007). Some policies, such as the WSP and DFO's Forage species policy, require ecosystem benchmarks or ecosystem considerations in developing reference points. DFO's Wild Salmon Policy requires the assessment of habitats relative to benchmarks. Habitat report cards have been developed to provide a snapshot of current risks to salmon habitats in a watershed (e.g., Porter et al. 2013; https://salmonwatersheds.ca/document-library/?searchtype=basic&searchall=report+card). These report cards are developed using pressure and state indicators, vulnerability indicators at different life-history stages, and upper and lower benchmarks to assign an aggregate risk rating (Red/high, Amber/moderate, and Green/low) for salmon habitat. Another example is DFO's policy on New Fisheries for Forage Species (DFO 2009) that requires inclusion of ecosystem considerations in developing LRPs. The policy states that LRPs "should ensure both that future recruitment of the target species is not impaired, and that food supply for predators is not depleted" and "reference points may also be set for properties such as growth rates, condition factor, or reproductive output of ecologically dependent marine predators".

2.2.2 China

Mission

Commercial fisheries within China's Exclusive Economic Zone are managed by the Ministry of Agriculture and Rural Affairs (MARA) of the People's Republic of China (PRC) and China Coast Guard, and fisheries inside the prohibited fishing zone line for motor-trawler managed by the Bureau of Fisheries (BoF) functioning under the MARA, fisheries outside the prohibited fishing zone line for motor-trawler managed by China Coast Guard. The mission of BoF is 'stewardship of living aquatic resources through science-based conservation, enhancement and management, and the promotion of ecological sustainability'. The mission is supported by four core mandates: 1) to ensure orderly utilization of living aquatic resources in accordance with laws and regulations (NPC 2013, MARA 2017) to reduce the total number and power of marine fishing vessels with engine by 20,000 and 1,500,000 kilowatts from 2015 to 2020, respectively (MARA 2017); 2) to set science-based total catch limit for domestic marine fisheries in China after 2020, which should be lower than the productivity of fishery resources in the four coastal seas surrounding China, generally no more than 10 million tons (MARA 2017), 3)to implement catch quotas for pilot fisheries of specific species ; and 4) to conserve and recover depleted fishery stocks together with rare or endangered wild aquatic species, and promote their habitat protection and restoration (NPC 2016, 2017). These mandates are mainly derived from three laws enacted by the Standing Committee of the National People's Congress (NPC) and recent official documents by the MARA, PRC.

Goals

The overarching goal of the science and management plans by BoF functioning under the MARA of PRC is to control fishing effort and set optimal total allowable catch of marine fishery resources, while promoting the conservation and enhancement of fishery resources and protecting the broader aquatic ecosystem, including rare or endangered wild aquatic species and their habitats. This goal has been accomplished through single- or multiple-species approaches together with imperfect science-based ecosystem considerations to fisheries management (NPC 2013, MARA 2017).

Government science and strategic plans relevant to reference points

Government strategic science plans are generally produced by MARA, Ministry of Science and Technology together with the National Nature Science Foundation of China (NSFC) at national level. Here we describe the national-level Research Institutes plans that point to the establishment and use of reference points. There are nine national fisheries research institutes throughout China, three of which carry out government science and strategic plans on sea areas and the others on water valleys or fishery engineering. In terms of sea areas, three institutes are Yellow Sea Fisheries Research Institute (YSFRI) located in Qingdao, East China Sea Fisheries Research Institute (ECSF) in Shanghai and South China Sea Fisheries Research Institute (SCSFRI) in Guangzhou.

MARA of PRC issued 'Notice on Further Strengthening the Management and Control of Domestic Fishing Vessels and Implementing the Total Catch Control of Marine Fishery Resources' in January, 2017. Recently, the State Council of PRC issued "the fourteenth five-year plan for promoting modernization of agriculture and rural areas" (2021, http://www.gov.cn/zhengce/content/2022-02/11/content_5673082.htm), which mandated the implementation of the Total Catch Control of Marine Fishery Resources, as well as improving quota-based fisheries management and strategies of fishing moratorium and bans. Under these documents, China's regional fishery management plans are required to specify reference points to identify when fishery stocks are overfishing or overfished. Stock status is determined by estimating current levels of fishing mortality, (relative) abundance, mean size and size composition of a fishery stock and comparing these metrics with specific reference points. There are two reference points used in China's fisheries management: annual catch limit (ACL) and total allowable catch (TAC). ACL is defined as 'the range of sustainable catch for a species or species group within a certain area of waters.' The ACL estimates are usually set as the maximum sustainable yield (i.e., MSY, the largest average yield that can be continuously taken from a stock at current status of exploitation under existing environmental conditions) of fishery stocks. Subsequently, the ACL estimates are multiplied by certain percentages to set TACs, based on the status of fishery stocks.

Single-species reference points are used for major fishery stocks with high or medium economic values. However, an overall ACL is set for all domestic marine fishery resources, since most (if not all) fisheries in China are indiscriminate and lack adequate data on catch, abundance index and other biological characteristics to estimate current stock size and MSY using conventional assessment techniques. In this context, the US-China Stock Assessment Project is conducted under auspices of the U.S.-China Fishery Dialogue with the goal to identify data sets (e.g. data-limited and/or data-poor) for which specific case studies can be developed subsequently to apply the best available modeling techniques to answer questions relevant to the assessment of Chinese fisheries, the data-limited stock assessment model has been developed in China and used for stock assessment of the specific species.

2.2.3 Japan

Mission

Commercial and recreational fisheries within Japan's Exclusive Economic Zone are managed by the Ministry of Agriculture, Forestry and Fisheries (MAFF), and more specifically the Fisheries Agency (FA). The mission of FA is 'to stabilize and improve the life of the citizens and to develop the national economy through comprehensive and systematic implementation of the policies for fishery' (http://www.cas.go.jp/jp/seisaku/hourei/data/fba_2.pdf). The mission is supported by two core mandates: 1) maintenance of stable supply of marine products and 2) sound development of fisheries (http://www.cas.go.jp/jp/seisaku/hourei/data/fba_2.pdf). These mandates are derived from the Fisheries Basic Act enacted by the National Diet of Japan.

Goals

One of the goals of Basic Plan for Fisheries 2017 (BPF 2017), relevant to the establishment of reference point across PICES member nations, is to appropriately conserve and manage fisheries resources and fishing grounds that enable those fishery resources to grow up (http://www.jfa.maff.go.jp/j/policy/kihon_keikaku/attach/pdf/index-3.pdf). To achieve this goal, the BPF 2017 sets a policy to promote management of fishery resources both nationally and internationally (http://www.jfa.maff.go.jp/j/policy/kihon_keikaku/attach/pdf/index-1.pdf). Also, the BPF set the target self-sufficiency rate of the fisheries production as 74% by 2027 (it was 67% in 2014).

2.2.4 Korea

Mission

Marine ecosystems and fisheries within the Republic of Korea's Exclusive Economic Zone are managed by the Ministry of Oceans and Fisheries (MOF), and more specifically divided into two branches, Office of Marine Policy (MOF Marine) addressing marine ecosystems and Office of Fishery Policy (MOF Fisheries) addressing fisheries under MOF. The mission of MOF Marine is 'healthy ocean, good quality of our life, and sustainable development of our nation through conservation and wise use of marine environment and ecosystem' (MOF 2017). The mission of MOF Fisheries is 'sustainable development and economic benefit for fishermen through efficient management of fishery resources' (MOF 2009). The MOF ecosystem mission is supported by five core objectives: 1) to reduce land-based pollution, 2) to reduce ocean-based pollution, 3) to conserve health of marine ecosystem, 4) to mitigate and adapt climate change and 5) to strengthen legal and social infrastructure (MOF 2011). These five objectives are legally binding to Marine Environment Conservation Act of 2017 (MECA). The second MOF fishery mission is supported by two fundamental managing directions: 1) to ensure ecosystem-based and efficient fishery resource management through integrative manners and restoration, and 2) to conserve and recover fishery species and their habitats (MOF 2016). These two mandates are legally binding to Fishery Resources Management Act of 2009 (FRMA).

Goals

The overarching goal of MOF Marine's science and management plans is to conserve ecologically healthy marine environments and ecosystems, including all marine mammals, endangered species, marine protected areas (MOF 2011). The overarching goal of MOF Fisheries' science and management plans is to establish efficient fishery resources management systems through integrating measures of management, including fishery resources protected areas. By making various management plans legally binding to several laws regarding marine environment, ecosystems and fisheries, the management actions adopt ecosystem-based approach to management rather than focus on single species and/or fragmented measures.

Institution

Traditionally, MOF missions have been scientifically supported by Korean National Institute of Fisheries Science (NIFS) and the Korea Institute of Ocean Science and Technology (KIOST). Recently, since 2008, Korean Marine Environment Management Cooperation (KOEM) has been working to support MOF Marine in science and management perspectives. Korea Maritime Institute (KMI) launched in 1997 to support MOF in legislating most of the ocean-related laws and preparing legally bound management plans. NIFS, the only governmental agency in the field of marine and fishery sciences, is currently implementing an ecosystem-based approach to fisheries management (EBFM), supporting both MOF Fisheries and Marine. KIOST is a more science-oriented institute that focuses on all aspects of ocean science and engineering, supporting MOF Marine. KOEM is currently supporting MOF Marine to scientifically implement several legal-binding management plans of marine environment and ecosystems.

Government science and strategic plans relevant to reference points

Both fisheries and ecosystems strategic science plans are produced by MOF Fisheries and Marine, respectively. Previously mentioned, those science plans are based on two management plans legally binding to FRMA (MOF Fisheries) and MECA (MOF Marine), respectively.

Fisheries Science Plan – Under the FRMA, Korean fishery management plan is required to specify measurable criteria, or reference points, to identify when fish stocks are vulnerable to overfishing or overfished. There are two categories of reference points used in Korean fisheries management: target and limit. The target reference points are a biological benchmark used to guide a desired outcome and the limit reference points indicate a state of the fishery or ecosystem to be avoided to prevent an undesirable outcome (MOF 2016). Based on these reference points, total allowable catches (TAC) of over 40 fishery species are annually determined in Korea. While single-species reference points are most commonly used in current national fisheries management plans, MOF Fisheries is implementing an EBFM plan with seven target areas in which a total of 26 action items are put into effect in 2016-2020 (MOF 2016).

Marine Ecosystems Science Plan – Under the MECA, Korean integrated management plan of marine environment is required to assess 'marine health' which is defined as current and future status of ecosystem contributing welfare and economy for future generation, including fisheries production, tourism, job, waste treatment, climate change mitigation, coastal protection, and to specify measurable environment (water and sediment) quality criteria, or reference points, to identify when the environment is vulnerable to pollution or polluted. However, ecosystem reference points are not presently set up nor considered by MOF Marine.

2.2.5 Russia

Mission

Any kind of fisheries within the Russian Exclusive Economic Zone (EEZ) is managed by the Federal Agency for Fishery (Rosrybolovstvo) which is under the jurisdiction of the Ministry of Agriculture of the Russian Federation. Rosrybolovstvo organizes state control in the field of fishery, aquaculture and conservation of aquatic biological resources in the internal waters of the Russian Federation, except for internal sea waters. It determines the total allowable catches (TACs) of aquatic biological resources in the internal waters of the Russian Federation, including the internal sea waters, as well as in the territorial sea, the continental shelf and in the EEZ of the Russian Federation, the Azov and Caspian seas (RFAF 2018). The mission of Rosrybolovstvo is supported by two core mandates: 1) to ensure the productivity and sustainability of fishing using TAC limits and recommended catches and 2) to conserve and recover protected species and their habitats. The first mandate is mainly derived through Scientific advice on values for TACs which are aggregated in VNIRO from the materials provided by its regional branches. The Pacific branch (TINRO) is responsible for stocks which occur in the Russian EEZ in the North Pacific. The process is regulated by the Order #104 issued on February 6 in 2015 by Rosrybolovstvo and Order #155 issued on March 29 in 2019 by VNIRO and Order #999 of the Ministry of Natural Resources of Russia "On approval of requirements for environmental impact assessment materials" issued on December 01 in 2020. In the case of recommended catch, the thresholds are monitored and if some of them are crossed then the decision will be made for each stock separately. The second mandate is mainly supported by Fishing Rules, where restrictions on gears, fishing seasons and grounds, limits on bycatch levels are embedded.

Goals

The goal of Rosrybolovstvo science and management plans is to optimize fisheries yield, prevent overfishing, and protect non-targeted species. This is accomplished using a single species approach to fisheries management. An EBFM is mentioned in the beginning of the Order #104 but it has never been implemented for the official TAC calculation.

Government science and strategic plans relevant to reference points

Both national-level and regional-level strategic science plans are produced through bottom-up suggestions from the branches of VNIRO and top-down orders from Rosrybolovstvo, so, they are identical in structure. To the best of our knowledge, there are no national-level and regional Science Centers plans that point to the establishment and use of ecosystem reference points. All reference points used for fishery management are coming from single stock assessment harvest control rules (HCR).

National Level – The Orders #104 and 155 require reference points to identify when fish stocks are vulnerable to overfishing or overfished. Stock status is determined by estimating current levels of fishing mortality F or harvest rate H or catch itself in the case of data poor stocks, abundance of cohorts or of a total fish stock and comparing these metrics with specific reference points. In general, there are three categories of reference points used in Russian fisheries management: target, limit, and precautionary (or buffered). Target reference points are used hoping to reach MSY, limit reference points indicate a state of the fishery to be avoided to prevent an undesirable outcome, and precautionary reference points are buffered using their errors. In some cases, target exploitation rate H_{tr} may be set higher than precautionary H_{pa} point, when logistic curve of the HCR is optimized during management strategy evaluation (MSE). MSE is required by the Order #104 and the Risk Curves and cumulative probabilities of undesirable future states are considered for Scientific Advice.

An interest in developing reference points which incorporate ecosystem considerations, including species interactions, arose due to the requests of Marine Stewardship Council during the audit of certification for walleye pollock trawl fishery in the Sea of Okhotsk. Ecosystem properties, such as large fish indicator, dynamic of fish biomass, α and β diversity, average of maximum fish length in catches, mean fish weight in catches, trophic level (TL) of the catch, Marine trophic index, and biomass-TL distributions have been constructed to show states and estimate trends (Kulik et al., unpublished data).

2.2.6 U.S.A.

Mission

Commercial and recreational fisheries within the U.S. Exclusive Economic Zone and outside of state waters are managed by the National Oceanic and Atmospheric Administration (NOAA), and more specifically the National Marine Fisheries Service (NMFS) or NOAA Fisheries. The mission of NOAA Fisheries is ‘stewardship of living marine resources through science-based conservation and management and the promotion of healthy ecosystems' (NOAA 2017a). The mission is supported by two core mandates: 1) to ensure the productivity and sustainability of fishing and fishing communities and 2) to conserve and recover protected species and their habitats (NOAA 2017a,b). These mandates are mainly derived from three laws enacted by the U.S. Congress, including the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), the Endangered Species Act, and the Marine Mammal Protection Act.

Goals

The overarching goal of NOAA Fisheries' science and management plans is to provide optimum fisheries yield while preventing overfishing and protecting the broader marine ecosystem, including marine mammals and species at risk of extinction (NOAA 2017a). Traditionally, this has been accomplished through a single species approach to fisheries management with ecosystem information used sparingly as background information. However, NOAA Fisheries is currently charged with implementing EBFM to better integrate biological, physical, and social factors in assessments of fish stocks (NOAA 2017b).

Government science and strategic plans relevant to reference points

Both national-level and regional-level strategic science plans are produced by NOAA Fisheries. Here we describe the national-level and regional Science Centers plans that point to the establishment and use of reference points. There are six regional Science Centers. The west coast and Alaska regions are focal components of North Pacific Ocean marine ecosystems and coastal communities within PICES.

National Level – Under the MSFCMA, U.S. regional fishery management plans are required to specify reference points to identify when fish stocks are vulnerable to overfishing or overfished. Stock status is determined by estimating current levels of fishing mortality, abundance and composition of a fish stock and comparing these metrics with specific reference points. Three categories of reference points used in U.S. federal fisheries management: target, limit, and threshold (or trigger) (See Table 2-1 for full definitions of reference points)

Single-species reference points are most commonly used in current U.S. federal fisheries management plans. However, there is increasing interest in developing reference points that incorporate ecosystem considerations including oceanographic conditions and species interactions. To support the shift toward an EBFM, NOAA Fisheries is implementing an EBFM policy and roadmap in which two guiding principles are to '*develop and monitor ecosystem-level reference points* [ERLPs]*'* and to '*incorporate ecosystem considerations into appropriate LMR* [Living Marine Resources] *assessments, control rules, and management'* (NOAA 2016a). There is growing recognition that ELRPs could be useful for detecting important dynamics, ecosystem properties, or ecosystem-wide shifts that could have large impacts on many ecosystem components, including LMRs and LMR-dependent human communities. Potential examples of

ELRPs include measures of ecosystem productivity, ecosystem indicator-based tipping points, and aggregate or system level yield (NOAA 2016a). Ecosystem properties, such as species diversity, trophic level of the catch, and biomass-size distributions could also serve as a basis for ELRPs. Further, NOAA Fisheries proposes developing and tracking ELRPs that can be useful measures of ecosystem-level resilience and community well-being (NOAA 2016a). To support these efforts, several recent studies have aimed to identify ecological thresholds to support the development of ELRPs for fisheries management (e.g., Large et al. 2013, Samhouri et al. 2017, Tam et al. 2017).

In addition to EBFM, NOAA Fisheries recognizes the need for 'Climate Smart' management decisions and thus has developed a national Climate Science Strategy (CSS). A key goal of this initiative is 'to address the impacts of climate change on fisheries, their habitats, and the communities that depend upon them' (Link et al. 2015). To achieve this, NOAA Fisheries has outlined seven main objectives, two of which include '*identifying appropriate, climate-informed reference points for managing LMRs*' and '*tracking trends in ecosystems, LMRs, and LMR-dependent human communities and providing early warning of change*' (Link et al. 2015).

Regional Level – Strategic Science Plans, EBFM Road Map Implementation Plans, and Regional (Climate) Action Plans are developed by each of the six NOAA Fisheries Science Centers in support of EBFM and the CSS, in addition to other national mandates and programs. The Alaska Science Center's Strategic Science Plan is largely focused on research activities that address the needs outlined in the national CSS. The Science plan highlights the need *'to identify and monitor thresholds in ecosystem parameters that signal the need to adjust management strategies'*, which could be done through Alaska's Integrated Ecosystem Assessment program (NOAA 2017c). The Strategic Science Plans for the West Coast (NOAA 2013a, NOAA 2013b), Pacific Islands (NOAA 2019a), Northeast (NOAA 2016b), Southeast / Gulf of Mexico (NOAA 2016c) do not explicitly mention the establishment of ELRPs. The Pacific Islands Center's EBFM Road Map Implementation Plan does includes the evaluation and tracking of ecosystem-level reference points to assess changes in ecosystem-level resilience as an ongoing action item (NOAA 2019b), and the Northeast Center's Plan identifies research to '*establish thresholds to determine ecosystem resilience*' as a dedicated area of work (NOAA 2019c).

Each Science Center's Regional (Climate) Action Plan points to the establishment of climate-informed reference points. The Alaska Regional Action Plan specifically mentions the identification of ecosystem thresholds to climate drivers as a research priority for the Alaska Center (NOAA 2016d). The West Coast Regional Action Plan aims to do the same through the California Current IEA program and related efforts (NOAA 2016e). In addition, the Northeast Science Center's Plan includes '*conducting research on regime shift effects on NOAA Trust Resources related to thresholds in climate-related variables*' (Lovett et al. 2016). The two Regional Actions Plans developed by the Southeast Science Center (Southeast U.S. and Gulf of

Mexico) highlight the need for identifying thresholds (or societal preferences) in social and economic indicators that could be useful for providing early warnings about climate impacts on the fishing industry and fishing communities.

2.3 Synthesis, commonalities and differences among member nations

Our review of the mission, goals, and governmental science plans of PICES member nations reveal that consideration of ecosystem information and ELRPs in fisheries management varies across the nations. Some nations are mandated by law to implement an EBFM rather than focus on single species, some nations do not mention the need for ecosystem information in their science and management plans, and other nations fall within this spectrum. In those nations that are currently working towards implementing an EBFM, ecosystem information is mostly used as background information to provide context for setting fisheries catch quotas. These nations do point to the establishment of ELRPs in their science and management plans, however they are not yet commonly required. Single species reference points are required in current fisheries management for all PICES member nations.

2.4 Conclusions

- All member nations are required to use single species reference point in fisheries management.
- ELRPs are not yet commonly required across PICES member nations.
- Most member nations point to the inclusion of ecosystem information in government science and management plans.
- A few member nations include the establishment of ELRPs as an important priority in government science and management plans.

Table 2-1: Definitions of limit, target and threshold reference points as defined by PICES member nations.

Reference Point	Definition
Target (TRP) U.S.A.	1. Benchmarks used to guide management objectives for achieving a desirable outcome (e.g., optimum yield). TRPs should not be exceeded on average[1] 2. Corresponds to a state of a fishery or a resource that is considered desirable. Management action, whether during a fishery development or a stock rebuilding process, should aim at bringing the fishery system to this level and maintaining it there. In most cases a TRP will be expressed in a desired level of output for the fishery (e.g., in terms of catch) or of fishing effort or capacity, and will be reflected as an explicit management objective for the fishery.[2]
Limit (LRP) U.S.A.	1. Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low. In the National Standard Guidelines, limits are referred to as thresholds. In much of the international literature (e.g., United Nations Food and Agricultural Organization) thresholds are used as buffer points that signal when a limit is being approached.[1] (see National Standard Guidelines)
Threshold (ThRP) U.S.A.	1. Indicates that the state of a fishery and/or a resource is approaching a TRP or an LRP, and that a certain type of action (usually agreed beforehand) needs to be taken. Fairly similar to a LRP in their utility, the specific purpose of the ThRP is to provide an early warning, reducing further the risk that the LRP or TRP are inadvertently passed due to uncertainty in the available information or inherent inertia of the management and industry systems. Adding precaution to the management setup, they might be necessary only for resources or situations involving particularly high risk.[2]
LRP Canada	Marks the boundary between the cautious and critical zones. When a fish stock level falls below this point, there is a high probability that its productivity will be so impaired that serious harm will occur. The limit reference point is established based on the best available scientific information. At this stock status level, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities. Several approaches for calculating the LRP are in use and may be refined over time. The units describing stock status will vary depending on the nature of the resource (groundfish, shellfish, salmonids or marine mammals). The LRP is based on biological criteria and established by Science through a peer reviewed process.
USR Canada	Marks the boundary between the healthy and cautious zones. When a fish stock level falls below this point, the removal rate at which the fish are harvested must be progressively reduced in order to avoid serious harm to the stock. The upper stock reference point (USR) is also a target reference point that is determined by productivity objectives for the stock, broader biological considerations, and social and economic objectives for the fishery. The USR, at minimum, must be set at an appropriate distance above the LRP to provide

	sufficient opportunity for the management system to recognize a declining stock status and sufficient time for management actions to have effect. Secondly, the USR can be a target reference point (TRP) determined by productivity objectives for the stock, broader biological considerations and social and economic objectives for the fishery. In either case, the USR would be developed by fishery managers informed by consultations with the fishery and other interests, with advice and input from Science. (see TRP)
TRP Canada	A TRP is a required element under UNFA and in the FAO guidance on the application of the Precautionary Approach, as well as eco-certification standards based on it, such those of the Marine Stewardship Council and may also be desirable in other situations. In practice, the threshold point below which removals must be reduced to avoid serious harm can be different than the TRP. However, it is essential that while socio-economic factors may influence the location of the USR, these factors must not diminish its minimum function in guiding management of the risk of approaching the LRP.

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3 Efforts identifying data availability within specific North Pacific ecosystems, fish stocks, and fishing communities.

3.1 Introduction

PICES WG36 was tasked with summarizing previous efforts that identified data availability for geographic areas and time periods of particularly strong climate influence and dependence on marine systems within specific North Pacific ecosystems, fish stocks, and fishing communities. In addition, the work done by WG36 built upon indicators identified by previous PICES expert groups, such as WG19, WG28, WG35, and the HD committee (Appendix 3 Table A1). WG36 members reviewed previous PICES work, data inventories, and recommended indicators while consulting with WG35 and the HD committee regarding indicators. WG36 members then updated the data inventory for indicators within member nations and selected indicators that could be used in analyses to address the remaining Terms of Reference. The objectives of selecting these indicators were to 1) identify common indicators across PICES member nations, 2) determine shapes or functional forms of pressure - response relationships from available datasets, 3) quantify thresholds to identify potential ecosystem reference points, and 4) identify ecosystem components that respond earliest to changes in biophysical drivers and could potentially serve as leading indicators of loss of resilience and ecosystem change.

3.2 Summary of PICES efforts to identify data availability and recommended indicators

In 2003-2004, a PICES Study Group on ecosystem-based management in science and its application to the North Pacific (SG-EBM) reviewed and described existing and anticipated ecosystem-based management initiatives in PICES member nations and the scientific bases for them. This group also identified emerging scientific issues related to the implementation of ecosystem-based management. They recommended the formation of PICES Working Group 19 (WG19; 2004-2009) on ecosystem-based management in science and its application to the North Pacific. As part of their terms of reference, WG19 described ecosystem-based management objectives of PICES member nations and ecosystem monitoring approaches for predicting human and environmental influences on marine ecosystems. In addition, they evaluated indicators from the 2004 Symposium on “Quantitative Ecosystem Indicators for Fisheries Management” for application to the North Pacific. In fulfilling these goals, WG19 identified lessons learned from the Bering Sea, Alaska. They concluded that to enable an operational ecosystem-based approach to fisheries management, requirements include the establishment of a policy, management, monitoring and assessment framework with measurable operational objectives. Indicators are then needed to quantify performance of management with respect to objectives (Kruse and Evans 2006). For identified core indicators, each PICES member nation in WG19 summarized data availability and whether the indicators were regularly updated (see Table 3.1.3 in Perry et al. 2010).

A 3-day PICES FUTURE Science Program workshop entitled "Indicators of Status and Change within North Pacific Marine Ecosystems", April 26-28, 2011, resulted in recommendations for the utilization of a framework for identifying and calculating indicators:

- identify objective of selecting indicators
- identify end user
- identify ecosystem attributes to be measured
- apply criteria to select indicators:
    - available regularly
    - available as time series
    - statistical properties are understood
    - related
    - specific
    - appropriate spatial and temporal scales
    - responsive
    - relevant
    - understandable
    - basis for comparison
- criterion should be weighted for relevance to end user identified.
- identify indicator reference levels
- test performance
- identify method of communication; report indicator uncertainty

The PICES FUTURE Science Program proposed a Working Group on the Development of Ecosystem Indicators to Characterize Ecosystem Responses to Multiple Stressors (WG 28; 2011-2015). WG28 updated the inventory of indicators, data existence, availability, and spatial extent (Takahashi and Perry 2019). The main recommendations from WG28 for developing indicators were:

- Defined strategic goals and ecological or management objectives for indicators are needed.
- There are multiple approaches to assess indicator responses to multiple stressors, such as data-based, expert judgement, a combination of data and expert judgement, and models. Given the strengths and challenges of these approaches and that data availability will continue to be lacking for some stressors and ecosystems, WG28 recommended using multiple approaches to identify indicators and evaluate multiple stressors on marine ecosystems. For example, data-driven approaches are preferred, however, expert opinion

may be necessary when the focus is on broad spatial scales where data is not necessarily available.

- Clearly documented conceptual or pathways-of-effects models and risk assessments are needed.
- Select a suite of integrative indicators that cover key components and gradients at the appropriate spatial scales.
- Indices for multiple stressors need to be “simple” but at the same time allow for users to “drill down” to obtain more details about how particular sets of stressors might be driving particular responses in habitats.
- When selecting indicators, use a toolbox approach; that is, use a core set of recommended indicators for all ecosystems and include additional ecosystem-specific, pressure-linked response indicators not reflected in the core set (Table 1).

In addition to the toolbox of indicators recommended by WG28, the PICES Human Dimensions (HD) Committee and Working Group on the North Pacific Ecosystem Status Report-3 (WG35; NPESR-3) identified supplemental indicators that would be beneficial to consider, such as, the quantity and value of catches and landings of seaweeds, fish, shellfish, and other invertebrates from inside and outside national Exclusive Economic Zones (EEZs; Appendix 3 Table A1).

PICES WG36 members reviewed and updated inventories of data existence, availability, and spatial and temporal extents for the toolbox of recommended indicators. Members then identified those indicators that could contribute to addressing their region’s strategic goals or ecological or management objectives, covered key components of selected ecosystems, for which data time series were readily available, and covered the longest time period for analyses in their regions. Members were able to assemble time series for most, but not all, recommended core indicators that were applicable and specific to their regional ecosystems. In some cases, indicators were excluded to maximize the length of time series or because they were highly correlated with other indicators. This provided a base set of time series on which to conduct analyses of ecosystems and indicators that were the focus of WG36 activities (Appendix 3 Table A1).

3.2.1 Canada

Ecosystem

For PICES WG36 analyses, Canada focused waters on the west coast of Vancouver Island (WCVI), British Columbia, that fall within the northern area of PICES bioregion #11 (Figures 1-1, 3-1). The WCVI is a highly productive upwelling area off the west coast of North America that supports some of British Columbia’s largest fisheries (Boldt et al. 2021). The WCVI is at the northern extent of the California upwelling zone (Ware and McFarlane 1989, McFarlane and Beamish 1992, Beamish and Bouillon 1993) and experiences seasonal (spring-summer) upwelling. The transition periods between the upwelling and downwelling seasons occur in

February-April and October-November (Ware and McFarlane 1995). Annual variation in the timing, duration, and magnitude of the spring upwelling, along with El Niño and marine heat waves events, may produce varying degrees of match or mismatch between biological processes and environmental conditions (Mackas et al. 2001, McFarlane et al. 1995, McFarlane et al. 1997, Ware and McFarlane 1995, Jamieson et al. 1989, Hourston and Thomson 2019). Zooplankton biomass anomalies are correlated with salmon marine survival, sablefish recruitment, herring growth, and sardine production (Mackas et al. 2007, Tanasichuk 2002). Predation and competition are other biological processes that may play a role in the WCVI ecosystem for some species, such as Pacific herring (Schweigert et al. 2010, Godefroid et al. 2019). For example, warm years resulting in increased hake abundance can negatively affect herring year-class strength, since hake are predators of herring and also competitors for euphausiid prey (Mysak et al. 1982, Ware and McFarlane 1986). Bottom-up processes, however, appear to be important drivers in this ecosystem, since resident fish yield was found to be correlated with phytoplankton and zooplankton production in BC (Ware and Thomas 2005, Boldt et al. 2021).

Exploitation

The productive WCVI area has supported multiple commercial fisheries at various times during the last century, including pelagic fisheries for Pacific herring (*Clupea pallasi*), Pacific hake (*Merluccius productus*), salmon (*Oncorhynchus* spp.), and Pacific sardine (*Sardinops sagax*), groundfish fisheries for flatfish and rockfish (variety of species), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*), lingcod (*Ophiodon elongatus*), Pacific halibut (*Hippoglossus stenolepis*), spiny dogfish (*Squalus acanthias*), as well as trap/trawl fisheries for Pandalid shrimp (*Pandalus* spp.). The average total catch of fish was approximately 30,000 t during the 1920s to the mid-1960s, increased to 100,000 t during the late 1980s to late 1990s (McFarlane et al. 1997). These trends are reflected in landings taken from offshore areas of statistical areas 24, 25, 124, 125, where catches were approximately 6,100 t in 1980 and increased in the early to mid-1990s (20,000 to 28,000 t). Catches were lower in the late 1990s to mid-2000s then increased to 20,000-30,000 range. Record high catches in 2010 were due to large Pacific hake landings.

Data and Indicators

For WG36 analyses and to address ecosystem objectives (specified in Table 3-1), indicators of environment, human, and ecosystem pressures and responses were selected based on indicator selection criteria and frameworks (e.g., Bundy et al. 2017; Drivers, pressures, status, indicators, responses (DPSIRS) approach; Table 1) and core indicators identified by previous studies (Appendix 3 Table A1; Shin et al. 2010a, Shin et al. 2010b, Link et al. 2010, Fu et al. 2012, 2015, 2019, Lucey et al. 2012, Boldt et al. 2014). Indicator time series were assembled for 1986-2017 (Table 3-1), the longest collective time period for selected indicators (Boldt et al. 2021).

Indicators of the physical environmental pressures that were examined included large-scale indicators of sea surface temperature change, such as the Pacific Decadal Oscillation (PDO, annual; Mantua et al. 1997), multivariate ENSO Index (MEI, annual; https://climatedataguide.ucar.edu/climate-data/multivariate-enso-index), and the local sea surface temperature as measured by satellite for the WCVI area (https://www.ncdc.noaa.gov/oisst; Banzon et al. 2016, Reynolds et al. 2007) (Table 1; Boldt et al. 2021). The North Pacific Gyre Oscillation (NPGO) was used as an indicator of water source (Di Lorenzo et al. 2008) and the magnitude and timing of upwelling were used as indicators of nutrient availability (Hourston and Thomson 2019).

Indicators of human pressures, such as fishery removals (landings) and ecosystem function, were derived from commercial landings data (Table 3-1; Boldt et al. 2021). Commercial landings data were available in BC for DFO statistical areas 24/124, and 25/125, overlapping spatially and temporally with data from the fishery-independent multi-species bottom trawl survey. Indicators included total landings, trophic level of the landings, and catch of foraging groups (benthivores, planktivores, zoopivores, and piscivores; based on Lucey et al. 2012), catch of habitat groups (pelagics, demersals), the ratio of pelagic to demersal fish landings, and the intrinsic vulnerability index (Cheung et al. 2007).

Several ecosystem response indicators were based on Fisheries and Oceans Canada's (DFO) fishery-independent, multi-species, small mesh bottom trawl survey conducted annually since 1973 in an area off the WCVI (statistical areas 124 and 125). The area covered by the survey is approximately 4,707 km^2 (statistical areas 125 and 125 combined) and stations are sampled at depths between 50 and 200 m during late April to May. Indicators from these survey data included: total surveyed biomass, biomass of foraging groups (benthivores, planktivores, zoopivores, and piscivores; based on Lucey et al. 2012), biomass of habitat groups (pelagics, demersals), and the ratio of pelagic to demersal fish biomass, the proportion of predatory fish, mean length, and mean lifespan (latter two indicators were based on published information combined with survey biomass). Beginning in 1986, there were also long time-series of zooplankton biomass and community composition for this marine ecosystem (Galbraith and Young 2018). Indicators examined included the biomass anomalies of southern, boreal, and subarctic copepods. Steller sea lion abundance time series was relatively long, but data were available every 2 to 5 years (Olesiuk 2018).

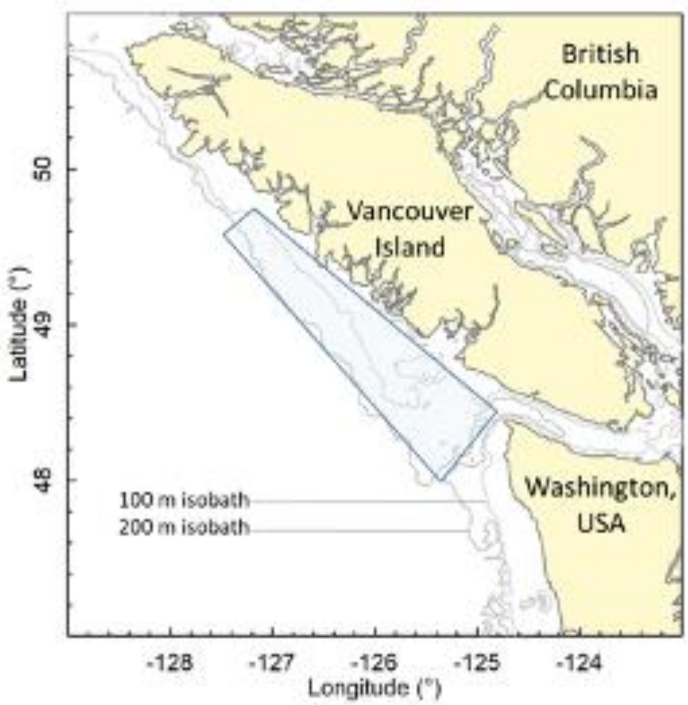

Figure 3-1. Generalized area off the west coast of Vancouver Island, British Columbia, Canada for which indicators were analyzed. Note: the small mesh, multi-species bottom trawl survey covers a smaller area within this generalized area.

Table 3-1. Drivers, objectives, pressures (A), responses (states and impacts) (B), indicators, and sources for the west coast of Vancouver Island and broader basin-scale ecosystem time series. Those indicators in bold font were included in further analyses; other indicators were excluded because they were highly correlated (r = 0.8) either among pressure or among response indicators. Table from Boldt et al. (2021).

(A) Drivers and Pressures

Component	Driver	Objective	Pressure	Pressure Indicator	Source
Environment	Atmospheric pressure and greenhouse gas	Monitor effects of climate change	SST change	**Pacific Decadal Oscillation (PDO_Annual)**	a
			Large-scale circulation	**North Pacific Gyre Oscillation (NPGO)**	b
			SST change	**Multivariate ENSO Index Version 2 (MEI_Annual)**	c
			SST change	**Local sea surface temperature (SST_satellite)**	d
			Nutrient availability	**Upwelling magnitude**	e
			Nutrient availability	**Spring transition timing**	e
Human	Seafood demand	Monitor effects of fisheries	Fishery removals (landings)	**Total landings (Tot_Landings)**	f
			Ecosystem function change	**Trophic level of landings (TL_Landings)**	g
			Ecosystem function change	Intrinsic vulnerability index (IVI)	g
			Ecosystem function change	Catch of foraging groups: benthivores, planktivores, zoopiscivores, piscivores	f
			Ecosystem function change	Catch of habitat groups: demersals, pelagics	f
			Ecosystem function change	Ratio of pelagics to demersals catch (C_Pel_Dem)	f

(B) Responses - States and Impacts

Component	Objective and Impacts	Response Indicator	Source
Ecosystem	Maintain structure and function	**Copepods southern biomass anomalies**	h
	Maintain structure and function	**Copepods boreal biomass anomalies**	h
	Maintain structure and function	**Copepods subarctic biomass anomalies**	h
	Maintain structure and function	**Trophic level of surveyed species (TL_SurveyedComm)**	i
	Maintain structure and function	**Steller sea lion abundance**	j
	Maintain structure and function	Mean length (Mean_Len)	g
	Maintain stability and resistance to perturbations	Mean lifespan	g
	Conserve biodiversity	**Proportion predatory fish (Prop_PredFish)**	i
	Maintain resource potential	**Biomass of surveyed species (Tot_B_Survey)**	i
	Maintain resource potential, structure, function	Survey biomass of foraging groups: benthivores, planktivores, zoopiscivores, piscivores	i
	Maintain resource potential, structure, function	Survey biomass of habitats groups: pelagics, demersals	i
	Maintain resource potential, structure, function	**Ratio of pelagics to demersals survey biomass (B_Pel_Dem)**	i

Source:

a. http://research.jisao.washington.edu/pdo/PDO.latest.txt; Mantua et al. 1997

b. Di Lorenzo et al. 2008

c. National Center for Atmospheric Research Staff (Eds). Last modified 20 Aug 2013. "The Climate Data Guide: Multivariate ENSO Index." Retrieved from https://climatedataguide.ucar.edu/climate-data/multivariate-enso-index.

d. "https://www.ncdc.noaa.gov/oisst. Dataset Citation: Banzon et al. 2016, Reynolds et al. 2007.

e. Hourston and Thomson 2019.

f. Maria Surry, Shelee Hamilton, Leslie Barton, Mary Thiess (DFO).

g. Caihong Fu (DFO).

h. Moira Galbraith, Kelly Young, Ian Perry (DFO); Galbraith and Young (2018).

i. Brenda Waddell, Ian Perry, small mesh multispecies survey (DFO).

j. Olesiuk 2018.

3.2.2 China

Ecosystem

For PICES WG36 analysis, China focused on waters on the east coast of Mainland China in the northern area of bioregion #20 (Figure 1-1 and see Guan et al. 2020 Fig. 1), a semi-closed basin on the continental shelf of the Northwest Pacific. In the broader large marine ecosystem, the mean sea surface temperature (SST) rose by 0.67 ℃ during 1982 – 2006. This rate of warming is much higher than the global mean rate over the same period. Moreover, with the general acceleration of ocean warming (Cheng et al., 2019), rapid warming continues in study region, especially during the months of May and August (see Guan et al. 2020 Fig. 2). In addition, the system is very productive ecosystem and serves as crucial spawning, nursery or feeding grounds for various fish stocks.

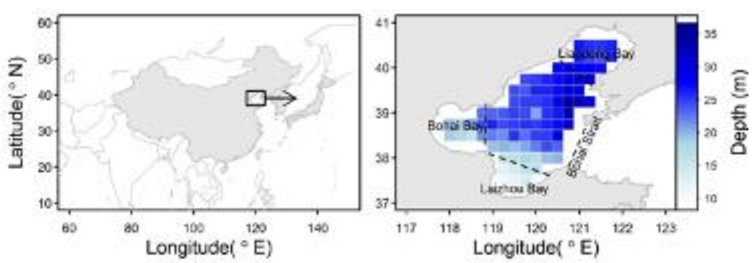

Figure 3-2. The study system for China’s case study (left) and regular fisheries monitoring focus on shaded area with bathymetric information (right) (From Guan et al. 2020 Fig. 1).

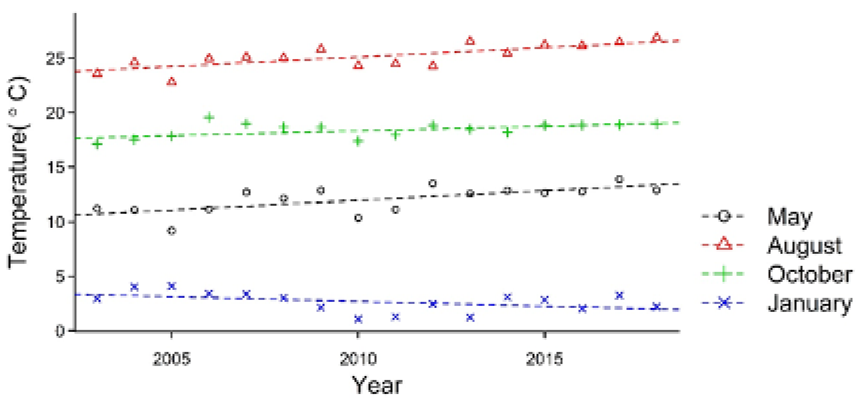

Figure 3-3. Temporal trends in average sea surface temperatures (SST) in the study system in May, August, October and January (from Guan et al. 2020 Fig. 2).

Exploitation

Fisheries in the northern area of bioregion #20 mainly operate with three types of fishing gears (trawl, gillnet and stow net). Most fisheries target at multispecies and could land all their captures before 2018, except national protected animals, A minimum size limit strategy was implemented for 15 commercially important fish species throughout China's marine waters since 2018, in order to promote effective protection of juvenile and yearling fish. Moreover, all fisheries except those using monofilament gillnets or jigs were prohibited in this ecosystem from June 1st to September 1st from 2009 to 2016. This suspension of fishing activities has been extended by one month earlier since 2017.

Under the combined impact of human activities and climatic changes, many stocks have depleted especially those at high trophic levels, e.g., small yellow croaker (*Larimichthys polyactis*), largehead hairtail (*Trichiurus japonicus*), Japanese Spanish mackerel (*Scomberomorus niphonius*), chub mackerel (*Scomber japonicus*) and Chinese shrimp (*Fenneropenaeus chinensis*). After 2000, major productions of capture fisheries in this ecosystem became increasingly dependent on small pelagic fish like anchovies and invertebrates including crabs, mantis shrimp (*Oratosquilla oratoria*), Acetes and squids. Their annual landings have been around half a million tons in recent years, with a rough worth of 18 billion RMB.

Data

Fishery-independent monitoring extended to the whole northern area of bioregion #20 in 1980s and 1990s. The 1st round of fishery resource surveys occurred monthly in this ecosystem from April 1982 to May 1983, which included bottom trawl surveys for adults and juveniles of nektonic species and horizontal trawl surveys for different types of plankton, especially ichthyoplankton (Deng, 1988; Wan and Zhang, 2016). The established sampling protocol of these surveys has remained in use. For each bottom trawl, catches of nektonic species were discriminated by species to count, weight and sample. Catches per trawl by species in number and biomass were recorded on the spot, along with the depth, temperature and salinity at the beginning and end locations. Moreover, sampled individuals for each species were measured for length and weight, and some samples needed to be analyzed for feeding condition, maturity stage, diet composition, fecundity and/or age identification. Such fishery resource surveys ceased in the subsequent years and were conducted again by season in August 1992 to May 1993 and May 1998 to February 1999 (Jin, 2001). These surveys provided ample data for studying the biology and ecology of various fishes and invertebrates, as well as species composition, community structure, biodiversity and food web dynamics of fishery resources in the northern area of bioregion #20 in 1980s and 1990s (e.g., Deng *et al.*, 1988a, 1988b, 1988c; Jin and Deng, 2000; Tong *et al.*, 2000; Jin, 2001)

Based on these historical fishery-independent surveys, regime shifts (including abrupt changes in species abundance, community composition and trophic organization) were recognized in the northern area of bioregion #20 at the beginning of the 21st century (Jin, 2004, 2001; Jin and Deng, 1999). Since then, this ecosystem has attracted growing monitoring efforts to evaluate the dynamics of its major fish stocks. First, fishery resource surveys upsurged in the Laizhou Bay (one of the three major coastal bays inside the study system) during the years of 2003 – 2008, with one cruise for each spring and several cruises in summer and fall, as this coastal bay serves as critical spawning and nursery grounds for various fishes and invertebrates (Wan and Zhang, 2016). Three cruises of these surveys broadly covered the whole Bohai Sea in the spring and fall of 2004 and the spring of 2005 (Li et al., 2008). Such surveys continued, but did not occur annually in 2009 – 2013. Recently, China initiated its national regular fisheries monitoring program in 2014, which supports two to four cruises of seasonal fishery resource surveys and additional ichthyoplankton surveys in the northern area of bioregion #20 each year.

Indicators

Indicators of environment, human and ecosystem pressures were selected for WG36 analyses and to address ecosystem objectives, based on data availability and core indicators identified by published studies. Indicators of environmental pressures included temperature, salinity, the volume and timing of freshwater discharge, days of gale weather. Indicators of human pressures included, 1) total landings data from wild fisheries; 2) landings of different taxa (seaweed, jellyfish, shellfish, cephalopods, crustaceans and fish), 3) landings at different trophic levels, and 4) landings of habitat groups (pelagics and demersals, or cold-water and warm-water species). Ecosystem indicators included total surveyed biomass, biomass of different taxa, mean trophic level, keystone/dominant species.

Table 3-2 Indicators of environment and human pressures and ecosystems responses for the northern area of bioregion #20, China.

Component	Objective	Pressure/ Response	Indicators	Source
Environment	Monitor effects of environmental changes	Temperature change	Surface and bottom temperature	c
		Salinity change	Surface and bottom salinity	c
		Nutrient availability	Volume and timing of freshwater discharge	a,d
		Disturbance on system productivity	Days of gale weather in spring	a,d
Human	Monitor effects of fisheries	Fisheries removals	Total landings from wild fisheries	e
		Effects on Ecosystem structure and function	Landings of different taxa	e
			Landings at different trophic levels	b
			Landings of habitat groups	b
Ecosystem	Monitor ecosystem changes	Changes in ecosystem structure, function and energy flow	Total biomass of fishery resource	c,f
			Biomass of different taxa	c
			Mean trophic level	h
			Keystone/dominant species	f,g

Source:

a. Deng, J., and Ye, C. 1986. The prediction of penaeid shrimp yield in the Bohai Sea in autumn. Chinese J. Oceanol. Limnol. 4(4): 343–352.

b. Ding, Q., Shan, X., Jin, X., and Gorfine, H. 2021. A multidimensional analysis of marine capture fisheries in China’s coastal provinces. Fish. Sci. 87(3): 297–309. Springer Japan. doi:10.1007/s12562-021-01514-9.

c. Jin, X.S., Shan, X.J., Li, X. Sen, Wang, J., Cui, Y., and Zuo, T. 2013. Long-term changes in the fishery ecosystem structure of Laizhou Bay, China. Sci. China Earth Sci. 56(3): 366–374. doi:10.1007/s11430-012-4528-7.

d. Liu, C., Yan, J., and Cui, W. 1981. A study on the method of prediction for the autumnal prawn catches in Bohai Sea. J. Fish. China 5(1): 65–73.
e. National Bureau of Statistics of China. 2006 to 2021. Fishery Statistical Yearbooks. China Statistics Press, Beijing
f. Tang, Q. 2006. Maine living resources and environment in the China exclusive economic zone. Science press, Beijing.
g. Yang, T., Shan, X., Jin, X., Chen, Y., Teng, G., and Wei, X. 2018. Long-term Changes in Keystone Species in Fish Community in Spring in Laizhou Bay. Prog. Fish. Sci. 39(1): 1–11. doi:10.11758/yykxjz.20170912001.
h. Zhang, B., Wu, Q., and Jin, X. 2015. Interannual Variation in the food web of commercially harvested species in Laizhou Bay from 1959 to 2011. J. Fish. Sci. China 22(2): 278–287. doi:10.3724/SP.J.1118.2015.14299.

3.2.3 Japan

Ecosystem

For PICES WG36 analyses, Japan focused on marine areas surrounding the Shiretoko Peninsula, Hokkaido in PICES bioregions #17 and 18 (Figure 1-3, 3-4). The marine areas surrounding Shiretoko Peninsula are parts of the Shiretoko World Natural Heritage (WNH) site. The marine areas are influenced by both the East Sakhalin cold current and the Soya warm current (Ohshima et al., 2001). Melting of seasonal sea ice, vertical mixing during winter, and nutrients brought by seasonal upwelling develop one of the richest and most diverse marine ecosystems in the world (Sakurai, 2006). The highly productive marine areas support a wide range of species including marine mammals, seabirds, and commercially important species (Sakurai, 2007). The Shiretoko WNH site is also characterized by its close interrelationship between marine and terrestrial ecosystems (Makino and Sakurai, 2012).

Exploitation

Marine area surrounding Shiretoko Peninsula is one of the most productive fishing grounds in Japan (Sakurai, 2006). Main target species are salmonids such as chum salmon (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*), Japanese common squid (*Todarodes pacificus*), walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), and Atka mackerel (*Pleurogrammus azonus*) (Makino and Sakurai, 2012). Fisheries is one of the most important industries in both Shari Town and Rausu Town. Annual fish catch of major species of Shari Town in 2018, facing to Sea of Okhotsk, was 16,338 ton, equivalent to 10.2 billion Japanese Yen (Shari Town, 2020). For five years from 2014 to 2018, respective annual fish catches have been lower than the average fish catch from 1985 to 2018, i.e. 25,273 ton (Shari Town, 2020). As for Rausu Town, facing to Sea of Okhotsk, annual fish catch of major species in 2019 was 21,289 ton, equivalent to 6.8 billion Japanese Yen (Rausu Town, 2019). Respective annual fish catches of major species of Rausu Town from 2017 to 2019 have been the lowest level since 2002, less than half of its peak of 50,600 ton in 2013 (Rausu Town, 2019; Kushiro Natural Environment Office of Ministry of the Environment et al., 2013). Sea lion is one of the major species representing predator at high trophic level in marine ecosystems in the Shiretoko WNH. In parallel with salmonids, walleye pollock and Japanese common squid, sea lion is designated as one of the indicator species in the Multiple Use Integrated Marine Management Plan for Shiretoko WNH Site (Ministry of the Environment and the Hokkaido Prefectural Government, 2018).

Data and Indicators

In the Shiretoko marine area, Ministry of the Environment of Japan and the Hokkaido Prefectural Government have carried out long-term monitoring for (1) marine environment conditions, (2) fish and shellfish, (3) sea mammals, (4) sea birds, and (5) local communities. Indicators were selected from long-term monitoring results, and compiled for WG 36 analysis (Table 3-3).

For indicators of the physical environmental pressures, sea surface water temperature (SST), current velocity and direction were selected to understand changes in sea conditions. The data were obtained from long-term monitoring of oceanographic buoys by Shiretoko Data Center, the Ministry of the Environment (Shiretoko Data Center, 2005-2018). Observation data were averaged by season (spring: April-June, summer: July-September, and autumn: October-December). Here, the winter observation data was not used for the analysis due to lack of data. In addition, summer and autumn current velocity and direction data in 2016 were also not used in the analysis due to the passage of four typhoons over eastern Hokkaido from August to October of the same year.

For indicators of the human pressures, the fish catches of ocean salmonids that was included with chum salmon (*Oncorhynchus keta*), walleye pollock (*Gadus chalcogrammus*), common squid (*Todarodes pacificus*), and yellowtail (*Seriola quinqueradiata*) in Shari and Rausu towns were selected as indicators to understand effects of human activities. Data was obtained from the Annual Fishery Production Statistics (MAFF, 2006-2018). Here, Yellowtail was added as an indicator due to the rapid increase in catches by salmon set nets in recent years. In addition, population of Steller sea lion (*Eumetopias jubatus*) have been controlled in order to reduce severe fisheries damage caused by them, which occur mainly along the coast of Hokkaido. Thus, the number of individuals captured of Steller sea lions was selected as an indicator, and the data was obtained from the State of conservation report of Shiretoko (Government of Japan, 2016). Note that the data include the number of individuals captured not only within the Shiretoko WNH marine areas but also outside the Shiretoko WNH marine areas in the Nemuro district.

For ecosystem response indicators, migrating populations of chum salmon, walleye pollock, common squid, and yellowtail, and the abundance of Steller sea lions in Shiretoko sea area were selected as indicators. Data on chum salmon, walleye pollock, and yellowtail stocks were obtained from the FRA's stock assessment results report (FRA, 2006-2019). Steller sea lion abundance data were referred from the State of conservation report of Shiretoko (Government of Japan, 2016).

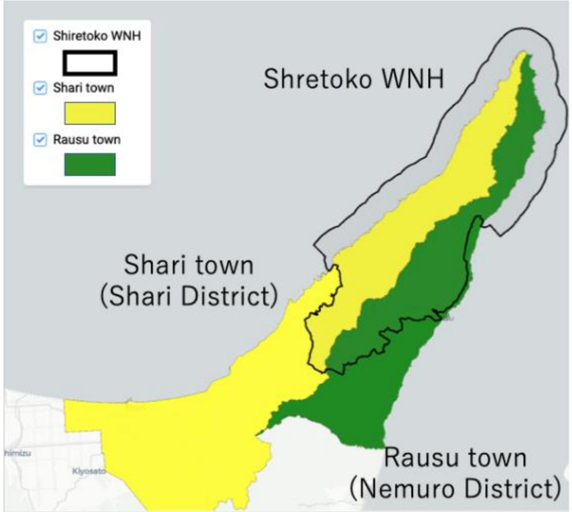

Figure 3-4. Generalized area of the Shiretoko Peninsula, Hokkaido, Japan for which indicators were analyzed (PICES bioregions #17 and 18, Fig. 1-3)

Table 3-3. Indicators of: (A) environment and human pressures, (B) ecosystem responses for the Shiretoko Peninsula, Hokkaido. Data sources are listed below.

(A)

Component	**Pressure**	**Indicator**	**Source**
Human	Fishery removals (landings)	Catch of salmon (including ocean salmonids other than chum salmon) in Shari and Rausu towns	1
	Fishery removals (landings)	Catch of walleye pollock in Shari and Rausu towns	1
	Fishery removals (landings)	Catch of common squid in Shari and Rausu towns	1
	Fishery removals (landings)	Catch of yellowtail in Shari and Rausu towns	1

	Ecosystem function change	Number of captured Steller sea lions in Nemuro Strait	2
Environmental pressures	SST change	Local sea surface temperature (spring, summer, autumn) by observation buoys in Shari side	3
	Current variability	Local current velocity (spring, summer, autumn) by observation buoys in Shari side	3
	Current variability	Local current direction (spring, summer, autumn) by observation buoys in Shari side	3

(B)

Component	**Objective**	**Indicator**	**Source**
Ecosystem	Maintain resource potential, structure and function	Age specific CPUE for chum salmon captured during summers in the Bering Sea.	4
	Maintain resource potential, structure and function	Predicted fish stock of walleye pollack (southern Sea of Okhotsk)	4
	Maintain resource potential, structure and function	Predicted fish stock of Yellowtail (all over Japan)	4
	Maintain resource potential, structure and function	Predicted the winter-spawning stock of common squid (all over Japan)	4
	Maintain structure and function	Number of Steller sea lion in Nemuro Strait by visual count from land (annual maximum number)	2

Source:
1. MAFF (2004-2018)
2. Government of Japan (2016)
3. Shiretoko Data Center (2005-2019)
4. FRA (1994-2019)

3.2.4 Korea

Ecosystem

For PICES WG36 analysis, Korea focused on the coastal waters around the Korean Peninsula in PICES bioregions #19, 20, and 21 (Figure 1-3, 3-5). The sea surface temperature of these waters increased during the last 51 years (1968-2018), at a rate 2.5 times higher than the global trend (Han and Lee 2020). Since the 1970s, low-oxygen water masses (hypoxia) caused by rising seawater temperature and eutrophication in the coastal areas have caused economic loss to the marine ecosystem and fishers. The zooplankton biomass and copepod biomass increased in the late 1980s and early 1990s, and the biomass increases were associated with a climate regime shift that occurred in 1989 (Rebstock and Kang 2003). The area of the spawning ground was highly correlated with the total catch of common squid, *Todarodes pacificus*, throughout four decades (1970~2010). The Pacific Decadal Oscillation (PDO) was negatively correlated with the area of the spawning ground in the southern areas of bioregions #19, 20, and 21 (Kim et al. 2018). These preceding studies indicate close relationships between changes in the marine ecosystems in bioregions #19, 20, and 21 and climate.

Exploitation

The coastal waters around the Korean Peninsula provide spawning and breeding grounds and fishing grounds for various commercial fish species, including skate, sole, hairtail (*Trichiurus japonicus*), sharp toothed eel (*Muraenesox cinereus*), chub mackerel (*Scomber japonicus*), Pacific saury (*Cololabis saira*), blackthroat seaperch (*Doederleinia berycoides*), Pacific cod (*Gadus macrocephalus*), sailfin sandfish (*Arctoscopus japonicus*), anchovy (*Engraulis japonicus*), pollock (*Gadus chalcogrammus*), white-spotted conger (*Conger myriaster*), blue crab (*Portunus trituberculatus*), and prawn (*Fenneropenaeus chinensis*). According to the Korea Statistical Office report (2018), warm-water fish species such as mackerels, anchovies, and squid have increased in the coastal waters since 1990 due to increased seawater temperature. The annual fish catch of mackerels was approximately 96,300 tons in 1991, which rose to 115,000 tons in 2017. The annual fish catch of anchovies was about 130,200 tons in 1991, and increased to 211,000 tons in 2017. The annual fish catch of squid was approximately 74,200 tons in 1991, which rose to 87,000 tons in 2017. However, cold-water fish species such as pollock and saury have decreased. The annual fish catch of pollock was approximately 9,800 tons in 1991, which rapidly reduced to 1 ton in 2017. The annual fish catch of saury was about 5,300 tons in 1991, which decreased to 757 tons in 2017.

Data and Indicators

For WG36 analyses, we selected indicators of environment and human pressures and ecosystem responses for the surface waters around the Korean Peninsula based on long-term data availability (Figure 3-5, Table 3-4).

The environmental pressures included physical properties (temperature and salinity), seawater pollution index (Chemical Oxygen Demand, COD), oxygen condition (Dissolved Oxygen, DO), nutrient availability (NH_4-N, NO_2-N, NO_3-N, DIN, DIP, and SiO_2-Si concentrations), pH, suspended solids (SS), and transparency. Data of indicators for the environmental pressures were obtained from the Marine Environmental Monitoring Program (MEMP) operated by the Korea Marine Environment Management Corporation (KOEM) (Figure 3-5). The monitoring occurs four times each year (February, May, August, and November). We estimated the annual means for each year and compiled the time series of annual means for each indicator from 2006 to 2016 using the monitoring data. Note that the KOEM data is only available in the coastal waters around the Korean Peninsula. We also used climate indices related to sea surface temperature changes, such as the Pacific Decadal Oscillation (PDO, https://www.ncdc.noaa.gov/teleconnections/pdo/), Nino3.4 (https://psl.noaa.gov/gcos_wgsp/Timeseries/Nino34/), and Multivariate ENSO Index (MEI, https://www.psl.noaa.gov/enso/mei). The North Pacific Gyre Oscillation (NPGO, http://climexp.knmi.nl/getindices.cgi?) index was used as an indicator of water mass transport (Di Lorenzo et al. 2008). The annual means were used to compile the time series for each climate index during the 17 years.

For indicators of the human pressures, the annual means of fish catches (squid, anchovy, eel, crab, shrimp, croaker, hairtail, mackerel, *Collichthys niveatus*, and mysid shrimp), total amount of fish landings, and total ships tonnages were obtained from the Fisheries Information Portal (FIP, https://fips.go.kr/p/Main/) (Table 3-4).

Chlorophyll-*a* concentrations, number of individuals of zooplankton (copepods, euphausiids, chordata, and notiluca), and zooplankton wet weight were selected to consider the ecosystem responses to the environment or human pressures in the Korean study area. The chlorophyll-*a* and zooplankton data for the ecosystem responses were obtained from the MEMP and the Korea Oceanographic Data Center (KODC, http://www.nifs.go.kr/kodc/index.kodc), respectively (Figure 3-5). In the same way as the time series of environmental indicators, the annual means of chlorophyll-*a* and zooplankton data were compiled. The zooplankton data measured six times each year (February, May, August, October, and December) were used to calculate the annual means.

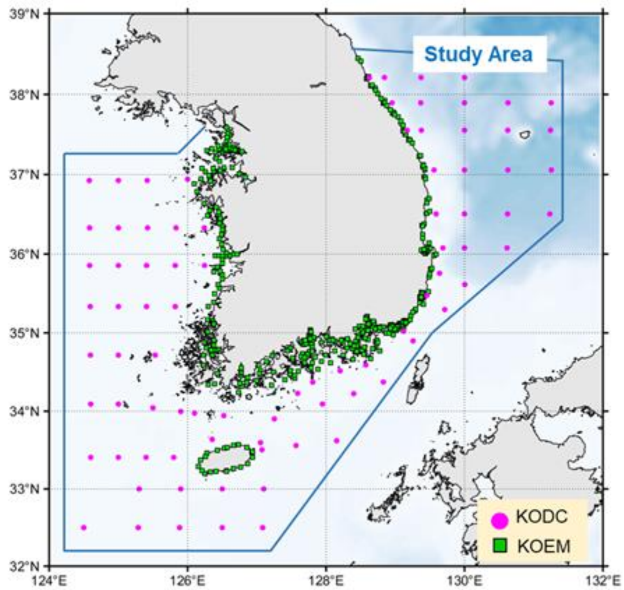

Figure 3-5. The study area and long-term monitoring stations around the Korean Peninsula for time series of environment and human pressures and ecosystem indicators (PICES bioregions #19, 20, and 21, Fig. 1-3).

Table 3-4. Indicators of (A) environment and human drivers and pressures and (B) ecosystem responses for the coastal waters around the Korean Peninsula (PICES bioregions #19, 20, and 21, Fig. 1-3).

(A) Drivers and pressures

Components	**Pressure**	**Indicators**	**Source**
Environmental drivers	SST change	Sea Surface Temperature (SST)	a
	SSS change	Sea Surface Salinity (SSS)	a
	pH change	Sea surface pH	a

	Oxygen change	Sea surface Dissolved Oxygen (DO)	a
	Seawater pollution	Chemical Oxygen Demand (COD)	a
	Nutrient availability	Sea surface nutrient: NH_4-N, NO_2-N, NO_3-N, DIN, DIP, SiO_2-Si	a
	Productivity and light availability	Suspended Solids (SS)	a
	Light availability	Transparency	a
	SST change	Pacific Decadal Oscillation (PDO)	b
		Nino3.4	c
		Multivariate ENSO Index (MEI)	c
	Transport of water mass	North Pacific Gyre Oscillation (NPGO)	d
Human drivers	Fishery removal (landing)	Catch: squid, anchovy, eel, crab, shrimp, croaker, hairtail, mackerel, *Collichthys niveatus*, mysid shrimp	e
		Total amount of fish landings	e

		Total ships tonnages	e

(B) Responses

Components	**Impacts**	**Indicators**	**Source**
Ecosystem responses	Phytoplankton biomass and productivity	Chlorophyll-*a*	f
	Zooplankton productivity	Number of individuals of zooplankton: Copepods, Euphausiids, Chordata, Notiluca	f
		Zooplankton wet weight	f

Source:
a. Marine Environmental Monitoring System (MEMS) operated by the Korea Marine Environment Management Corporation (KOEM), https://meis.go.kr/portal/main.do
b. NOAA/NCDC, https://www.ncdc.noaa.gov/teleconnections/pdo/
c. NOAA/PSL, https://www.psl.noaa.gov/
d. Di Lorenzo et al. (2008), http://climexp.knmi.nl/getindices.cgi?
e. Fisheries Information Portal (FIP), https://fips.go.kr/p/Main/
f. Korean Oceanographic Data Center (KODC), https://www.nifs.go.kr/kodc/index.kodc

3.2.5 Russia

Indicators and Data

Among several indicators submitted from Russia for consideration by WG-35 to prepare NPRESR3 there were annual and monthly means of trophic level (TL) of catches and marine trophic index (MTI, which was calculated from the subset of TL $\geq$ 3.25). Those ETSOs were grouped by fishing zones in the Russian EEZ PICES bioregion #19 (Fig. 1-3) approximately matching the regions suggested by WG-35. Unfortunately, specialists from Russia did not use MTI and TO time series in the chapters of NPESR3. Meanwhile traditional ETSOs like biomass of different groups of animals and plants, water temperature, ice concentrations etc. were analyzed. In addition to NPESR3 specialists from the Pacific and Sakhalin branches of VNIRO published their peer reviewed research on the state and trends of different components in the Sea of Okhotsk ecosystem, which is the main fishing ground of Russia in the Pacific (https://doi.org/10.26428/1606-9919-2019-197-35-61). That publication can be used as a source of ETSOs after digitizing them. We had to digitize many more timeseries from publications to extend available time frame and spatial coverage. VNIRO took the leading role in that process. Finally, we prepared a dataset which included different temporal and spatial slices of abiotic pressures or drivers, suspected in the influence on the fish (https://doi.org/10.17632/d5hy9smz5p.3#file-c90adcdd-803c-485f-a00b-c3f519699f0c). The problem is that many time series have different time span, e.g. many abiotic factors (described in papers) end before the year of the paper being published and have no data afterwards (https://doi.org/10.17632/d5hy9smz5p.3#file-c90adcdd-803c-485f-a00b-c3f519699f0c). Therefore, we could not use gradient forest directly joining tables with abiotic stressors and biological indicators. Though we are planning to do that after selecting appropriate subsets. So, we started checking nonlinear relations using pairwise MIC calculations hoping that we will not find many strong relations and creation of suitable subset for gradient forest analysis will be fast. But we have found thousands of significant MIC between abiotic and biotic factors without lags (https://doi.org/10.17632/d5hy9smz5p.3#file-d606e85e-8be0-4e7c-a792-fce170638189) and even more with lags (https://doi.org/10.17632/d5hy9smz5p.3#file-ca52afd3-5a5e-4845-bd8f-d881e2e0eda0). Most of those relations are overly complex but considering more than 1 stressor in multiple regression (GAM) made splines linear in several cases one of which is walleye pollock in the western part of PICES bioregion #19. An overview of those findings has been published recently (Datsky et al., 2021, Appendix 4).

3.2.6 U.S.A.

Ecosystem

The southern area of PICES bioregion #11 (Fig. 1-3), located off the U.S. west coast, is a highly productive eastern boundary current system, which supports a diversity of marine life and fisheries. This region can be divided into three alongshore regions based on differences in physical and biological processes (Figure 3-6). The southernmost region encompasses waters from south of Point Conception to Baja, Mexico (though the U.S.-Mexico border (31-34.5˚N) demarks the EEZ), the central region spans between Point Conception and Cape Mendocino (34.5-40.5˚N), and the northern region extends north of Cape Mendocino to the U.S.-Canada border (40.5-47˚N) (Figure 3-6). Some of the major processes driving species dynamics in this bioregion at seasonal, inter-annual, and decadal time scales include changes in source waters, timing and intensity of coastal upwelling, surface temperatures, and vertical stratification. Multiple studies have demonstrated strong linkages between variability of source waters and upwelling and the recruitment of pelagic juvenile groundfish and forage species (Santora et al. 2014, Ralston et al. 2015, Schroeder et al. 2019). For example, in the central region, high abundance of pelagic juvenile groundfish, squid, and krill are associated with strong upwelling and/or higher transport of cool, fresh subarctic waters into the region, whereas the abundance of forage fishes, such as sardines and anchovies, are more abundant during weaker upwelling conditions (Ralston et al. 2015, Schroeder et al. 2019). Higher transport of sub-arctic waters into the northern region is also linked to enhanced biomass of lipid-rich northern copepods, a valuable component of the food web in this region. In contrast, higher transport of warm sub-tropical waters results in higher biomass of lipid-poor southern copepods (Peterson et al. 2014).

Shifts in ocean temperatures also have important effects on marine fauna. Changes in ocean temperatures affect prey abundance and cause shifts in their distributions, which in turn can impact the growth and survival of their predators (Santora et al. 2020). For example, if adult female sea lions need to travel farther in search of sufficient quality food, they may leave their offspring without sustenance for long periods of time, and seabirds experience higher die-offs and abandon their colonies due to a lack of high-quality prey (Piatt et al. 2020). Increases in ocean temperature also contribute to stronger vertical stratification, which prevents the delivery of nutrient and oxygen-rich waters to the upper ocean. This in turn causes declines in lower trophic level productivity and lower dissolved oxygen content in continental shelf waters, both of which can impact the survival and abundance of marine fauna.

Exploitation

The southern area of bioregion #11 has supported numerous fisheries over the past century. Commercial landings peaked at over 700,000 mt in the mid-1930s, a period during which coastal pelagic species, namely Pacific sardine, dominated fisheries landings (Miller et al. 2017). In the 1970s, salmon fisheries thrived as the most lucrative fisheries and groundfish landings surpassed landings of coastal pelagic species. Rockfish and flatfish comprised the highest groundfish landings until the early 1990s when Pacific hake (whiting) became the top fishery. Pacific hake has dominated fisheries landings the southern area of bioregion #11 ever since. Over the past 20 years, the average annual landings and dollar value of Pacific hake have been around 180,000 mt and $33 million, respectively (NOAA). Pacific sardine, market squid (*Doryteuthis opalescens*), and Dungeness crab (*Metacarcinus magister*) have also contributed to the bulk of fisheries landing during this period, with the most highly valued fishery the southern area of bioregion #11 being Dungeness crab followed by squid and salmon (NOAA, https://www.fisheries.noaa.gov/foss/f?p=215:200:10219517579087:Mail:NO:::).

Indicators and Data

The ecosystem, environmental, and human dimensions indicators used in the U.S. case study (Table 3-5) are an extension of those used in previous analyses of ecosystem thresholds conducted by Samhouri and colleagues (2017). The indicators and time series used in their study and in our analysis were compiled from NOAA's California Current Ecosystem Integrated Ecosystem Assessment (CCIEA; Harvey et al. 2014). The CCIEA is an indicator framework that provides science support for ecosystem-based management in the southern area of PICES bioregion #11. WG36 applied analyses to time series for a modified set of CCIEA indicators, which are publicly available on the CCIEA website.

Coastwide indicators of physical environmental pressures used in U.S. case study are similar to those included in the analysis for the WCVI in British Columbia, Canada. The PDO index tracks changes in sea surface patterns in the northeast Pacific and the NPGO index tracks the strength of transport by the North Pacific Gyre. The multivariate ENSO index (MEI) and Oceanic Niño Index (ONI) are also large-scale indicators of sea-surface temperature, and the Northern Oscillation Index (NOI) and area of the North Pacific High are measures of changes in sea level pressure. In addition, we included several regional level physical indicators. For each sub-region of the southern area of bioregion #11 (north: 33N; central: 39N; south = 45N, Fig. 3-6), we used remotely sensed sea-surface temperature data, estimates of dissolved oxygen, the Coastal Upwelling Transport Index (CUTI), and the Biologically Effective Upwelling Transport Index (BEUTI). The CUTI and BEUTI indices are measures of coastal vertical transport and nitrate flux, respectively (Jacox et al. 2018).

Indicators of human pressure on ecosystem components included coastwide estimates of fisheries landings. Specifically, we used the summed total of fisheries landings (combined commercial and recreational landings on the U.S. west coast) and separate estimates for coastal pelagic species (northern anchovy, Pacific sardine, Pacific herring, round herring, chub mackerel, jack mackerel) and groundfish species (flatfishes, rockfishes, and abundant demersal fishes).

Ecosystem response indicators used in the analysis are based on the ecological integrity indicators compiled for the CCIEA. The indicators for higher trophic level biology include seabird productivity anomalies at the southeast Farallon Islands in the central region of the study region, and female California sea lion pup production and growth rates at San Miguel Island in the southern region of the study system. We also included indicators for middle and lower trophic level species that were derived from U.S. West Coast monitoring surveys. These included larval fish abundances in the southern region, catches of forage fish and young-of-year groundfish in the central region, and copepod biomass anomalies in northern region of the case study ecosystem.

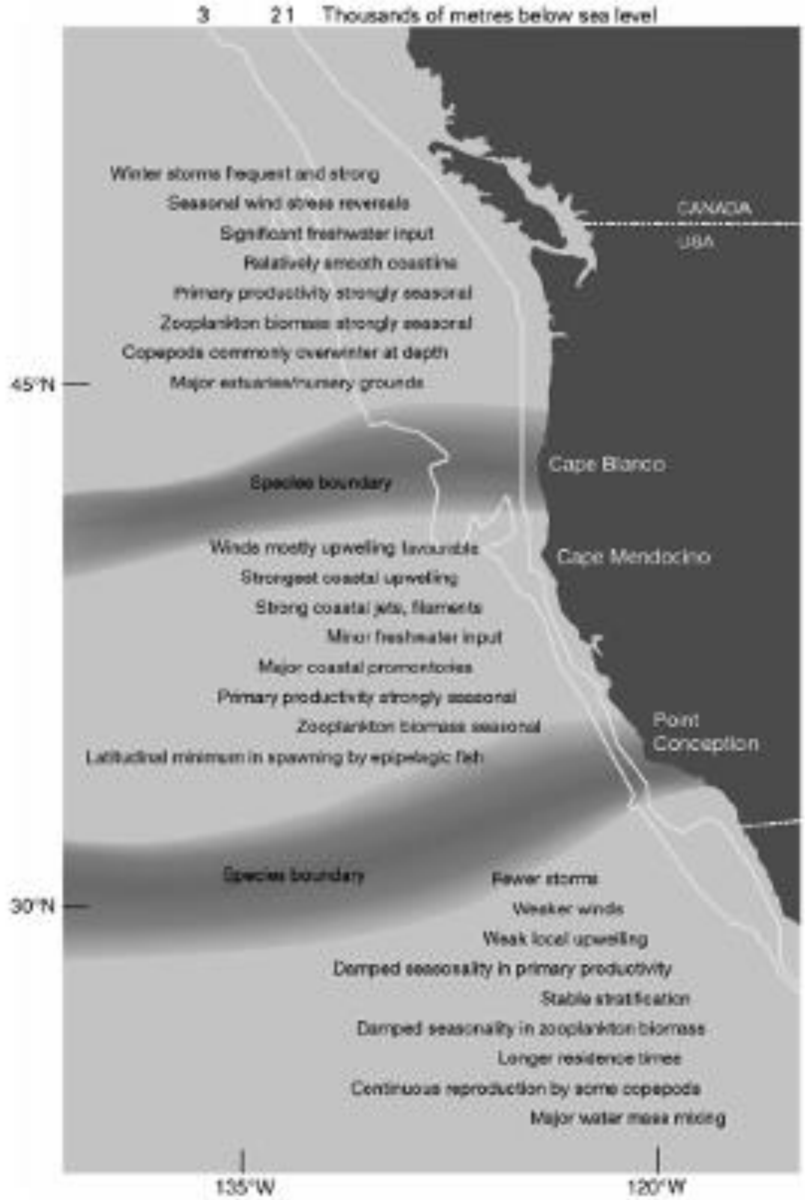

Figure 3-6: Generalized variations in physical and biological processes across three sub-regions within the southern area of PICES bioregion #11 (from Agostini et al. 2005).

Table 3-5. Indicators of environmental and human pressures (A); ecosystem objectives, ecosystem pressures and responses (B), and regions and abbreviations of data sources for the U.S. case study

(A)

Component	Pressure	Indicator	Region	Years	Source
Environment	SST change	Pacific Decadel Oscillation (PDO)	Coastwide	1970-2019	a,b
	Transport	North Pacific Gyre Oscillation (NPGO)	Coastwide	1970-2019	c,b
	SST change	Multivariate ENSO Index (MEI)	Coastwide	1979-2019	b
	SST change	Oceanic Nino Index (ONI)	Coastwide	1970-2019	b
	Sea level pressure	Northern Oscillation Index (NOI)	Coastwide	1970-2019	d,b
	Sea level pressure	Area of North Pacific High (NPH)	Coastwide	1970-2019	e,b
	SST change	Sea surface temperature (SST)	SCC, CCC, NCC	1982-2019	b
	Productivity	Upwelling (CUTI)	SCC, CCC, NCC	1988-2019	f,b
	Surface nitrate flux	Nitrate (BEUTI)	SCC, CCC, NCC	1988-2019	f,b
	Oxygen change	Dissolved oxygen	SCC	1990-2018	b
Human	Fishery removals	Total landings	Coastwide	1996-2018	g,b
		CPS landings	Coastwide	1981-2018	g,b
		Groundfish landings	Coastwide	1996-2018	g,b

(B)

Component	Objective	Indicator	Region	Years	
Ecosystem	Maintain structure and function	Brandts cormorant reproductive success	CCC	1972-2019	h,b
		Casseins auklet reproductive success	CCC	1972-2019	h,b
		Common murre reproductive success	CCC	1972-2019	h,b
		Pigeon guillemot reproductive success	CCC	1971-2019	h,b
		Rhinocerus auklet reproductive success	CCC	1986-2019	h,b
		Female CA sea lion pup growth	SCC	1997-2019	b
		Female CA sea lion pup production	SCC	1997-2019	b
		Adult forage fish catch	CCC	1990-2019	b
		Adult anchovy catch	CCC	1990-2019	b
		Adult sardine catch	CCC	1990-2019	b
		All young-of year (YOY) catch	CCC	1990-2019	b
		Anchovy yoy catch	CCC	1990-2019	b
		Pacific hake yoy catch	CCC	1990-2019	b
		Rockfish yoy catch	CCC	1990-2019	b
		Sardine yoy catch	CCC	1990-2019	b
		All larval fish abundance	SCC	1983-2019	b
		Pacific hake larvae abundance	SCC	1983-2019	b
		Pacific sardine larvae abundance	SCC	1983-2019	b
		Rockfish larvae abundance	SCC	1983-2019	b
		Copepod biomass anomaly summer	NCC	1996-2019	i,b
		Copepod biomass anomaly winter	NCC	1997-2019	i,b

Source:

a. Mantua et al. 1997

b. California Current Integrated Ecosystem Assessment: http://www.integratedecosystemassessment.noaa.gov/regions/california-current-region/index.html

c. Di Lorenzo et al. 2008

d. Schwing et al. 2002

e. Schroeder et al. 2013

f. Jacox et al. 2018

g. Pacific Fisheries Information System

h. Point Blue Conservation Science

i. Peterson et al. 2015

3.3 Summary

Towards the goal of examining nonlinear ecosystem responses to climate and anthropogenic drivers and pressures, WG36 members selected indicators from a toolbox of recommended indicators (based on WG28, WG35, and the HD committee) for each region of study. Many of the recommended core indicators were selected in all ecosystems to reflect environmental and human pressures and ecosystem responses; however, not all core indicators could be examined because, for example, data were not available or to maximize the length of the time series examined. In addition to core indicators, some additional, ecosystem-specific indicators were included. For these analyses, a data-based approach was used (time series of data to calculate indicators) and indicators were selected to address ecosystem-based management objectives, where possible.

3.4 Conclusions

WG36 members selected indicators from a toolbox of recommended indicators for each region of study.

- Many of the recommended core indicators were selected in all ecosystems to reflect environmental and human pressures and ecosystem responses; however, not all core indicators could be examined (because, for example, data were not available or to maximize the length of the time series examined). Member nations had different priorities for their recommended core indicators that influence their data collection and sharing protocols.
- In addition to core indicators, some additional, ecosystem-specific indicators were included.
- For these analyses, a data-based approach was used (time series of data to calculate indicators) and indicators were selected to address ecosystem-based management objectives, where possible.

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4 Methods for determining thresholds in ecosystem indicators

4.1 Introduction

Over the past few decades, there have been many advancements in statistical methods for detecting thresholds in time series data (Andersen et al. 2009). The application of these methods in environmental sciences has also been accelerating, as thresholds hold promise within management and regulatory frameworks as reference points for informing decision-making. Until recently, threshold detection methods have mostly been applied to univariate time series. For example, myriad studies have used these methods to the identify the status of single species or ecosystem state, and to identify evidence of regime shifts in climate and biological time series (Rodionov 2004, Kortsch et al. 2012, McMahon et al. 2015, Kun Jung et al. 2017, Mollmann and Diekmann 2012, Goto et al. 2020, Furuichi et al. 2020, Nishijima et al. 2020, Yonezaki et al. 2015). However, increased attention on understanding mechanisms driving ecosystem dynamics coupled with the desire to avoid large, abrupt changes in social-ecological systems has galvanized the development and application of tools to detect nonlinearities and thresholds in relationships between ecosystem components and human and environmental pressures.

The primary goal of TOR 3 is to summarize methods used to quantify nonlinearities and thresholds in pressure-response relationships in marine ecosystems with an emphasis on the methodologies that we selected for the member nation case studies presented in TOR 4. We also highlight methods used for detecting thresholds in single time series and for identifying common trends in multivariate time series. This summary is not intended to be an exhaustive review of relevant methodologies. Instead, we aim to provide a brief overview of methods that are commonly used in scientific literature, sometimes in multi-model frameworks, and are easily accessible (e.g., well documented, open-source R scripts) to a broad community of fisheries scientists across PICES member nations and beyond. A quick guide to the various methods discussed here and their key attributes are presents in Tables 4-1 and 4-2.

4.2 Identifying nonlinearities and thresholds in pressure-response relationships

4.2.1 Decision Trees

Decision tree-based methods, including boosted regression trees, random forest, and gradient forest have been increasingly used to model nonlinear relationships between pressures and ecological indicators and to identify thresholds in those relationships. These methods build on traditional regression and classification trees, which partition data into groups at specific split values to maximize group homogeneity, by using an ensemble approach to combine many single trees into a more powerful model. The ensemble methods differ with respect to how the single trees are aggregated and how the models are tuned (see Elith et al. 2008, Ellis et al. 2012), however the overall approach has substantially improved the accuracy and predictive performance of decision trees. One of the many advantages of these methods is that interactions between predictor variables and their effects on threshold locations are automatically handled (Elith et al. 2008). Some recent studies have used random forest and gradient forest analyses to identify the importance of human and environmental pressures on ecological indicators in marine systems and to detect ecosystem-level thresholds associated with those pressures (Large et al. 2015a, Samhouri et al. 2017, Tam et al. 2017, Boldt et al. 2021). Random forest analysis is useful for assessing the ability of multiple pressures to predict a single indicator and for quantifying possible shifts or thresholds in an indicator's response along pressure gradients. Gradient forest analysis, an extension of the random forest approach, can fit models to multiple indicators and pressures and identify the aggregate responses of the indicators to the pressures (Ellis et al. 2012). Gradient forest is particularly useful for evaluating ecosystem-level thresholds as it detects thresholds in a multivariate context.

4.2.2 Generalized Additive Models and Derivative Analysis

Generalized additive models (GAM; Hastie and Tibshirani 1986) are a tried-and-true method for identifying and characterizing nonlinear relationships between physical and biological pressures and ecosystem components. These relationships are captured through smooth, non-parametric functions (e.g., splines), which allow for the flexible estimation of the functional forms of the relationship without knowing a priori what the functional forms might be. Within the past decade, several studies have combined GAM (or other nonlinear functions) with derivative analysis to detect thresholds in smoothed functions of ecological responses to single pressures (Fewster 2000, Lindegren et al. 2012, Large et al. 2013, 2015b, Burthe et al. 2016, Samhouri et al. 2010, 2017, Tam et al. 2017, Boldt et al. 2021) and multiple pressures (Large et al. 2015). For example, a threshold, or inflection point in the trajectory of a smoothed function, is delineated when the second derivative of the function changes sign. More specifically, the threshold point may be defined as the location where the second derivative is most different from zero and the threshold range is where the 95% confidence intervals of the second derivative are not equal to zero (Large et al. 2013, Samhouri et al. 2017). The detection and visualization of thresholds using GAMs and the derivative analysis is easily interpretable, which is a strong advantage of this method. However, the smoothed nature of GAM splines may underestimate phase shifts compared to the tree-based approaches above. We note that GAMs and derivative analysis have also been used to detect nonlinearities and thresholds in single time series as well.

4.2.3 Threshold regression models / specified functional forms

Threshold regression models are similar to regression spline models (e.g., GAMs) in that they are capable of modeling nonlinearity in pressure-response relationships and detecting thresholds or change points. They are also easily interpretable and perhaps the most easily interpretable of all the threshold detection methods. Three common implementations of threshold regression models in R include the *segmented* (Muggeo et al. 2008, 2022), *strucchange* (Zeileis et al. 2019), and the *chngpt* (Fong et al. 2017) packages, all of which take a fixed number of change points and a user-specified regression model or functional form, e.g., step, hinge, segmented. The *chngpt* package builds on the other packages by supporting models with interaction terms between predictors and providing confidence intervals around the estimates of change points to account for uncertainty (e.g., Fong et al. 2017). In addition, a recent Bayesian implementation of threshold regression allows users to specify the functional form on a per-segment basis when there are multiple change points (*mcp*, Lindeløv 2020). An example of how threshold regression models can be used to detect ecological thresholds for setting management targets in the North Pacific marine ecosystems is illustrated by Samhouri et al. 2010, 2011 and Bestelmeyer et al. 2011.

4.2.4 Nonparametric multiplicative regression (NPMR)

NPMR models are used to assess the relationships between an ecological response and multiple pressures. An advantage of this parameter-free method is that it can adapt to any type of response shape, including thresholds. Unlike the parametric regression models discussed above, specific shapes or shape families are not imposed a priori on data patterns, instead characterization of the response shape is guided by the data itself (Lintz et al. 2011, McCune et al. 2011). With respect to thresholds, NPMR models quantify the strength and diagonality of thresholds with multiple predictors in state space. The strength of the threshold is defined by the abruptness of the threshold in state space, and diagonality measures the degree to which the response shape is influenced by more than one predictor (Lintz et al. 2011, McCune et al. 2011). NPMR may also be used to estimate causality (Nicolau and Constandinou 2016), which may help elucidate causal understanding of thresholds. One potential limitation of this method is that it cannot accurately capture discontinuous or cusp response surfaces, but only smooth functions between a response and predictor variables (Nicolau and Constandinou 2016). This approach has been applied to habitat modeling and animal movement data. For example, Palacios et al. 2019 used this method to model the relationship between the movement behavior of blue whales and environmental variables.

4.3 Detecting thresholds in single time series

4.3.1 Change point analysis

Change point analysis is different from the models described above in that it only detects structural changes in single times along a time series or sequence. An advantage of change point analysis is that the number of change points does not need to be known a priori. One of the disadvantages is that it only provides point estimates of change points. Some studies have used the sequential t-test analysis of regime shifts (STARS) to detect abrupt shifts in climatology (Gardner and Sharp 2007) and in marine ecosystems (Daskalov 2007). STARS is a sequential algorithm that tests for regime shifts in the mean of individual time series and was developed by Rodionov (2004). This data-driven approach does not require an a priori hypothesized estimate of when a regime shift occurred, can be used on raw or standardized data, and may be able to detect regime shifts relatively early (Rodionov 2004, 2015). Rodionov (2015, 2016) recently expanded this approach in the software package Sequential Regime Shift Detector (SRSD). This package can be used to detect regime shifts in the mean and variance of individual time series and in the correlation coefficients of two variables. While STARS is not available as an R package, there are several R packages available to analyze change points (e.g., *changepoint*, Killick and Eckley 2014; *cpm*, Ross 2015).

4.4 Identifying common trends in multivariate time series

4.4.1 Dynamic Factor Analysis (DFA)

This dimension-reducing multivariate analysis identifies shared trends (common patterns) in a suite of indicators (e.g., ecosystem response indicators), detects their relationship with explanatory variables (e.g., pressures), and may be able to predict trends 2-3 years into the future (Zuur et al. 2003). Limitations of DFA include: 1) it is computer intensive, 2) does not address nonlinearities among the suite of indicators when looking for common trends, and 3) large numbers of time series or including covariates increases the complexity of the model and results can be difficult to interpret (Hasson and Heffernan 2011). Some applications of this method in marine ecosystems include the detection of trends in the abundance of ichthyoplankton (Marshall et al. 2019), zooplankton (Kimmel et al. 2020), fish stocks (Azevdo et al. 2008) and community dynamics (Suryan et al. 2021). In addition, a Bayesian implementation of DFA has been developed by Ward et al. (2019, 2021 *In review*) that allows for the detection of rare or extreme events (Anderson et al. 2017) and regime shifts in shared trends (Litzow et al. 2020, Hunsicker et al. 2022).

Table 4-1. A quick guide to various methods used to detect nonlinearities and thresholds in single and multivariate time series, and to identify common trends among environmental and ecological time series.

Methodology	Purpose	Examples
Regression/ Classification Trees	Identify nonlinearities in pressure-response relationships (not limited to temporal time series) and threshold values in univariate responses to multiple pressures	Elith et al. 2008, Jouffray et al. 2015
Decision-tree based ensemble methods	Detect thresholds in univariate and multivariate responses to multiple pressures	Large et al. 2015a, Samhouri et al. 2017, Tam et al. 2017, Boldt et al. 2021

Generalized additive models	Identify nonlinearities in single time series and pressure-response relationships, determine the signs and forms of those relationships, can include threshold formulation	Ciannelli et al. 2004, Llope et al. 2011, Hunsicker et al. 2016 Boldt et al. 2018, https://saskiaotto.github.io/INDperform/
Derivative analysis	Determine sign and inflection point in single time series and pressure-response relationships.	Lindegren et al. 2012, Large et al. 2013, 2015b, Samhouri et al. 2017, Boldt et al. 2021
Threshold regression models / Specified functional forms	Identify nonlinearities in single time series and pressure-response relationships, as well as signs and forms of those relationships, and threshold values	Samhouri et al. 2010, Bestelmeyer et al. 2011
Non-parametric multiplicative regression	Quantify threshold strength and diagonality (measurable shape attributes of multi-dimensional thresholds)	Lintz et al. 2011, McCune et al. 2011, Palacios et al. 2019
Changepoint analysis	Threshold detection in single time series	Rodionov 2004 (STARS)
Dynamic Factor Analysis	Identify common trends in multiple time series and detect relationships between time series and explanatory variables. Detect extreme events and regime shifts in common trends.	Zuur et al. 2003, Tam et al. 2017, Ward et al. 2019, Boldt et al. 2021

Table 4-2. Key attributes of methods used to detect thresholds in pressure-response relationships

Attributes	**Specified functional forms**	**Threshold regression models**	**Generalized Additive Models**	**Derivative analyses**	**Non-parametric multiplicative regression**	**Gradient forest analysis**	**Random forest, BRT**
Unknown functional form / versatility	-	-	+	+	+	+	+
Multiple stressors	-	-	+	+	+	+	+
Multiple responses	-	-	-	-	-	+	-
Significance test	+	+	+	+	+	+	+
Requires long time series	-	+	+	+	+	-	-

Handles missing data	-	+	-	-	-	-	+
Handles interactions among pressures automatically	-	-	-	-	-	+	+
Easily interpretable	+	+	+	+	+	-	-

4.5 Summary and Conclusions

- We provided an overview of a suite of quantitative methods that are more commonly used to detect thresholds in pressure-response relationships in marine ecosystems, as well as methods to detect thresholds in single time series and common trends in multivariate time series.
- All of the methods reviewed here have advantages and drawbacks. For example, some can handle multiple pressures and multiple responses, but are not easily interpretable while others are easily interpretable, but require long time series and cannot handle missing data.
- There are additional advanced statistical methods for threshold detection that we did not review here because either (1) to the best of our knowledge there are no existing applications to marine ecosystems, or (2) the methodology (e.g., R code) is not easily accessible.
- To address TOR 4, we selected Generalized Additive Models with derivative analysis, gradient forest analysis, and Dynamic Factor Analysis for our working group activities. These analyses were selected because (1) the methods have been thoroughly vetted by ecologists and fisheries scientists, (2) multiple working group members had prior knowledge of and experience working with these methods, (3) the R code associated with the analyses are well documented and were readily available for our working group.

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5 Identifying shapes or functional forms of pressure - response relationships from available datasets, and quantifying thresholds to identify potential ecosystem reference points

5.1 Introduction

Coastal ocean ecosystems are increasingly vulnerable to the impacts of a rapidly changing climate coupled with an expansion of anthropogenic activities. To sustainably manage targeted fish populations and broader ecosystem components in the face of ocean change, there is a pressing need for information that can help resource managers and stakeholders better anticipate the response of marine organisms to climate perturbations and anthropogenic pressures (Mason et al. 2021). Such knowledge could improve decision making in a manner that reduces the potential for ecological surprises, socio-economic hardship, and irreversible shifts in ecosystem structure and function.

Understanding the functional forms or shapes of the relationships between climate and human pressures and ecosystem components is key for anticipating ecological responses and for identifying appropriate management strategies (Selkoe et al. 2015). For example, strong nonlinear relationships, where a small incremental change in a pressure elicits a disproportionately large response, could result in abrupt, unintended outcomes that are difficult to reverse (Liu et al. 2007; DeYoung et al. 2008). Often these relationships have quantifiable thresholds (i.e., inflection points, Large et al. 2013, Samhouri et al. 2017) which indicate where there is potential for abrupt change in an ecological response along the continuum of a pressure level. Such thresholds could be applied within management frameworks as ecosystem reference points for avoiding nonlinear change and for informing a broader, more holistic picture of ecosystem conditions for decision-making. Knowledge of strong linear responses between pressures and ecological responses is also useful for understanding ecosystem dynamics and for decision-making in coastal systems. However, there are less ecological and socio-economic risks associated with incremental changes in pressure levels when pressure-response relationships are linear than when the relationships are nonlinear with threshold dynamics.

To advance knowledge of ecosystem reference points in PICES member nations, PICES WG36 was tasked with the fourth TOR to 1) identify the status and trends of key climate and biological variables in member nation coastal ecosystems, 2) characterize key pressure-response relationships using those variables, and 3) determine whether there is evidence of ecosystem thresholds in the pressure-response relationships examined. Each member nations analyses or ‘case study’ differed based on data availability and previous studies conducted in those systems, and not every member nation was able to complete the proposed tasks for this TOR. Here we present case studies for waters on the west coast of Vancouver Island that fall within the northern area of bioregion #11 (Canada), waters around the Shiretoko Peninsula, Hokkaido in bioregions #17 and 18 (Japan), waters around the Korean Peninsula in bioregions #19, 20, and 21 (Korea), the "Primorskiy kray" in the Russian continental EEZ in bioregion 19 (Russia), and waters off the U.S. west coast (California, Oregon, Washington) that fall within the southern area of bioregion #11 (U.S.A.).

5.2 Methods

A description of the indicators of environment, human, and ecosystem pressures used in each case study are presented in TOR 2. To identify ecosystem status and trends, multivariate Dynamic Factor Analyses (DFA; Holmes et al. 2012) were applied to time series to identify common trends among the different sets of the environment, anthropogenic, and ecosystem indicators. Gradient forest analyses (Ellis et al. 2012) were used to identify important environment and human pressures on ecosystem responses and thresholds. Generalized Additive Models (GAMs; Hastie and Tibshirani 1990) were used to examine single pressure-response relationships (environment and human pressures of ecosystem responses) for nonlinearities and thresholds, following methods of Large et al. 2013 and Samhouri et al. 2017. The specific location and range of a threshold (inflection point) was determined based on the second derivative of the GAM smoother. The R scripts used for all these analyses can be accessed via the GitHub repository (https://github.com/elhazen/WG-36).

5.3 Results

5.3.1 Canada

Status and trends

As presented in Boldt et al. (2021) ecosystem indicators for the WCVI show varying trends during 1986 - 2017 (Figure 5-1); the most notable trends were increases in small mesh multispecies survey biomass, total landings, and Steller Sea Lions over the time series, as well as declines in subarctic copepods since the 1990s, and declines in the trophic level of the catch from the early 2000s to approximately 2012 (Figure 5-1). Trends in landings and trophic level of landings were likely driven in part by changes in biomass but also by management actions. Multivariate DFA reduced these to three trends: one for environmental, one for human, and one for ecosystem indicators (Figure 5-1); model fits to most, but not all, time series were good.

Pressure-response relationship and ecosystem thresholds

In single pressure-response models, five pressure-response relationships were linear and four were nonlinear (identified using GAMs). Nonlinearities were between (1) the proportion of predatory fish and the PDO, (2) southern copepod biomass anomalies and the PDO, (3) trophic level of the surveyed community and the PDO, and (4) the boreal copepod biomass anomalies and spring transition timing (Figure 5-2). Gradient forest analysis highlighted three important environmental pressures that may be associated with ecosystem thresholds (nonlinearities): PDO, spring transition timing, and sea surface temperature (Figure 5-3). Further exploration of results from DFA and gradient forest analyses will clarify important pressure-response relationships (see Boldt et al. 2021). For example, the relationships among DFA trends will be important to explore. In future analyses, non-stationarity of relationships will have to be considered.

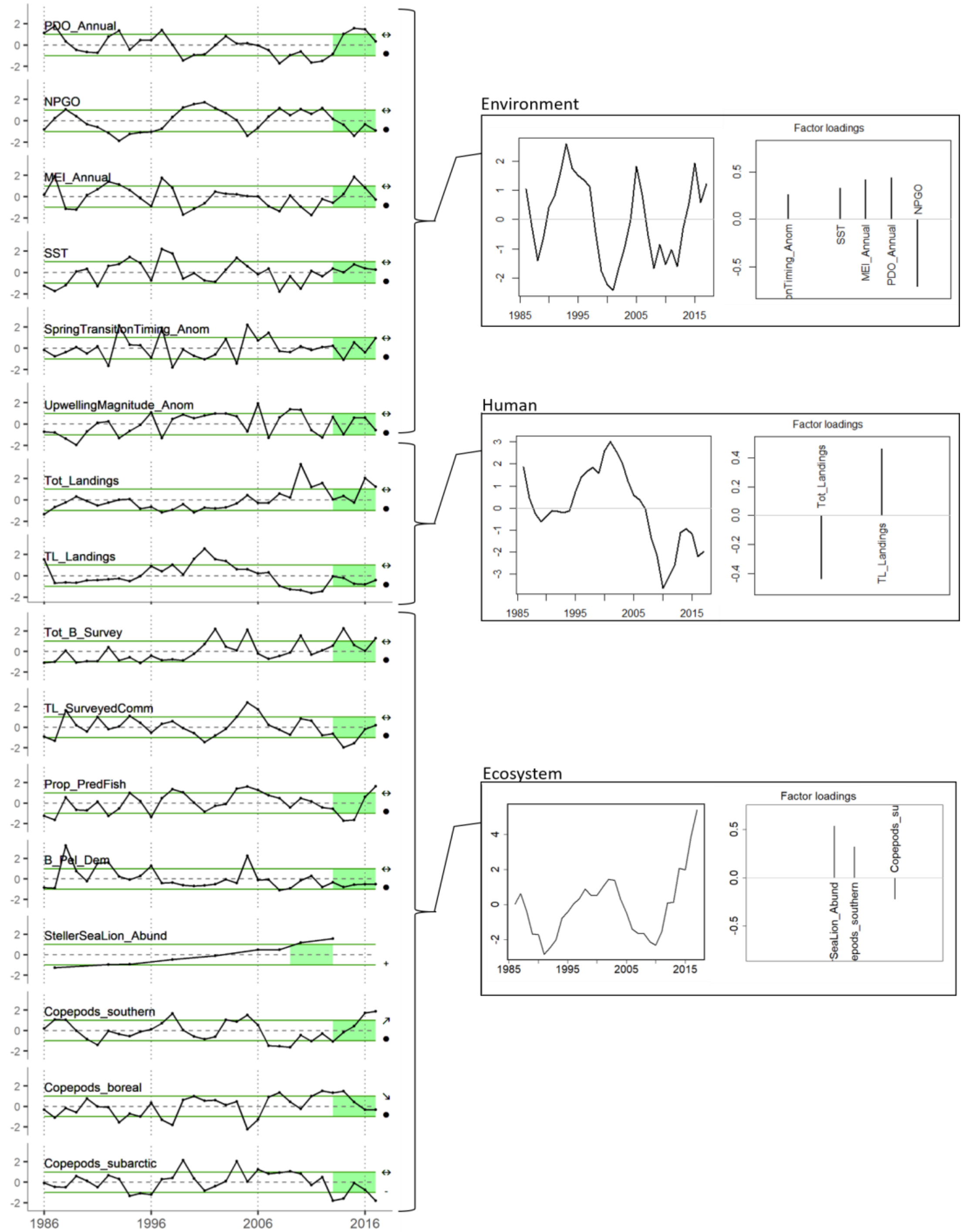


Figure 5-1. Time series anomalies of indicators of environment and human pressures and ecosystem responses (left column), trends identified from these indicators using Dynamic Factor Analyses (middle column), and factor loadings on trends (right column; factor loadings >0.2 are displayed) for the west coast of Vancouver Island. See Table 3-1 for indicator abbreviations. Green shaded areas represent the last five years of the time series and the green horizontal lines are plus and minus one standard deviation. Figure adapted from Boldt et al. (2021).

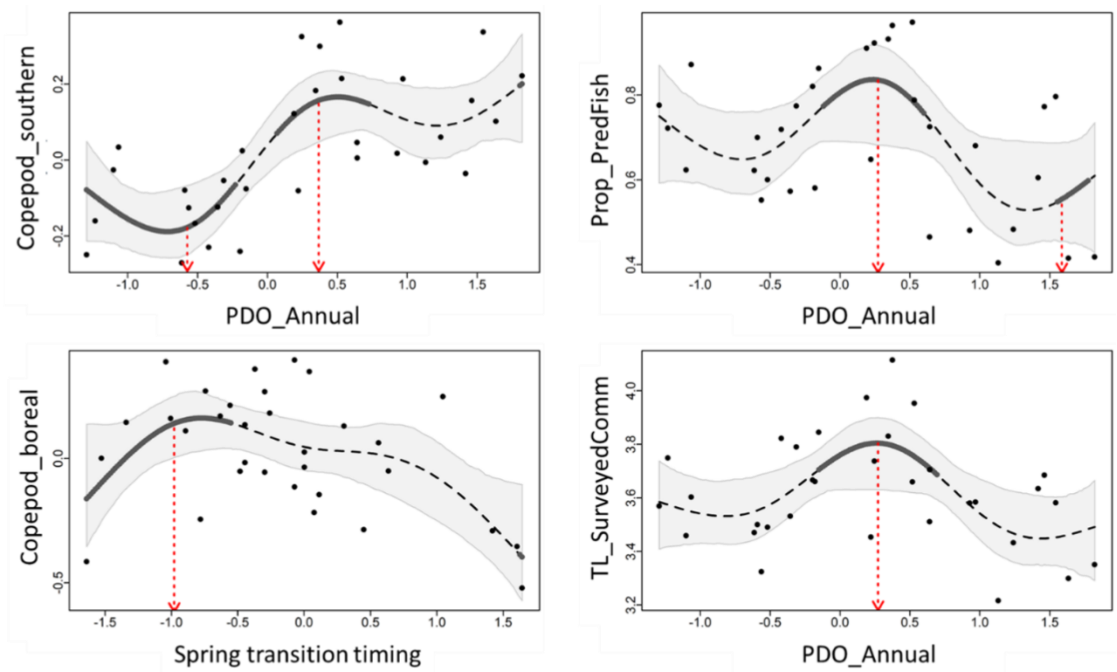


Figure 5-2. Nonlinear relationships between environmental pressures and responses identified with General Additive Models (GAMs). Dashed line is the GAM smoother, gray shaded area is the 95% CI, points are raw data, the thick solid line is the threshold range where the 95% CI of the first derivative of the GAM smoother line does not include 0, red dotted arrow indicates the best estimate of the threshold locations. (i.e., where the 2nd derivative is at its absolute maximum value within the threshold range). See Samhouri et al. (2017) for method details. Figure from Boldt et al. (2021).

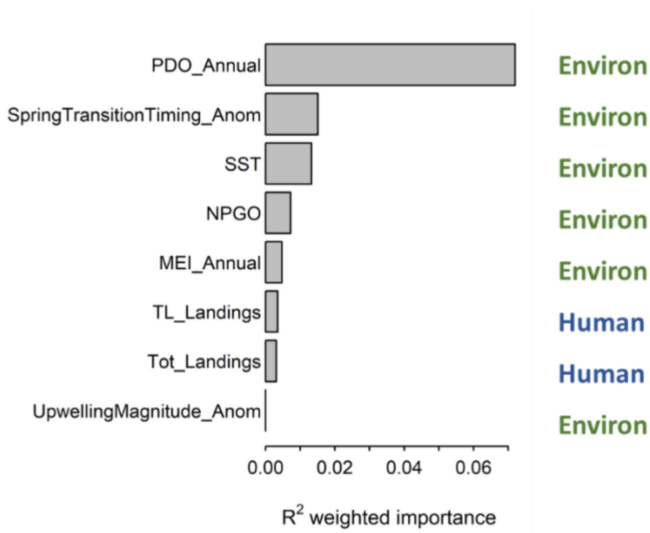


Figure 5-3. Important environmental and human pressures of ecosystem responses identified with gradient forest analysis. Figure adapted from Boldt et al. (2021).

5.3.2. China

Analyses for China's case study are in progress.

5.3.3. Japan

Status and trends

With respect to human pressures, a common linear trend was extracted (trend 1 in Figure 5-4 A). The catches of walleye pollock and ocean salmonids had a decreasing trend that positively responded to trend 1. While the catches of yellowtail had an increasing trend that negatively responded to trend 1. However, the catch of common squid had low correlation with trend 1 (absolute value of factor loadings < 0.2). Here, the number of captured Steller sea lions was not used in the final analysis.

For environmental pressures, a common linear trend was extracted (trend 1 in Fig. 5-4 B). The spring and summer SST had an increasing trend that positively responded to trend 1. However, the SST in the autumn season had low correlation with trend 1 (the absolute value of factor loadings < 0.2). Therefore, these results emphasized that change of the SST in spring and summer had been remarkable from 2006 to 2018 in waters around the Shiretoko Peninsula. Here, observation buoy's data for the velocity and direction of current were not used in the final analysis, as significant trends could not be extracted due to lack of observation data after 2015.

Analysis of ecosystem responses indicate that Steller sea lion abundance and migrating population of common squid in waters around the Shiretoko Peninsula had a common unimodal trend with a peak in 2011 (trend 1 in Figure 5-4 C), while migrating populations of walleye pollock, chum salmon and yellowtail had low correlation with trend 1 (the absolute value of factor loadings < 0.2). Goto et al. (2017) reported that Steller sea lions rarely preyed on common squid in Shiretoko sea area. Therefore, the extracted trends are considered to be pseudo-correlations. However, this unimodal trend was similar to the trend of the catch of the octopus (*Octopus dolfleini*) in Nemuro straits from 2006 to 2014 (Marine Net Hokkaido, 2021). Thus, additional data on food sources for Steller sea lions such as octopus, Pacific cod (*Gadus macrocephalus*) and Okhotsk atka mackerel (*Pleurogrammus azonus*) are necessary to refine analysis results. In addition, it should be noted the data used as an indicator of the abundance of Steller sea lions in the Nemuro Straits as below: 1) it is the annual maximum value of the number of individuals by visual count from land in the season (not the annual average value) and 2) it is limited to the period from 2006 to 2016.

Comparing the trends extracted by the DFA analysis, there was a common trend between the trend 1 for human pressures (increasing/decreasing catches of walleye pollock, chum salmon and yellowtail) and the trend 1 for environmental pressures (increasing the SST in spring and summer). This result suggested that there were certain relationships between the trend for human pressures (fish catch) and the trend for environmental pressures (SST). However, the trend in ecosystem responses had no relationship to the trend for environmental pressures (increasing SST). This result emphasized that additional data for environmental pressures were needed to explain the relationship to the unimodal trend for ecosystem states.

Implications of trends

In this study, one trend for human pressures and one trend for each environmental pressur and ecosystem responses were extracted from the long-term monitoring data for waters around the Shiretoko Peninsula that had been accumulated by the Shiretoko Data Center. Among the three trends, two trends were linear trends, while another one trend was non-linear with a peak in 2011. These results suggested that indicators in the Multiple Use Integrated Marine Management Plan for Shiretoko WNH Site were effective in monitoring trends for human and ecological pressures, and ecosystem responses in marine areas around the Shiretoko Peninsula.

However, local SST data of the observation buoys for environmental pressure indicators could not capture the unimodal trend for ecosystem responses. Kuroda et al. (2020) has reported that seasonal trends of SSTs were changed around Japan in the mid-2010s. This may suggest that the SST dataset for this analysis doesn’t grasp the trend of ecosystem responses due to different spatial scales. Therefore, it is necessary to define the spatial scale for the analysis, then, to obtain additional oceanographic data (e.g., chlorophyll, salinity, current velocity and direction, etc.) using such as satellite images and oceanographic models in addition to observation buoys. Moreover, this study has focused on only four fish species and one sea mammal species as ecosystem responses indicators. In order to refine this research, additional data on food sources for Steller sea lions are also necessary.

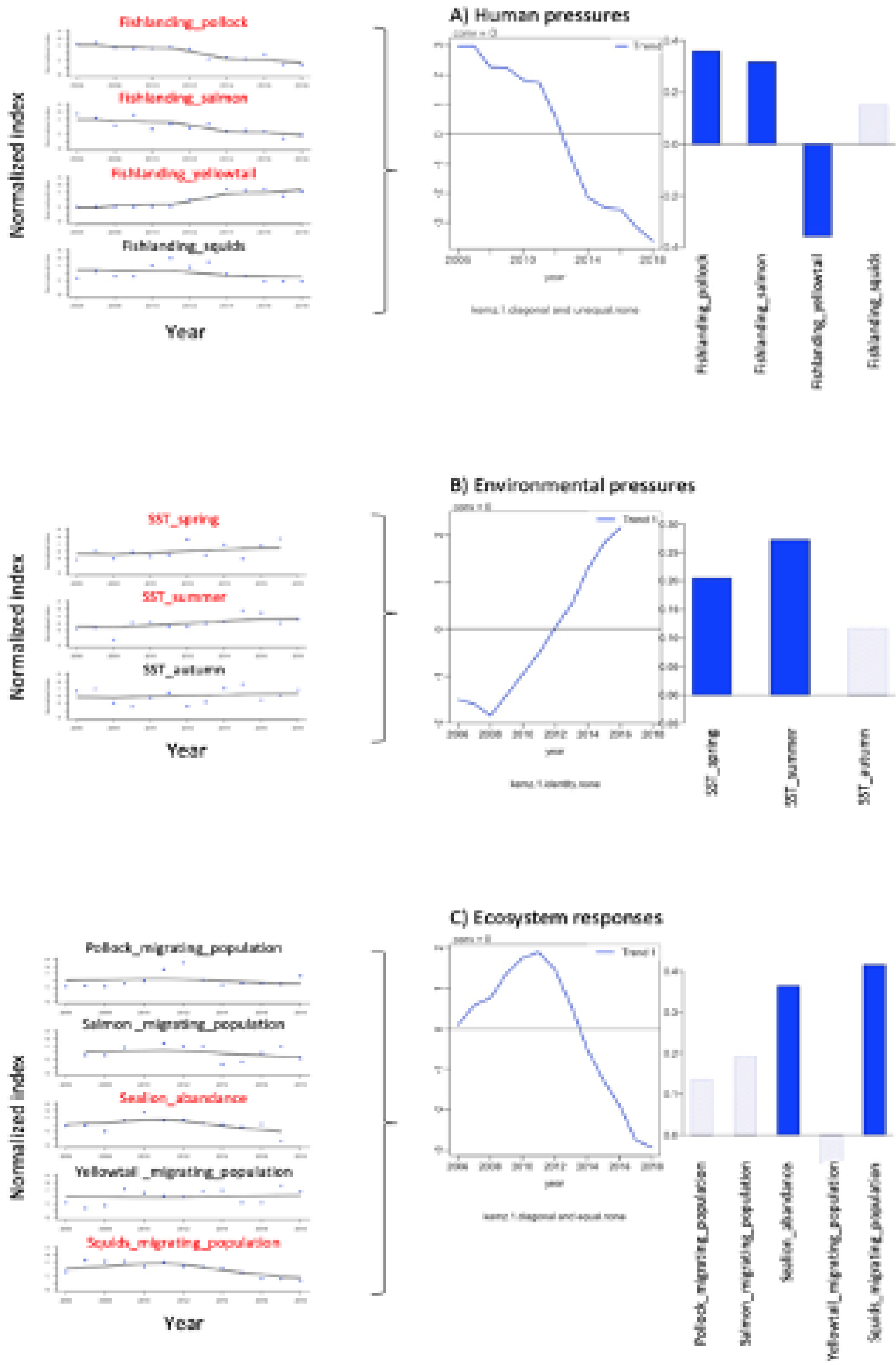


Figure 5-4. Time series changes of indicators of human and environment pressures, and ecosystem responses (left column) and trends and factor loadings identified from these indicators with Multivariate Dynamic Factor Analyses (right column), for marine areas around the Shiretoko Peninsula. The red indicator means that an absolute value of factor loadings is more than 0.2.

5.3.4 Korea

Status and trends

Environment indicators for the coastal seas around the Korean Peninsula show two common trends during 2000 – 2016 (Figure 5-5). The first common trend (Trend 1) shows an increase until 2004, a decrease until 2010, and a sharp increase after 2010. PDO, NINO3.4, and MEI series were predominantly determined by Trend 1 (Figure 5-5). On the other hand, NPGO shows an opposite response in Trend 1. The second common trend (Trend 2) shows a sharp decrease during 2002 – 2016 (Figure 5-5). Temporal variations of nutrients such as NH_4-N, NO_2-N, DIN, and DIP were mostly determined by the Trend 2. However, SiO_2-Si shows an opposite response to Trend 2. COD time-series was commonly associated with the two trends.

For human pressures, the catches of squid have been decreased since 2002 (with positive loadings for Trend 1 in Figure 5-6), whereas the catches of crab and croaker have been increased (with negative loadings for Trend 1). The catches of anchovy and eels and the total of ships tonnages have been increased until 2013 and remained constant after the increase. The catches of mysid shrimp were associated with Trend 1 and 2.

To extract common trends from ecosystem indicators, we compiled time series data of chlorophyll-a concentrations, individual numbers of copepods, euphausiids, chordates, *Notiluca*, and total wet weight of zooplankton. One common trend was extracted from the time series of ecosystem indicators (Trend 1 in Figure 5-7). In particular, time series of copepods, euphausiids, and chordates were predominantly determined by Trend 1. However, it should be noted that the temporal trend is only valid during the period of 2010 – 2016 due to the limitation of zooplankton data before 2010.

Implications of trends

Application of the DFA to the environment, human, and ecosystem indicators for the coastal sea around Korean Peninsula identified five trends: two for environment pressures, two for human pressures, and one for ecosystem response indicators (Figure 5-5, 5-6, 5-7). Especially, the second trend (Trend 2) for the environment indicators (NH_4-N, NO_2-N, DIN, DIP, COD) was significantly correlated with the first and second trend for human indicators of fishery landings (squid, mysid shrimp, crab, croaker, anchovy, eel, shrimp) and the first trend for ecosystem indicators (copepods, euphausiids, and chordates) (Table 5-1). These close correlations among the trends for the environment, human, and ecosystem indicators suggest that there is some evidence of structural or functional relationships between pressures and responses in seas around the Korean Peninsula.

Table 5-1. Pearson correlation coefficients between two trends of environmental (ENV) and human (HUM) pressures and ecosystem response (ECO) indicators

	Trend 1 (ENV)	**Trend 2 (ENV)**	**Trend 1 (HUM)**	**Trend 2 (HUM)**	**Trend 1 (ECO)**
Trend 1 (ENV)	1	-0.22	-0.15	0.40	-0.27
Trend 2 (ENV)	-0.22	1	**0.78***	**-0.86***	**0.57***
Trend 1 (HUM)	-0.15	**0.78***	1	**-0.55***	**0.49***
Trend 2 (HUM)	0.40	**-0.86***	**-0.55***	1	-0.44
Trend 1 (ECO)	-0.27	**0.57***	**0.49***	-0.44	1

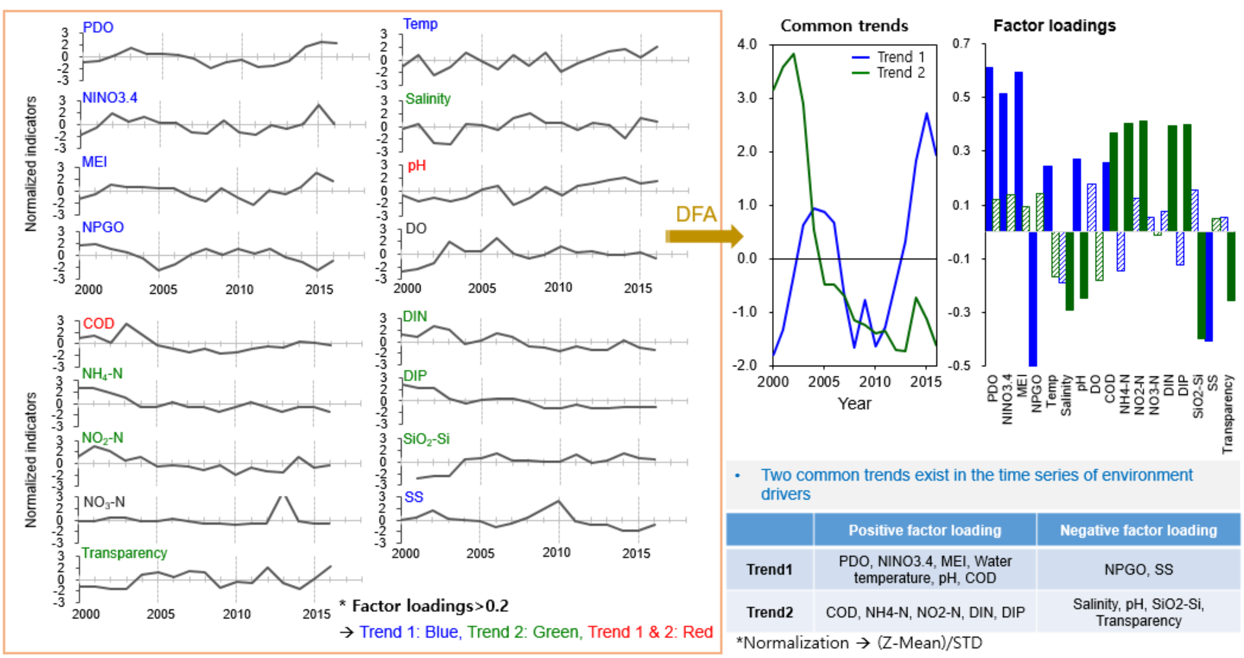


Figure 5-5. Temporal variations of 17 environment pressure (left column) and trends and factor loadings (right) extracted by Multivariate Dynamic Factor Analyses for the seas around the Korean Peninsula. Table in the lower right corner shows environment pressures over 0.2 of positive or negative factor loadings in each trend.

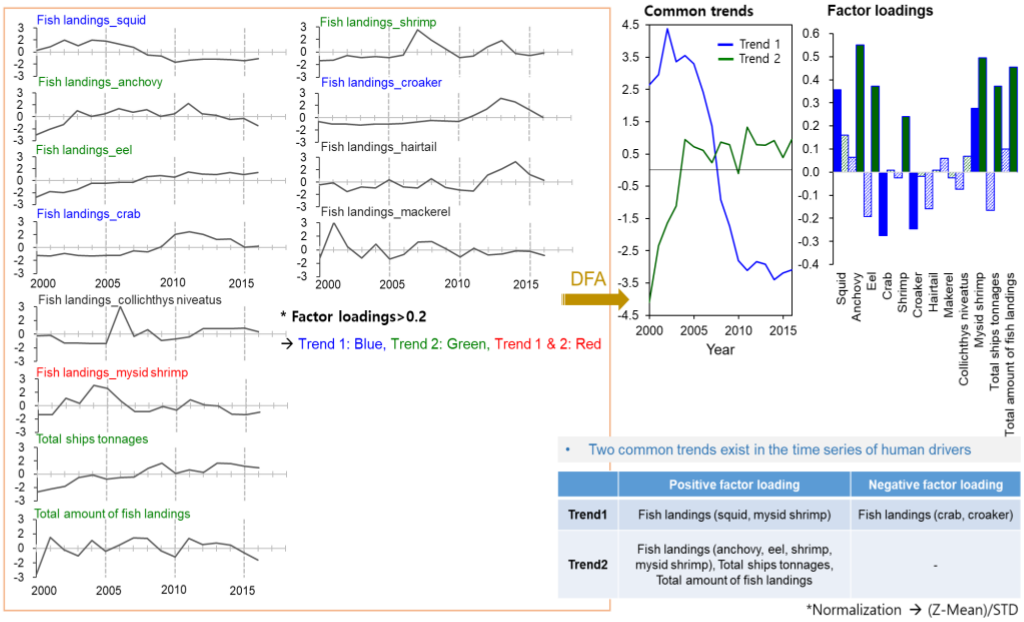


Figure 5-6. Temporal variations of twelve human pressures (left column) and trends and factor loadings (right) extracted by Multivariate Dynamic Factor Analyses for the seas around the Korean Peninsula. Table in lower right corner shows human pressures over 0.2 of positive or negative factor loadings in each trend.

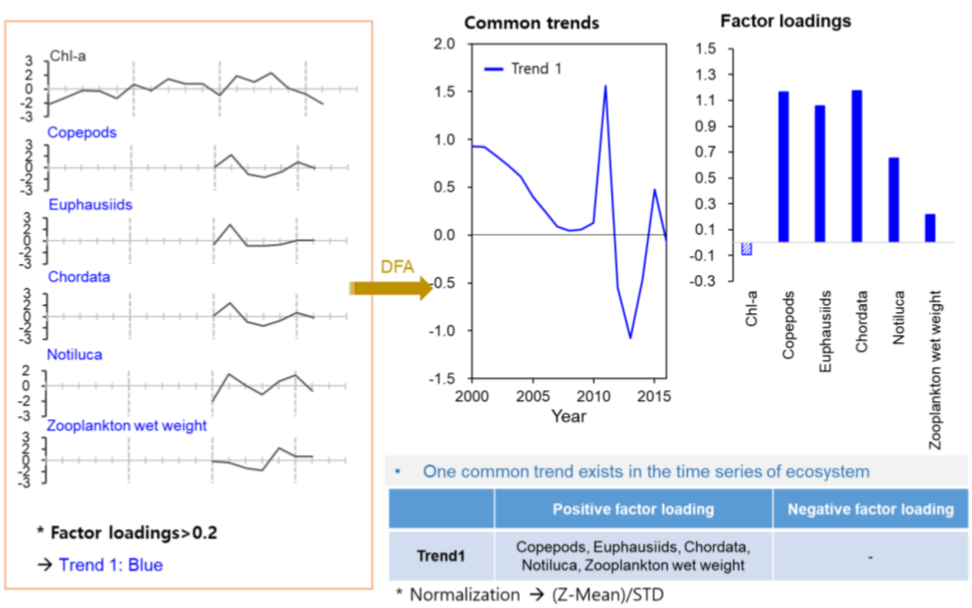


Figure 5-7. Temporal variations of six ecosystem response indicators (left column) and a trend and factor loadings (right) extracted by Multivariate Dynamic Factor Analyses for the seas around the Korean Peninsula. Table shows ecosystem response indicators over 0.2 of positive factor loadings in trend 1.

5.3.5 Russia

With regards to other methods of research of multivariate environmental times series observations, suggested by WG-36, we took the liberty of exploring changes in the mean annual Trophic Level (TL) and Mean Trophic Index (MTI) changes in connection with top species fishery catches. Preliminary analyses of changes in TL and MTI as response variables and catches as pressures showed that shifting time series against each other to account for time lag in effects of catches increase explained variance in GAMs, e.g., 3 years lag led to maximal cross-correlation and made the relation non-linear (Fig 5-8), but the absence of lags made the same relation linear and we could not extract a threshold from it as it is supposed in the R script developed for the WG36.

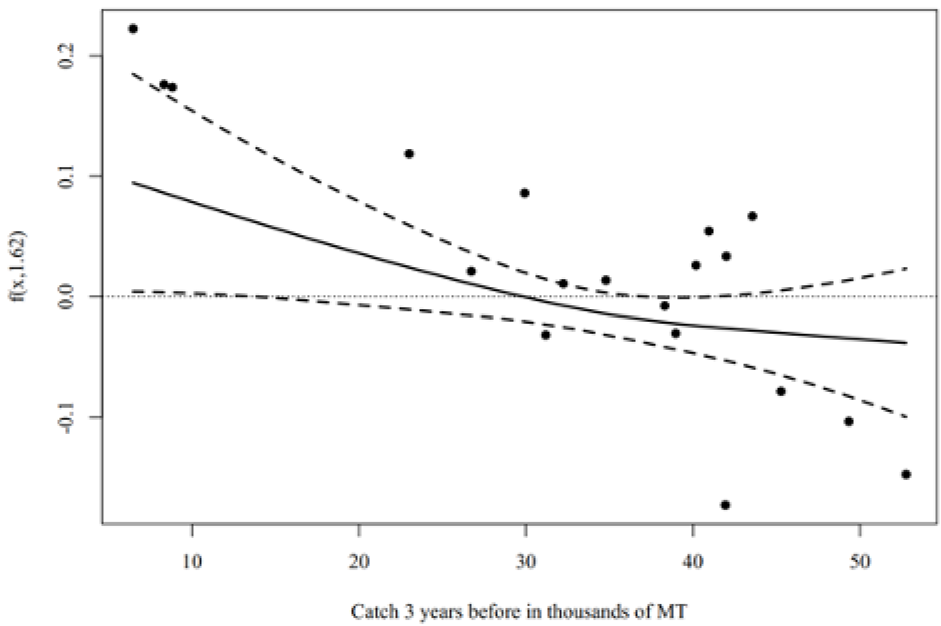


Fig. 5-8. Thin plate regression spline over centered with 4.18 intercept in Generalized Additive Mixed Models for TL dependence from catches 3 years before in the Russian Exclusive Economic Zone in PICES bioregion #19.

We selected “Primorskiy kray” (Russian continental EEZ in PICES bioregion #19) for further research, because it had the strongest linear decrease of MTI and TL in the timeframe of NPESR3 between 2011 and 2016 (Fig. 5-9). Moreover, it was the only place where we could clearly see bell -shaped trace plot between mean TL and the catches (Fig. 5-10).

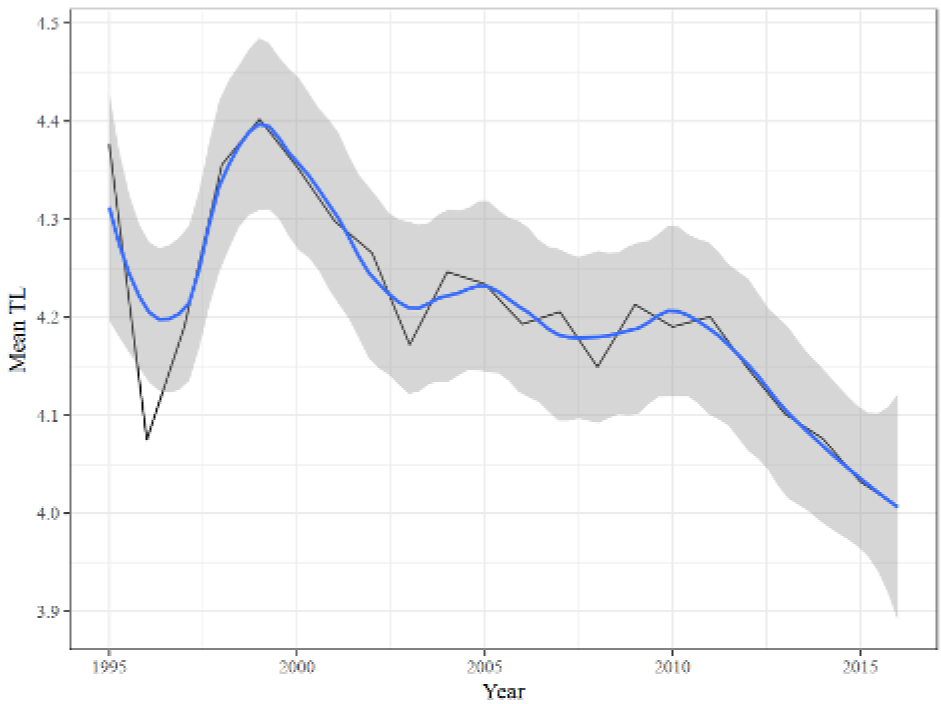


Fig. 5-9. Mean annual TL of catches in the Russian part of bioregion #19.

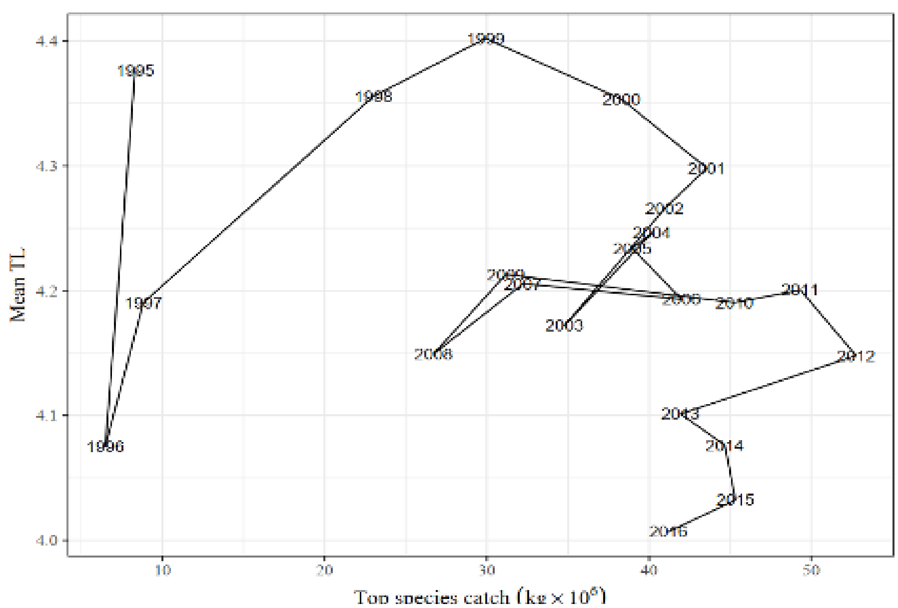


Fig. 5-10. Mean TLs versus the catches in the Russian part of bioregion #19.

Following the examples provided with the source code for R prepared for the WG-36 we tested catches in the Russian part of bioregion #19 against TL and MTI. Methods of extraction of tipping points from GAM could not find the threshold in the relation between TL and catches, because it was linear. Gradient forest though was tuned without errors. Some of the results are shown below (e.g., Fig 5-11) using abbreviations from the Cornell Ecology Program (R package rioja version 0.9-15.2) for species names. Weighted importance plot (Fig 5-11) confirmed our previous results from Principal Component Analyses (see NPSER3) that changes in TL and MTI were positively related to the catch variation of Okhotsk atka mackerel (*Pleurogrammus azonus* Jordan and Metz, 1913), which had high trophic level 4.9 as a main fishing target in *Hexagrammidae* family. In the opposite low trophic level species such as shrimps decreased TL and MTI when their catches were high. Recently (in the second decade of the 21 century), the catch of another carnivorous fish, the pacific cod (*Gadus macrocephalus*), began to increase and we expect that TL and MTI will return back to the average level. Unfortunately, that new data was not included in the analyses, but we are going to follow the suggested methods by WG36 in near future and we will extend pressures and responses with other sources than just catches and TL. Thus, we found that development of R scripts in the WG36 was very useful for us to begin research using modern methods.

So, we are very thankful to the members of WG36 for the development of user-friendly scripts in R and we have already planned further research utilizing the scripts with inclusion of more stressors and indicators in the upcoming years.

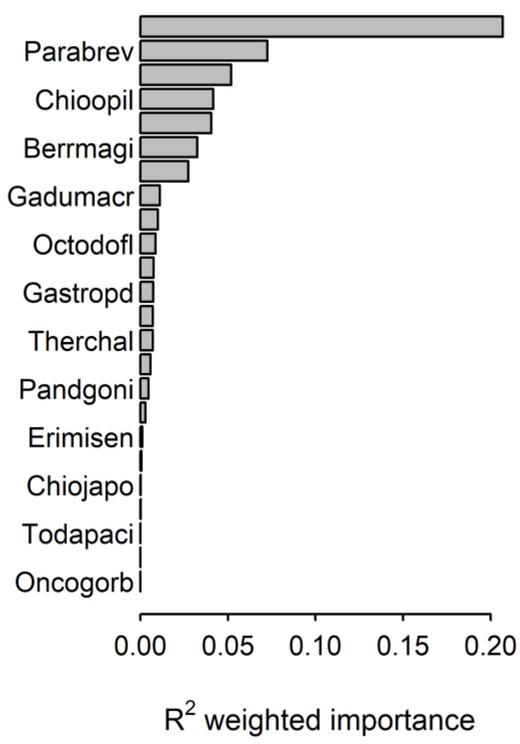


Fig. 5-11. Weighted importance of catches on changes in TL and MTI. Top 3 are *Hexagrammidae* fish (mainly Okhotsk atka mackerel), *Paralithodes brevipes* and pacific herring (*Clupea pallasii*)

5.3.6. U.S.A.

Status and trends

Through a parallel effort to the PICES WG36, Hunsicker et al. (2022) used a Bayesian version of Dynamic Factor Analysis (Ward et al. 2019) to summarize climate and biological variability in the southern and central regions of the southern area of PICES bioregion #11. A strong motivation for this analysis was to examine the ecosystem's response to the 2014-2016 marine heatwave in comparison to past climate perturbations. Many of the regional climate and biological time series used in that study were also applied to the U.S. case study for the PICES WG described below. The DFA applied to the climate series indicated that all but one of the climate time series were associated with a single trend (Fig. 5-12A). Sea surface temperature, sea surface height, and water column stratification (Brunt-Väisälä frequency) time series from the southern and central sub-regions of the southern area of PICES bioregion #11 loaded positively on this trend (Fig. 5-12B). The BEUTI and CUTI times series from both sub-regions and the isothermal layer depth time series from the central sub-region loaded negatively on the trend (Fig. 5-12B). Overall, the climate trend captured a well-documented cooling period in the CCE between 1980-2010 (Trenbeth and Fasullo 2013), as well as strong El Niño events (e.g., 1982-83, 1997-98, 2015-16) and the 2014-2016 marine heatwave. The trends and loadings indicate that these climate events were associated with weaker upwelling, reduced mixed layer depth, low nutrient flux, and warm, stratified waters (Fig. 5-12).

The DFA applied to the biology series showed strong coherence in the community signal; a majority of the time series (31 of 38) loaded strongly on a single trend and most of them demonstrated positive loadings (Fig. 5-13). The trends and loadings reflect the response of the relative abundance of most juvenile groundfishes (rockfish, flatfish), squid, krill, and some ichthyoplankton species to the climate perturbations mentioned above. Interestingly, the results suggest that the relative abundance of these species increased and the reproductive success of some seabird species was higher around the time of the 2014-2016 heatwave, whereas an opposite response is observed for the El Niño events. The few time series loading negatively on the trend indicate a reduction in sea lion pup growth rate and in the abundance of juvenile sardine and a few ichthyoplankton species (e.g., larval northern anchovy and Pacific hake) associated with the heatwave.

Pressures-response relationship and ecosystem thresholds

The goal of the U.S. case study for the PICES WG36 was to identify the presence of nonlinear and threshold dynamics in pressure-response relationships off the U.S. west coast, with a focus on the response of ecology to basin and regional scale climate variables. This work builds on the analyses of pressure-response relationships presented in Samhouri et al. 2017. We applied the same modeling approach to a broader suite of climate variables and ecological indicators that are included in the California Current Integrated Ecosystem Assessment (CCIEA). All of the climate and biology times series used in our analysis are described in Table 3-3 and are available on the CCIEA dashboard.

Overall, we tested 600 pressure-response relationships. The nonlinear model was the best supported model for 25 relationships (Table 5-2). The linear model was the best supported model for the remaining pressure-response relationships with 119 of those relationships considered significant at an alpha level of 0.05. In addition, 41 pressure-response relationships had R-squared values greater than 0.33 indicating that those relationships were moderate to strong (Table 5-2). Below we present examples of the strongest nonlinear pressure-relationships for four taxa, including sea lions, seabirds, coastal pelagic fishes, and zooplankton. We also indicate those nonlinear pressure-response relationships that have persisted for at least the past five consecutive years, i.e., 2015-2019. This was determined by applying the GAM analysis to the first 15 years of the time series and then iteratively adding an additional year of data to the analysis until we reached the end of the time series. We do not show results for pressure-response relationships in which larval fish were the ecological response or human activities were the pressures because those relationships were fairly weak overall (Table 5-2).

Seabirds - The strongest nonlinear pressure-response relationships for seabirds were between and common murre reproductive success and basin-scale variables. Specifically, common murre productivity was high when the winter averaged Multivariate El Niño/Southern Oscillation (ENSO) index (MEI) and spring averaged Oceanic Niño Index (ONI) were low and their productivity abruptly declined as MEI and ONI values approached 1 and 0.5, respectively (Figure 5-14 A, B). These relationships have persisted for greater than 25 consecutive years and likely reflect the abundance, availability and quality of prey available to common murre under different ocean conditions.

Sea lions - Our analysis indicates that California sea lion pup growth and pup production respond nonlinearly to both basin-scale and regional-scale climate variables. For example, pup growth was greatest when the Pacific Decadal Oscillation (PDO) index was negative (cold phase in the northeast Pacific) and growth estimates quickly declined as the PDO index became increasingly positive (warm phase in the northeast Pacific) (Figure 5-15A). This relationship has persisted for the past 6 years. Our results also indicate that pup growth was high when BEUTI (a measure of nitrate flux) in the southern region of the study system was high but declined when BEUTI dropped below a threshold of 0.3-0.4 (Figure 5-15B). In addition, we found a negative, linear relationship between pup growth and sea surface temperature in the southern and central regions of the study region (not shown). Similar to seabirds, these relationships are likely driven by the availability of prey to nursing sea lions that provide nourishment for young pups and are limited by how long they can leave their pups to forage for prey, rather than a direct temperature effect. For example, cooler and nutrient-rich coastal waters have been thought to support higher production or distribution of prey in sea lion foraging areas, although the 2014-16 marine heatwave in the northeast Pacific demonstrated that this is not always the case (e.g., anchovy abundance was high during the heatwave). The relationships between pup production and climate pressures, including cumulative upwelling (CUTI) in the central CCE and the Northern Oscillation Index (NOI), are weaker than those relationships identified for pup growth (Figure 5-15 C, D). However, they also suggest that stronger upwelling and cooler waters have supported a stronger prey base for pregnant and nursing sea lions during the study period and this translates into higher pup production and survival. Follow up work should evaluate the response of sea pup condition to changes prey resources directly rather than relying on ocean conditions as a proxy.

Coastal pelagic fishes - As expected based on past literature, our analysis identified strong relationships between coastal pelagic species and climate pressures. Specifically, we found strong and persistent nonlinear relationships between juvenile Pacific sardine abundance and the winter averaged PDO index, and between juvenile Pacific sardine abundance and sea surface temperature throughout the central and southern regions of the study ecosystem (Figure 5-16 A, B). These relationships indicate the sardine production has been higher during positive PDO phases and warm ocean conditions (which are negatively correlated with upwelling in the central region, Jacox et al. 2014) and vice versa, and this finding has been documented previously (see Checkley et al. 2017). We also found a strong, nonlinear relationship between adult northern anchovy and the spring averaged North Pacific Gyre Oscillation (NPGO) index (Figure 5-16 C), and a moderately strong positive, linear relationship between juvenile anchovy and offshore sea surface temperature in the southern region of the study system (Figure 5-16 D). Our results indicate that anchovy production was highest when the NPGO index was the most negative but then declined quickly and remained low as the NPGO index increased to zero and became increasingly positive. Again, this finding aligns with past studies: negative NPGO index is indicative of lower nitrate and lower primary productivity in continental waters off the U.S. west coast and higher anchovy production has been associated with less productive ocean conditions (Santora et al. 2014, Ralston et al. 2015). However, the mechanisms driving fluctuations in anchovy and sardine abundance are complex and not well known (Checkley et al. 2017, Sydeman et al. 2020)

Copepods - Our analysis identified strong, nonlinear relationships between northern copepod biomass anomalies and regional climate pressures. Winter northern copepod anomalies have demonstrated a persistent nonlinear response to CUTI and BEUTI, with the highest anomalies occurring during periods of strong upwelling and high nitrate flux off the coast of northern California, and vice versa (Figure 5-17 A, B). Summer copepod anomalies also showed a weak, nonlinear response to cumulative upwelling off the Oregon coast (Figure 5-17 C). These results are intuitive as upwelled, nutrient-rich waters fuel primary production, which in turn supports the production of zooplankton, such as copepods. In addition, we identified negative linear relationships between sea surface temperature and the winter copepod anomalies (not shown) and between the winter mode of the PDO and summer copepod anomalies (Figure 5-17 D).

These relationships likely reflect the transport of coastal, cold, subarctic waters from the north, which is pronounced during the negative phase of the PDO, and brings a high abundance of coastal, subarctic “northern” species to waters off the Oregon coast (Peterson and Miller 1977).

Comparisons to prior work

As mentioned above, the analyses for the U.S. builds on the analyses of pressure-response relationships presented in Samhouri et al. 2017. In our current work, we updated analyses for two pressure - response relationships identified as strongly nonlinear with thresholds in the prior study. This allowed us the opportunity to evaluate if strongly nonlinear relationships identified in the Samhouri et al. 2017 study persisted with additional years of data. We found that the strongly nonlinear relationships previously identified between (1) the PDO and sea lion pup production and (2) the NPGO and northern copepod biomass anomalies broke down with five additional years of data. Neither of the relationships were significantly linear or nonlinear based on our analysis.

Table 5-2. Results of analyses to identify nonlinear and threshold dynamics in pressure-response relationships in the southern area of bioregion #11, with a focus on the response of the ecology to basin and regional scale climate variables. This table combines model results based on climate pressures averaged across winter months (Dec, Jan, Feb) and spring months (March, April, May) with the exception for models in which sea lion pup growth or production was the response variable (see legends in figures 5-2 and 5-3 for details). Regional climate variables were estimated at three latitudes: 33N, 39N, 45N; with heights of 1 degree (e.g., 33N is the average of all points between 32.5N to 33.5N). For SST, both nearshore (N, 0-75 km) and offshore (O, 75-150 km) times series were included in our analysis. Dark orange cells = nonlinear relationship, light orange cells = significant linear relationship (p value < 0.05), and gray cell = non-significant linear relationship. Asterisks indicate those relationships with R-squared value greater than 0.33, indicating moderate to strong relationships.

	Basin-scale environment (win & spr)						Regional environment (win & spr)												Landings (annual)	
							SST						CUTI			BEUTI				
	PDO	NPGO	MEI	ONI	NOI	NPH	33N (N)	33N (O)	39N (N)	39N (O)	45 (N)	45 (O)	33N	39N	45N	33N	39N	45N	CPS	GF
Response																				
Brandt's cormorant reproductive success											-	-			-			-		
Cassin's auklet reproductive success											-	-			-			-		
Common murre reproductive success			*	*							-	-			-			-		
Pigeon guillemot reproductive success											-	-			-			-		
Rhinocerus auklet reproductive success											-	-			-			-		
CA sea lion pup growth (Aug-Feb)	*		*	*			*	*	*	*	-	-		*	-	*		-		
CA sea lion pup production (May-Jun)											-	-		*	-			-		
CA sea lion pup production (Oct-Jun)			*		*						-	-			-			-		
Adult forage fish catch											-	-			-			-		
Adult anchovy catch		*									-	-			-			-		
Adult sardine catch											-	-			-			-		
All young-of year (YOY) catch											-	-			-			-		
Anchovy yoy catch		*						*			-	-			-			-		
Pacific hake yoy catch															-			-		
Rockfish yoy catch											-	-			-			-		
Sardine yoy catch	*						*	*	*	*	-	-			-			-		
All larval fish abundance											-	-			-			-		
Pacific hake larvae abundance											-	-			-			-		
Pacific sardine larvae abundance											-	-			-			-		
Rockfish larvae abundance											-	-			-			-		
N. copepod biomass - summer anomaly	*		*				-	-	*	*	*	*	-			-			-	-
N. copepod biomass - winter anomaly	*		*	*			-	-	*	*	*	*	-	*	*	-	*		-	-

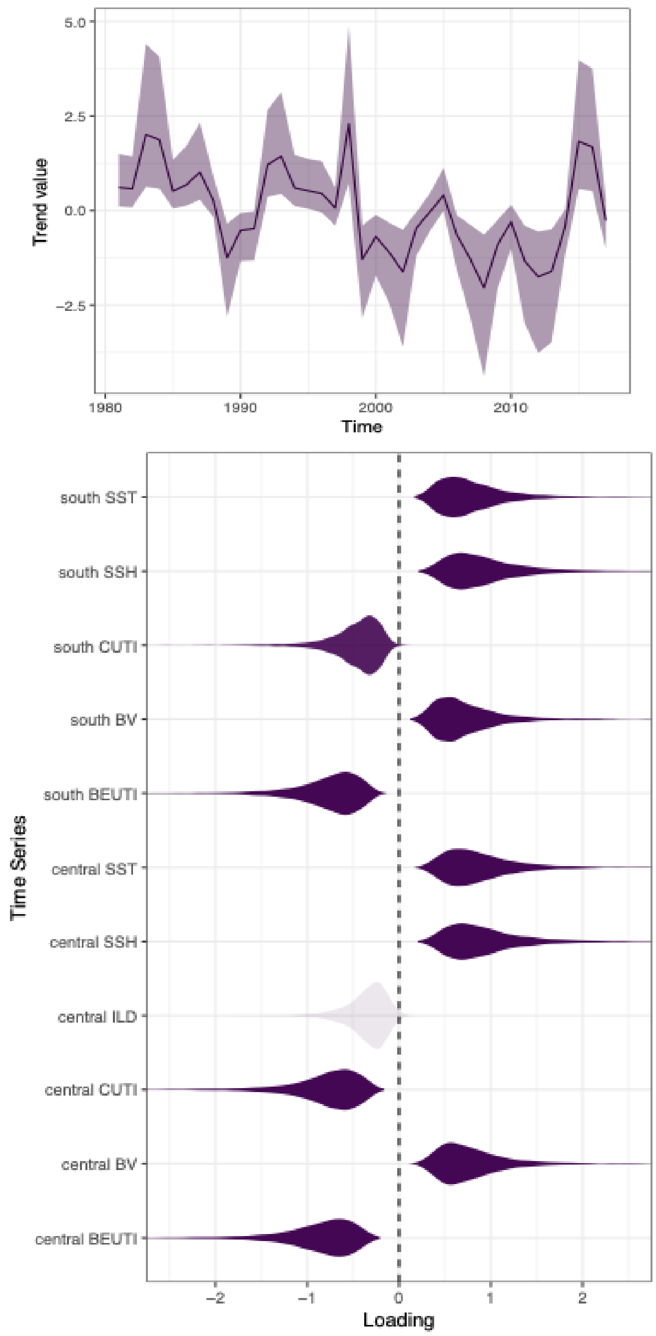
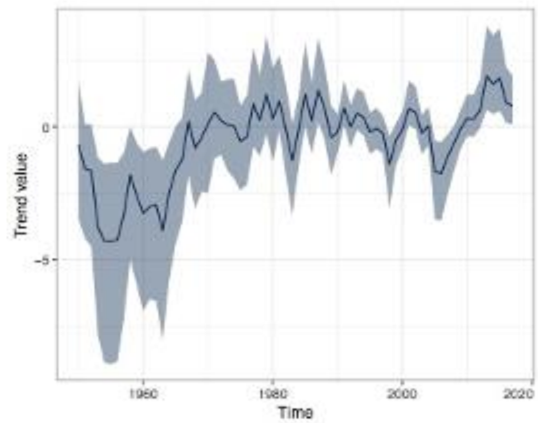


Fig 5-12 Climate variability in southern and central region of the study ecosystem: a) shared trend with 95% credible intervals (1981-2017, top figure), b) posterior distributions for loadings on all of the individual time series (bottom figure). Loadings with darker shading indicate time series loading most strongly on the climate trend. SST, sea surface temperature; SSH, sea surface height; ILD, isothermal layer depth; BV, Brunt-Väisälä frequency (stratification); CUTI, Coastal Upwelling Transport Index; BEUTI, Biologically Effective Upwelling Transport Index. See Hunsicker et al. 2022 for more information. Figure adapted from Hunsicker et al. (2022).



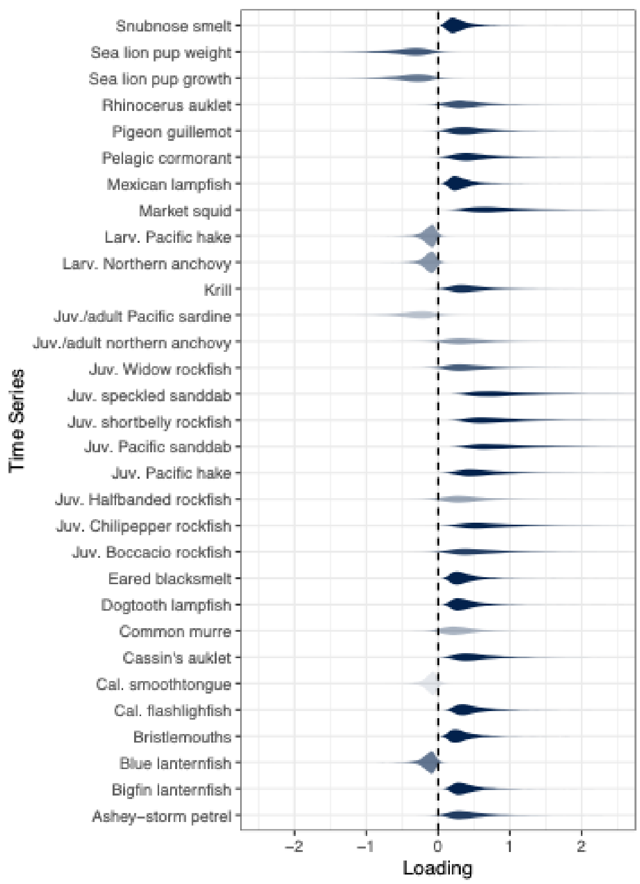


Fig 5-13. Community variability in the southern region of the study ecosystem: a) shared trend with 95% credible intervals (1951-2018, top figure), b) posterior distributions for loadings on individual time series (only time series with ≥ 90% of the loading distributions above or below zero are shown, bottom figure). Loadings with darker shading indicate time series loading most strongly on the biology trend. See Table S1 for times series details. Cal. = California, Juv. = juvenile fish stage, Larv. = larval fish stage, Juv./adult = juvenile and adult stages combined. See Hunsicker et al. 2022 for more information. Figure adapted from Hunsicker et al. (2022).

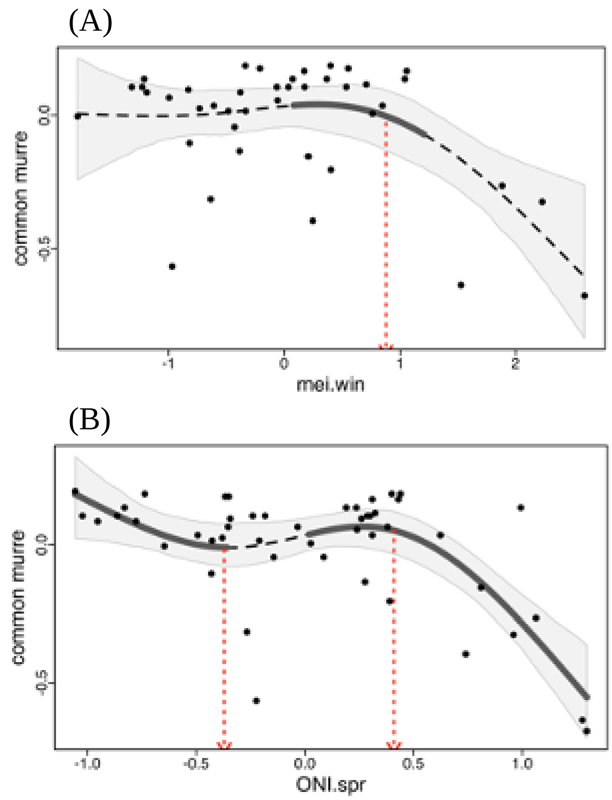


Figure 5-14. GAM analyses showing response of common murre reproductive success to A) the winter averaged MEI (R^2= 0.33) and B) the spring averaged ONI (R^2= 0.48). The dashed black line is the GAM smoother, gray polygon is 95% CI, black points are raw data, thick solid line indicates the threshold range where the 95% CI of the 2nd derivative does not include 0, and red dotted arrow indicates the best estimate of the location of the threshold (i.e., where the 2nd derivative is at its absolute maximum value within the threshold range). See Samhouri et al. (2017) for method details.

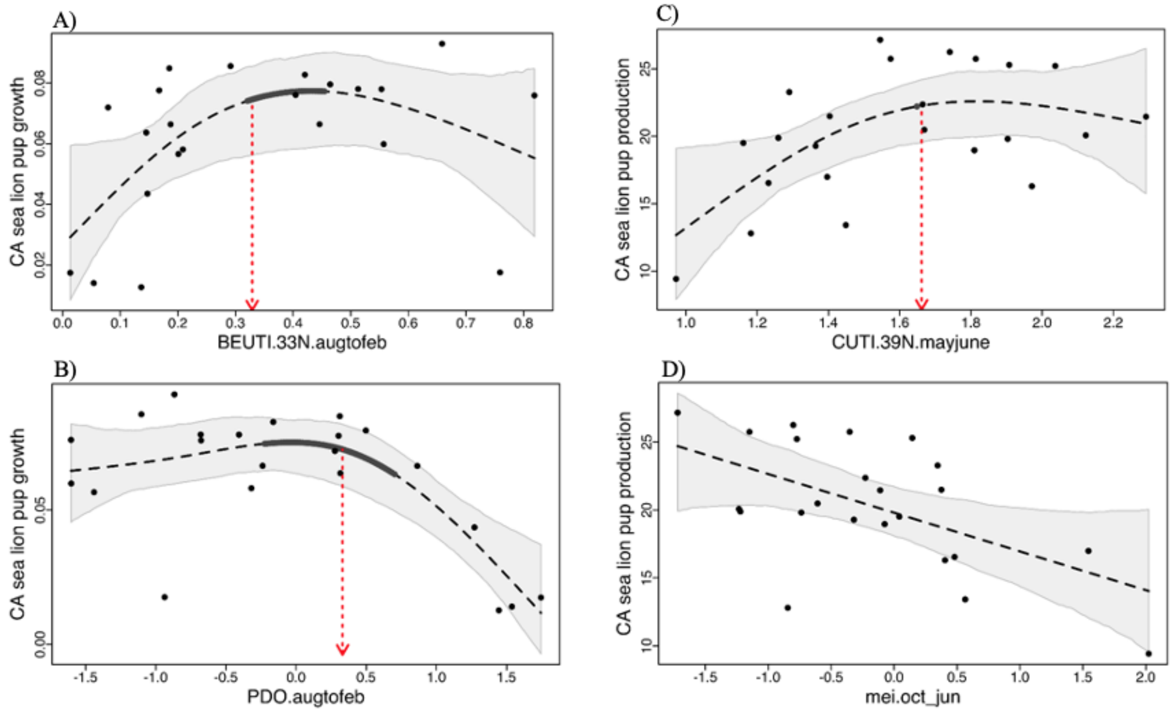


Figure 5-15. GAM analyses showing the response of California sea lion pup growth to A) estimates of BEUTI (nitrate flux, R^2= 0.33) off the Southern California Bight (33N) and B) the PDO = 0.56). These two climate indices are averaged across August to February because sea lion pups are born in June or July and growth is measured sometime between the following October and February. Also shown are the responses of California sea lion pup production to C) estimates of CUTI (cumulative upwelling) off the coast of northern California (39N) and averaged over months just prior to pup births (May-June, R^2= 0.35) and D) and the MEI averaged over months covering the gestation period for adult female sea lions (October-June, R^2 = 0.32).

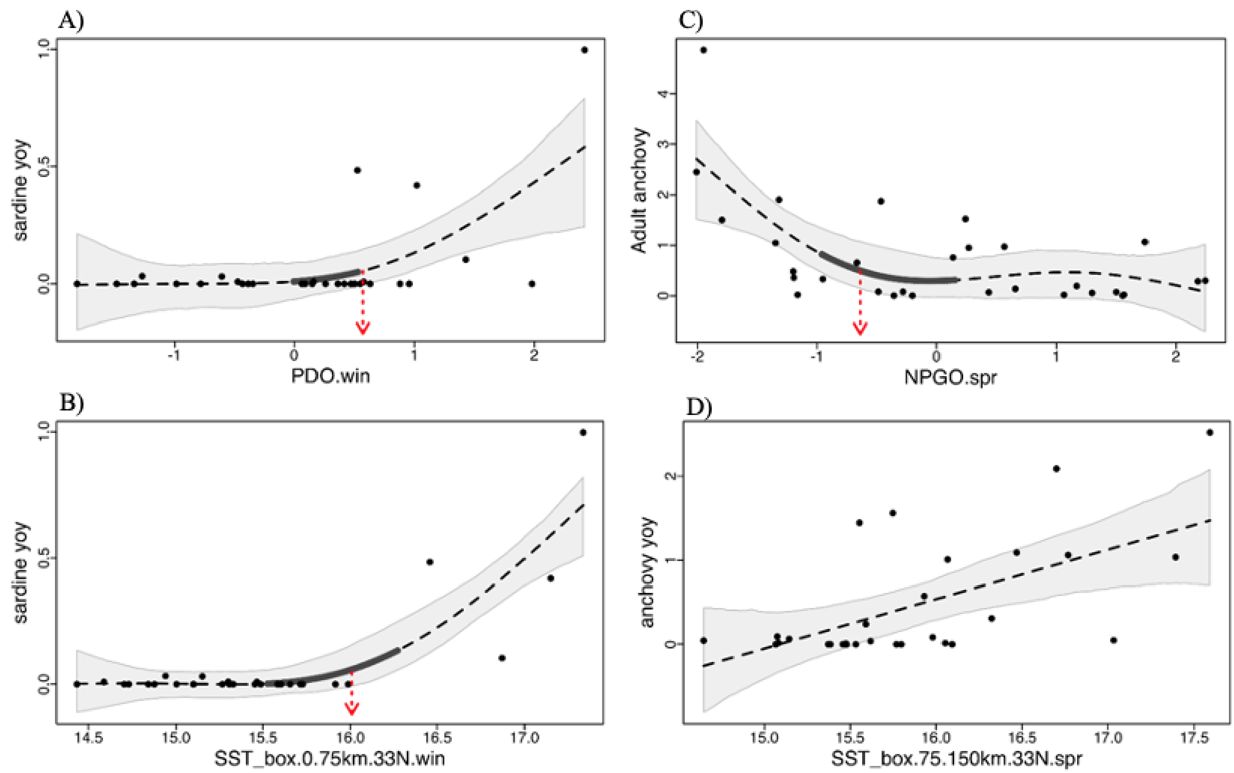


Figure 5-16. GAM analyses showing the response of juvenile sardine abundance to A) the winter averaged PDO index (R^2= 0.41) and B) nearshore winter SST off the coast of the southern California bight (33N, R^2= 0.74). Also shown are C) the response of adult northern anchovy to the spring averaged NPGO index R^2= 0.45) and D) the response of juvenile anchovy to offshore spring SST in the southern California Current (R^2= 0.36). We note that the estimates of uncertainty around the GAM smoothers are negative at times. Future work will evaluate alternate model formulations to identify a more appropriate model for the sardine and anchovy time series on light of the high prevalence of zeros.

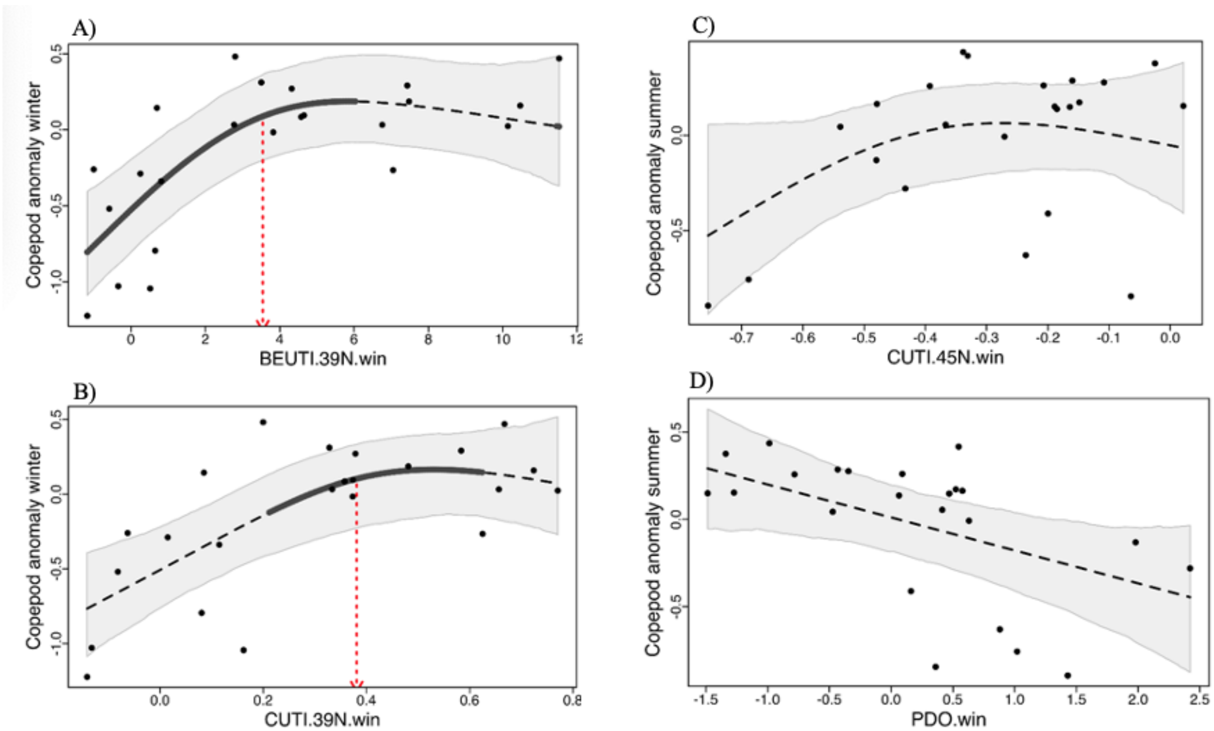


Figure 5-17. GAM analyses showing the response of the northern copepod winter biomass anomalies to winter estimates of A) BEUTI (nitrate flux, R^2= 0.51) and B) CUTI (cumulative upwelling) off the coast of northern California (39N, R^2= 0.48). Also shown are the responses of the northern copepod summer biomass anomalies to winter estimates of C) CUTI (cumulative upwelling) off the coast of Oregon (45N, R^2= 0.30) and D) the PDO index (R^2= 0.49).

5.4 Summary and Conclusions

We characterized key pressure-response relationships and examined evidence of ecosystem thresholds in the pressure-response relationships. We used Dynamic Factor Analyses to identify common trends, gradient forest analyses to identify important pressures on ecosystem responses and thresholds, and general additive models (GAM) to examine nonlinearities in pressure-response relationships.

- Where significant single pressure-response relationships were found, about >50% were linear and <10% were nonlinear. The nonlinear relationships may provide leading indicators with thresholds.
- Dimension-reducing analyses, such as Dynamic Factor Analysis, can simplify a suite of indicators to a few important trends. For example, for most of the case studies the pressures and ecosystem responses loaded on single trends. This was especially true for those models based on a small number of time series, e.g., less than 10 (Japan), and those that demonstrated strong coherence among the time series (U.S.A.). In some cases, correlations among DFA trends can be used to provide evidence of structural or functional relationships

between pressures and responses (e.g., Korea). Future analyses could be aimed at combining human pressures, environmental pressures, and ecosystem responses within the same model to evaluate potential associations among the time series.

- The WCVI case study applied both gradient forest and GAM analyses to environmental and biological time series. The Gradient Forest analysis identified similar nonlinearities as the single pressure-response GAM models, and additional nonlinearities as well. These findings support the use of a multi-model approach to detect nonlinearites and thresholds in marine ecosystems.
- Top pressures include both basin and regional scale environmental pressures. Human pressures were not identified as important in the WCVI or the U.S. case studies. However, human pressures were important in the Samhouri et al. 2017 U.S. case study, especially in the gradient forest analysis.
- Identification of pressure-response relationships likely depends on the length of time series, frequency of measurements (seasonal vs annual), spatial scale of indicators analyzed, as well as the ecosystem being examined. A recent update of the Samhouri et al. (2017) analyses using a longer time series resulted in the identification of fewer nonlinearities (M. Hunsicker et al., unpublished). Very high signal-to-noise-ratios may also be needed to reliably detect thresholds in ecosystem variables (Hillebrand et al. 2020).
- Future studies could take into account more proximate pressures of ecological responses. For example, changes in predator abundances could be evaluated with respect to prey abundance and condition rather than using environmental pressures as a proxy. The potential for nonstationarity in pressure-response relationships also deserves consideration in future efforts to quantify nonlinearities and threshold locations in those relationships.

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6 Leading indicators of loss of resilience and ecosystem change

6.1 Introduction

Traditional observing systems, including ship- and shore-based sampling, satellite-borne sensors, moorings, autonomous floats and underwater vehicles, are capable of monitoring a wide range of physical and environmental properties (Miloslavich et al. 2018). This direct sampling is effective for understanding physical oceanographic processes. However, understanding how and when physical changes cascade through ecosystems and elicit biological responses remains difficult. Potential ecosystem responses include oceanographically-driven changes in ecosystem function, changes in the spatial distribution, abundance, and composition of the forage community, and changes in food web dynamics. These ecological factors influence trophic transfer, and in turn can affect ecosystem productivity. While one can hypothesize how and when environmental changes (e.g., a delay in upwelling or an increase in temperature) will affect an ecosystem more broadly, leading indicators, such as ecosystem sentinels (i.e., species that can provide information about unobserved ecosystem components, Zacharias and Roff 2001), can help identify when and where these broad-scale impacts have or are likely to occur, and identify thresholds or tipping points when physical processes translate to broad-scale implications for the ecosystem.

Biological taxa ranging from plankton to top predators have been proposed as potential elucidating or even leading indicators of ecosystem change in marine ecosystems (Boeing & Duffy-Anderson 2008, Brodeur et al. 2008, Racault et al. 2015, Hazen et al. 2019, Nielsen et al. 2021). For example, zooplankton have short life cycles (weeks) and are closely associated with water masses. Thus, they respond quickly to both seasonal and event-scale changes in environmental conditions driven by shifts in ocean circulation and atmospheric forcing. Ichthyoplankton have narrower thermal tolerances than older life stages (Pörtner & Peck 2010) and therefore are more sensitive to fluctuations in ocean conditions and respond faster to environmental perturbations than adult fishes (Asch 2015; Auth et al. 2018; Goldstein et al. 2018; Koslow et al. 2017). These characteristics of zooplankton and ichthyoplankton, as well as their important role in the trophodynamics of marine pelagic ecosystems, make them effective sentinel taxa for ecosystem variability (Boeing & Duffy-Anderson 2008, Brodeur et al. 2008, Mackas and Beaugrand 2010; Mackas et al. 2012). As such, they are regularly monitored through various ocean observing systems and are used as indicators of ecosystem state in various marine ecosystems (Beaugrand 2005, Peterson et al. 2015, Gallo et al. 2022, Ndah et al. 2022).

Top predator-measured metrics have also been proposed as essential ocean variables that can contribute to the global ocean observing system (Miloslavich et al. 2018). Several key characteristics are common to top predator taxa (e.g., seabirds and marine mammals) that are well suited for use as ecosystem sentinels. These include 1) conspicuousness, 2) sensitivity to ecosystem processes and timeliness in their responses, and 3) ability to collect multiple indicators from a single individual or population that are informative about ecological processes over a range of spatial and temporal scales (Figure 6-1, 6-2). The relative importance of these characteristics will depend on the ecosystem process and timescale of interest. For example, detecting the implications of short-term climate variability may require multiple consecutive measurements over a relatively short time-frame, thus ideal indicators should be conspicuous and show an appropriately rapid response. In addition, measures of biodiversity (e.g., taxonomic diversity, functional diversity and community composition) have been proposed as good leading indicators of ecosystem change because loss of diversity decreases ecosystem resilience which can cause dramatic ecosystem shifts (Mori et al. 2013). Social drivers underlying ecosystem change have been explored less in the literature but they may also provide earlier indication of impending shifts (Hicks et al. 2016).

6.2 Methodologies for identifying leading indicators of ecosystem change

The development and testing of methodological approaches for detecting early warning signs of ecosystem change has been the focus of myriad research efforts over the past few decades. For example, many studies have investigated whether the application of theoretical early warning indicators, statistical metrics of ecological resilience, datasets from empirical ecosystems including lakes, seas, and open oceans could hold promise for informing natural resource management (Dakos et al. 2012, 2017, Scheffer et al. 2015, Gsell et al. 2016, Burthe et al. 2015, Litzow et al. 2013). These indicators essentially capture the 'critical slowing down' of degraded systems as they are about to become unstable and approach a critical transition or tipping point. This slowing down can be detected in the statistical properties of time series, such as increased temporal or spatial autocorrelation and variance in the system state (Scheffer et al. 2015). To date, there has been mixed success in applying early warning indicators to empirical systems (Gsell et al. 2016, Burthe et al. 2016), and they have been unreliable in ocean ecosystems (Litzow and Hunsicker 2016). Given these outcomes, a multiple-methods approach for early detection of large ecosystem shifts that is tailored to local ecosystem characteristics and mechanistic understanding has been suggested for providing timely advice for management actions (Lindegren et al. 2012). In addition, other research efforts have been aimed at providing the earliest possible detection of an ecosystem that is already shifting to a different state. For example, multivariate statistical analyses, such as Dynamic Factor Analysis, are being used to synthesize information from multiple biological taxa that respond quickly to climate perturbations in effort to develop an overall indicator an ecosystem state and to identify the probability of an ecosystem shifting to a previous or novel state (see TOR 3 and TOR 4, Ward et al. 2019, 2021, Litzow et al. 2020, Hunsicker et al. 2022). Extensions of these analyses are also underway to provide reliable forecasts of ecosystem state one year in advance based on future ocean conditions (Hunsicker et al. 2022).

6.3 Management relevant indicators derived from pressure-response relationships

While the pursuit of effective leading indicators or early detection of ecosystem change is ongoing, there are management relevant indicators that have already been derived from significant pressure-response relationships (both linear and nonlinear), including anthropogenic and environmental pressures. For example, in Canada, relationships between both physical environmental and biological pressures and endangered Northern Abalone (*Haliotis kamtschatkana*) abundance have been used to improve abundance estimates for northern abalone (Hansen et al. 2020), which will be directly used by management to assess their current status in British Columbia. Environmental conditions in both freshwater and marine ecosystems are used to forecast returns of many stocks of both Sockeye and Pink Salmon (DFO 2021, Hyatt et al. 2020). To identify fishing opportunities and avoid overfishing, DFO Science provided pre-season forecasts of adult Fraser Sockeye Salmon (*Oncorhynchus nerka*) arrival times in local waters and migration routes around Vancouver Island, based on the statistical relationships between migratory patterns and environmental variables (DFO 2016). In addition, Xu et al. (2020) used boosted regression trees to link Fraser River watershed Chinook salmon growth rates to three environmental variables. Incorporating those environmental variables in salmon stock assessment models will improve science advice to fisheries management.

Likewise, in the southern area of bioregion #11, a suite of physical and biological indicators of ocean conditions experienced by out-migrating juvenile salmon are summarized annually in a 'stoplight table' and can be used to predict returns of adult Chinook salmon (Burke et al. 2013). Evidence of thresholds in relationships of multiple environmental pressures and Chinook salmon forecast model performance could also be used to improve forecast models and to potentially anticipate and adjust management strategies to account for environmental conditions where forecast performance may be particularly poor (Satterthwaite et al. 2019). Strong relationships have been identified between ocean conditions and fish recruitment variability and productivity that can inform assessment models and management decision making for commercially important groundfish species (Tolimieri et al. 2018, Haltuch et al. 2020, Vestfals et al. *In Review*). In addition, nowcasts of mammal marine distributions, based on observed ocean conditions, can help resource managers and users manage risks associated with fisheries bycatch and ship-strike (Hazen et al. 2017, 2018, Welch et al. 2019, Samhouri et al. 2021).

There are also examples of multiple indicators relevant to ecosystem-based management in north Pacific marine ecosystems stemming from WG36 analyses. For instance, in the WCVI ecosystem, boreal copepod biomass anomalies were nonlinearly related to the timing of spring transition and southern copepod biomass anomalies were nonlinearly related to the PDO (Fig. 4.2). Copepod community composition can represent the amount of energy available to higher trophic levels; for example, boreal copepods have higher amounts of lipid than southern copepods and can therefore translate to more energy available to upper trophic levels. In the U.S. case study ecosystem, sea lion pup weights were nonlinearly related to basin-scale environmental indices, such as the PDO (Table 5-2, Fig. 5-21). In the WCVI, the proportion of predators and the trophic level of the surveyed community were also nonlinearly related to the PDO (Fig. 5.2). In addition to nonlinear relationships, several linear pressure-response relationships were identified that may inform management or single species stock assessment models. For example, in marine areas around the Shiretoko Peninsula, there was a relationship between a human pressure DFA trend and an ecosystem response DFA trend (Fig. 5.4). In coastal waters around the Korean Peninsula, DFA trends indicate that squid catches and increases in croaker and crab catches were significantly correlated with nutrient concentrations and individual numbers of zooplankton (Fig. 5-5, 5-6, 5-7, Table 5-1).

6.4 Challenges in identifying leading indicators and thresholds

Identifying reliable leading indicators and thresholds of ecosystem change continues to be an important goal of many science and management plans, however there are several challenges in doing so. For example, the absence or lack of adequate data on ecosystem responses to environmental and anthropogenic pressures can make these efforts difficult or even impossible. Ecosystem indicators investigated to date in the PICES bioregions and elsewhere may depend on data or time series availability. However, the efficacy of these indicators depends on whether the 'right' data are being collected at the 'right' scales to detect early signs of ecosystem change. A combination of interacting stressors is likely to produce nonlinear and threshold responses rather than a single causal factor, therefore detection of ecosystem change may require data on a broad range of ecosystem variables (Huggett 2005, Groffman et al. 2006). Also, environmental stressors may be operating at different scales, and the perception of an ecosystem functioning, in terms of indicators, may also be scale dependent (Heim et al. 2021).

6.5 Recommendations for future research

There are several avenues of research that may improve the detection and reliability of leading indicators and ecosystem thresholds for managing marine resources. Examining whether the statistical methods used to identify thresholds in pressure-response relationships in empirical systems is one of them. For example, some pressure-response relationships identified as nonlinear in the U.S. study system were subsequently identified as linear when the same analysis was updated using additional years of data (Samhouri et al. 2017, Hunsicker et al. unpublished). Simulation studies and sensitivity analyses could be useful for determining whether various methods used to identify ecological thresholds are reliable and to reveal circumstances in which they might not be. Simulation models based on ecosystem modeling frameworks might be particularly useful to detect and/or stress test indicators of ecosystem change and reference points (e.g., Fulton et al. 2005). More research is also needed on identifying the potential for nonstationary in pressure-response relationships and accounting for these dynamics in modeling efforts (Puerta et al. 2019, Litzow et al. 2020a,b, Malick et al. 2020). Nonstationary dynamics can change the usefulness of leading indicators and impact forecasting efforts (Wainwright et al. 2021). Process-based studies are key to improving our understanding of the mechanisms that might underlie nonstationary relationships and strengthening our abilities to anticipate or forecast ecosystem shifts. Lastly, but of critical importance, is the need to develop guidelines for how to frame these research efforts for managers so that we can move investigations of leading indicators and ecosystem thresholds from science activity into management action.

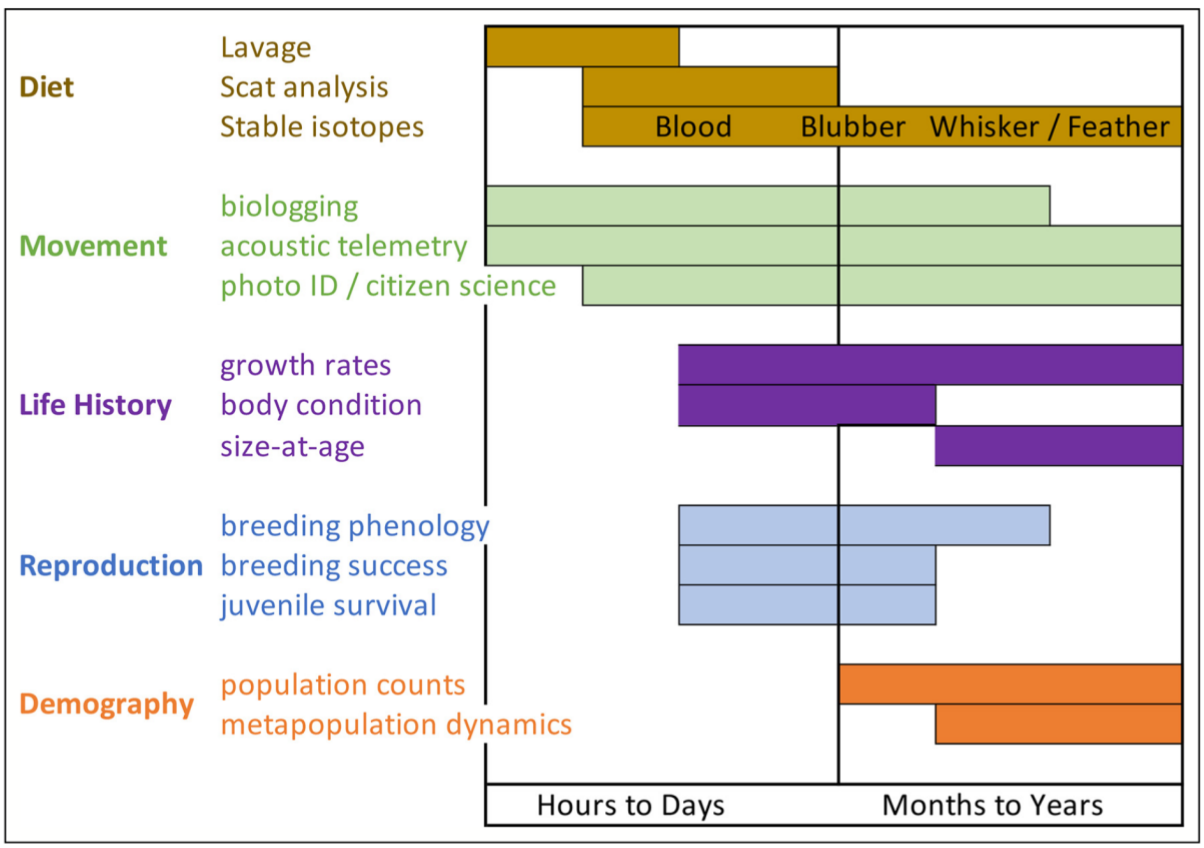

Figure 6-1: Multiple timescales of data are available from top predator sentinels that can give insight into multiple aspects of the ecosystem (from Hazen et al. 2019).

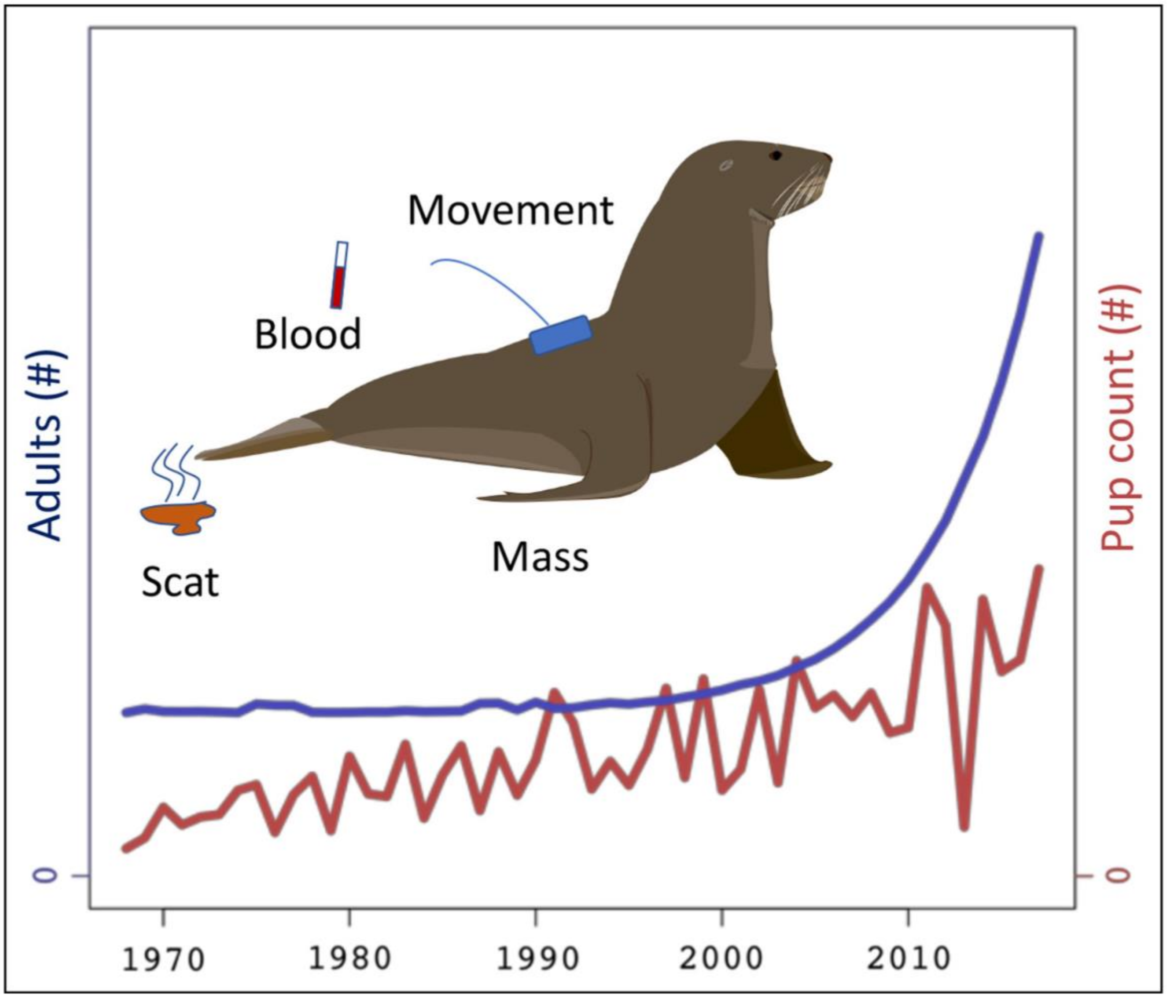

Figure 6-2: Top predators can be sampled using multiple technologies that give insight into different aspects and different time scales of ecosystem response (from Hazen et al. 2019).

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7 The value in developing heuristic models to examine pressures and ecological responses in ocean ecosystems

7.1 Introduction

Understanding and predicting marine ecosystem dynamics is challenging largely due to the multitude of environmental and anthropogenic pressures on target and non-target species and the complexities of their interactions. It is made even more challenging by the dynamic nature of the ocean environment. Heuristic models can be a useful tool for increasing understanding of complex relationships between pressures and ecosystem responses and how they might inform management actions or outcomes. Such models are simplified representations of ecosystem structure and functioning and are constructed based on hypotheses about the causal relationships among several variables. In fishery and ocean ecosystem studies, heuristic models have been used to follow ecosystem changes in marine food webs, explore unintended consequences from management actions, and make linkages between climate change and marine ecosystems, and the humans that depend on them (Harvey et al. 2016, Pollnac et al. 2015, 2019).

For TOR 6, WG36 aimed to develop heuristic models of pressures (climate forcing, fishing) and ecosystem responses using thresholds or reference points, based on WG analyses. Our goal was to demonstrate how indicators with defined thresholds could be useful for assessing ecosystem state and formulating responsive management strategies. However, the outcome of our analyses from TOR 4 precluded us from developing heuristic models for all ecosystems examined. For example, (1) single pressure-response relationships were not examined in all ecosystems, (2) of those where single pressure-response relationships were examined, a small number resulted in defined thresholds, and (3) the identified pressure-response relationships with defined thresholds did not always have clear links to management actions. Here, we provide two examples of heuristic models, for the U.S. (Fig. 7-1) and Korea (Fig. 7-2) case study regions, to illustrate how such models could be constructed and how they might be useful for making management decisions. This heuristic has also been used as a backbone for FUTURE, PICES' main science program, with Bograd et al. (2019) reviewing how changes in the physical system, such as marine heatwaves, translate to broader ecosystem processes.

7.2 Examples of heuristic models

7.2.1. U.S.A.

Marine heatwaves have highlighted the need for responsive ecosystem-based management for the north Pacific. Recent marine heatwaves, due to long-term warming trends and decreased surface mixing (Jacox et al. 2016), have resulted in increased sea surface temperatures (SSTs), with greater ecosystem impacts when the marine heatwaves move close to shore. These increased SSTs can displace species poleward (Pinsky et al. 2013), or towards the shore to find refuge in cooler, upwelled waters. Warmer SSTs can lead to increased prevalence of harmful algal blooms whose toxins can have cascading ecosystem effects (Anderson et al. 2021). The 2014-15 marine heatwave in the Northeast Pacific was named "the blob" because of its immensity and consequent ecosystem impacts. The toxins from harmful algal blooms extended from California to Washington delaying the opening of dungeness crab fishing (Santora et al. 2020). Consequently, foraging opportunities for recovering humpback whales were condensed inshore putting them at increased risk of entanglement once the crab fishery opened (Santora et al. 2020). Since then, the dungeness crab fishery has faced additional closures resulting in lost revenue and pressures on coastal fishing communities. Ultimately, if we can find thresholds in ecosystem state, e.g., when warming waters are most likely to translate to unanticipated risks, we can better anticipate and react to changing ecosystem conditions to minimize impacts, and maximize sustainable uses of the ocean.

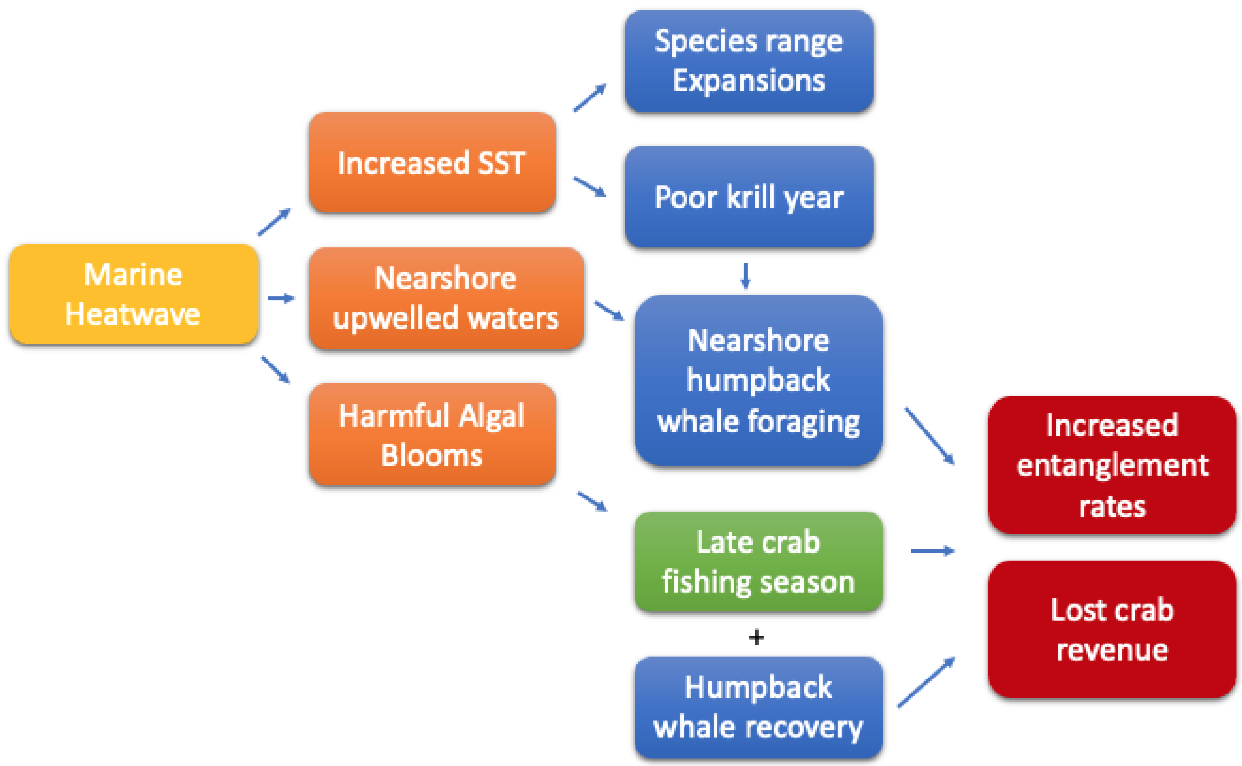

Figure 7.1: Example of a heuristic model where a marine heatwave is the driver of marine ecosystem dynamics off the U.S. west coast.

7.2.2 Korea

In response to TOR 4, Dynamic Factor Analysis was applied to extract common patterns in time series of the environment (N = 17), human pressures (N = 12), and ecosystem components (N = 6) for coastal waters around the Korean Peninsula during 2000-2016. DFA identified two common trends for environmental pressures, two common trends for the human pressures, and one common trend for the ecosystem indicators (Figure 5-5, 5-6, 5-7). Trend 1 for the environment pressures was predominant in climate indices (PDO, NINO3.4, MEI, NPGO) and water temperature (Figure 5-11). This aspect suggests that the temperature changes around the Korean Peninsula waters could be affected by changes in the North Pacific climate. However, Trend 1 for the climate indices was not significantly correlated with Trend 1 (squid, mysid shrimp, crab, croaker, and shrimp) and Trend 2 (anchovy and eel) for fish landings and Trend 1 for ecosystem response indicators (individual numbers of copepods, euphausiids, and chordates) (Table 5-1). On the other hand, Trend 2 for the environment pressures (NH4-N, NO2-N, DIN, DIP) was significantly correlated with Trend 1 and Trend 2 for fish landings and Trend 1 for ecosystem response indicators (Table 5-1). It seems that fishing and zooplankton are more likely to be affected by regional-scale environmental pressures in waters surrounding the Korean Peninsula.

The significant correlations among the common trends suggest a predictable relationship between environmental and human pressures and ecosystem response indicators for the Korean study system. The decreases in NH4-N, NO2-N, DIN, and DIP concentrations were correlated with reductions in individual numbers of copepods, euphausiids, and chordata (Figure 5-11, 5-13, Table 5-1). Decreases in squid catches and increases in croaker and crab catches were also correlated with decreases in nutrient concentrations and individual numbers of zooplankton (Figure 5-5, 5-6, 5-7, Table 5-1). Furthermore, increases in anchovy catches were related to decreases in squid catches and increases in croaker, crab, and eel catches. Squid, croaker, and eel feed on anchovies (https://www.nifs.go.kr/frcenter/). It seems that these carnivorous fishes are in competition for prey and mutually affect each other. We summarize these correlations among nutrients, zooplankton, and fishes in Figure 7-2.

According to a report (2018) provided by KNSO (Korea National Statistical Office), the annual catches of squid, anchovies, and mackerel have been increasing since the temperature increase in the 1990s. These concurrent increasing trends suggest that fishing in Korea could be affected by changes in the physical environment driven by climate change. However, in our analysis, we did not find a significant correlation between the common trends of climate indices and fishing (Table 5-1). The common trends for the fish landings and ecosystem indicators were derived from the annual means calculated over all the regions of the study area withing bioregions #19, 20, and 21. However, the fishing grounds of squid, croaker, anchovy are found in different parts of these bioregions (http://www.nifs.go.kr/). If common trends for the climate indices and fishing in each region are examined, we may identify stronger relationships that lend to predicting ecosystem responses by climate and environmental pressures. Furthermore, we used only chlorophyll and zooplankton data for ecological response indicators due to the absence of long-term monitoring data of fish stocks. To understand more clearly and quantify ecosystem responses to climate and environmental pressures in waters around the Korean Peninsula, scientists and the Korean government need to obtain fish stock data.

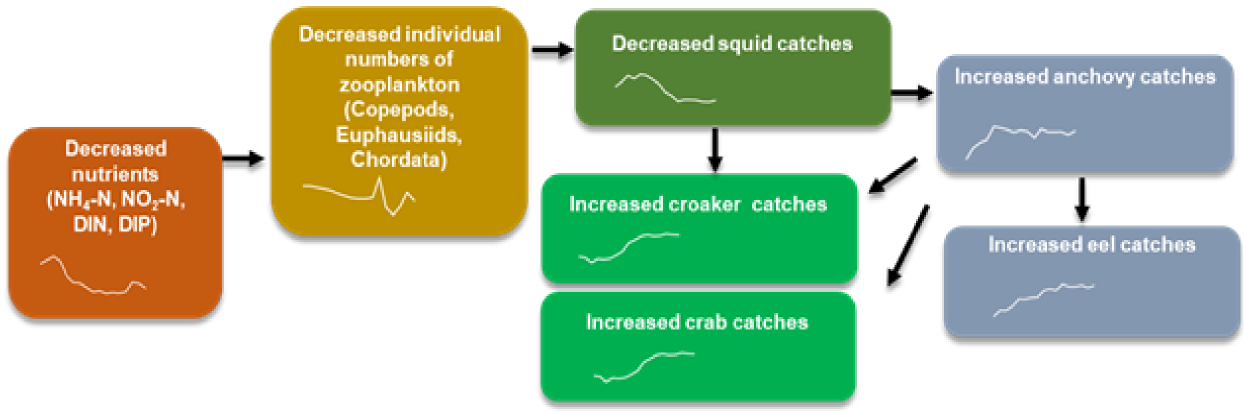

Figure 7-2. Example of a heuristic model derived from correlations between environmental and human pressures and ecosystem response indicators in Korea's case study ecosystem (see Figures 5-5, 5-6, 5-7, Table 5-1).

7.3 Recommendations for future research

As environmental, human and ecological time series lengthen and become more readily available, continued efforts to examine pressure-response relationships will enable the development of similar types of heuristic models presented here. Those relationships that may have clear links to management actions should be prioritized. These efforts would help support the development of heuristic models, regardless if the identified relationships are linear or nonlinear. In addition, this information could be used to develop and inform other types of models not explored here (e.g., qualitative or quantitative network models) and to assess ecosystem linkages and dynamics. For example, qualitative networks models are a useful tool for conducting dynamic simulations of conceptual models and evaluating how perturbations might affect different components of an ecosystem as well as management strategies (Harvey et al. 2016, Sobocinski et al. 2018, Forget et al. 2020). They are also well suited for data poor systems where precise quantitative relationships among different stressors and ecological components are unknown (Reum et al. 2015). All of these modeling approaches may serve as valuable tools for supporting ecosystem-based approaches to the management of marine resources in PICES member nations.

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Appendix 1. WG36 Terms of Reference (TOR)

TOR 1. Outline each country's mission, goals, and governmental science plans that point to the establishment of ecosystem reference points across PICES member nations, and identify those that are comparable.

TOR 2. Summarize previous efforts identifying data availability for geographic areas and time periods of particularly strong climate influence and dependence on marine systems within specific North Pacific ecosystems, fish stocks, and fishing communities.

TOR 3. Summarize and select previous methods for determining thresholds (both non-linear and societal limits) in ecosystem indicators. Includes statistical and objective-based approaches.

TOR 4. Determine shapes or functional forms of pressure - response relationships from available datasets, and quantify thresholds to identify potential ecosystem reference points.

TOR 5. Identify ecosystem components that respond earliest to changes in biophysical drivers and could potentially serve as leading indicators of loss of resilience and ecosystem change.

TOR 6. Develop a "heuristic model" to examine drivers (climate forcing, fishing) and ecosystem response using selected ecosystem reference points for member nations.

Appendix 2. WG36 Membership

Co-chairs: Dr. Xiujuan Shan (China) and Dr. Mary Hunsicker (U.S.A.)

Members: Dr. Robert Blasiak (Japan), Dr. Jennifer Boldt (Canada), Dr. Elliott Hazen (U.S.A.), Dr. Vladimir V. Kulik (Russia), Prof. Jongseong Ryu (Korea), Dr. Shion Takemura (Japan), Dr. Kazumi Wakita (Japan), Dr. Yanbin Gu (China) and Dr. Sangchoul Yi (Korea)

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Appendix 3

Table A1. Member nation considerations of PICES Working Group 28 (WG28) recommended list of indicators for use analyses. Indicators in bold are WG28-recommended 'as a core set' of indicators. PICES member nations noted if time series data were available for each indicator ("X") and noted additional details or if data would be requested. This was an initial screening and was refined for inclusion in analyses.

Theme/Sub-theme	Indicator *	Canada	China	Japan	Korea	Russia	US
Climate	**ENSO (Multivariate ENSO Index MEI; Oceanic Nino Index ONI)**	X	X	X	YES	X	X
	Pacific Decadal Oscillation (PDO)	X	X	X	YES	X	X
	North Pacific Gyre Oscillation Index (NPGO)	X	X	X	YES	X	X
	Aleutian Low Pressure Index (ALPI)				help from US or CAN		
	North Pacific Index (NPI)				help from US or CAN		
	Southern Oscillation Index (SOI)				help from US or CAN		
	Arctic Oscillation index				help from US or CAN		

Physical Environment	**Sea Surface Temperature (SST) averages by season (D,J,F for W)**	Average for N. California Current (by survey)	X	X	Yellow Sea and National waters	NOAA datasets	California Current
	Sea Level Pressure (SLP) anomaly averaged by season	will ask	will ask	will ask	will ask	average anomaly (and gradients)	average anomaly (and gradients)
	Seasonal projections of SST from National Multi-model ensemble						
	Winter maximum sea ice area or extent	NA	NA	X	NA	sea ice concentrations	Kirstin will bring some data
	Freshwater discharge	NA	Yangtze, Yellow river discharge, will ask	For some major rivers, yes	Major rivers	Amur river, will ask	X, David Hill & Rob Suryan to ask for GoA
	Upwelling (strength and/or timing)	X					X
	Transport (currents)						
Chemical Environment	**Nitrate**	will ask	X	will ask	coastal only	not long time series	X
	Phosphate				coastal only		
	Silicate				coastal only		

	pH	will ask	X	will ask	coastal only	not long time series	X, but short
	Dissolved oxygen	will ask	X	will ask	Yellow Sea and National waters	not long time series	X
Contaminants	**PCB**	short time series	will ask	will ask	coastal only	coastal	coastal
	POP	short time series	will ask	will ask	coastal only	coastal	coastal
	Total mercury	short time series	will ask	will ask	coastal only	coastal	coastal
	Tributylin (TBT)			will ask	coastal only		
	Toxics in biota (selected species)			for some species yes	mussels, oysters		
	Swimming beach closures for coliform bacteria contamination			For some beach, yes	NA		
Biological Environment/ Ecosystem Structure	**Harmful Algal Bloom area or frequency (HABs)**	NA for chosen ecosyste m	short time series (red tide, green tide)	X	Coastal only	X but rare event	X
	Habitat-forming species biomass				NA		
	Spawning Stock Biomass (SSB of selected species)	X	NA	X	will ask	X when published	X

	Mean individual fish weight			X	will ask		
	Mean age at first maturation (for selected species)			X	will ask		
	Mean length at first maturity (for selected species)			X	will ask		
	Distribution range (of selected species)			X	NA		
	Slope of size spectrum	in progress	from publications, will ask	X	in progress	could be done	Groundfish survey data
Biological Environment/ Biodiversity	**Species richness**	X	X	X	short time series	X (but not used)	X (juveniles)
	Taxonomic diversity	X	X	will ask	short time series	X (but not used)	X (juveniles)
	Number of taxa representing 80% of biomass	X	X	will ask	short time series	X (needs to be calculated)	X (needs to be calculated)
Biological Environment/ Food web energy flows	**Chlorophyll *a***	X (satellite)	X (survey & satellite)	will ask	survey (coastal) satellite	X (satellite)	X (satellite)
	Crustacean plankton biomass	X	X (some species)	will ask	short time series	X	X

Gelatinous plankton biomass (or volume)	X	X	will ask	short time series	X	X
Cephalopod biomass				NA		
Small pelagic fish biomass	X (modeled ?)	X from publication	X	NA	will ask, to be calculated	X
Demersal fish biomass	X (modeled ?)	X from publication	X	NA	will ask, to be calculated	X
Piscivorous fish biomass	X (modeled ?)	X from publication	X	NA	will ask, to be calculated	X
Nekton (at trophic level >3) biomass				NA		
Top predator biomass,	X (modeled ?)	X from publication	X	NA	NA	X
Seabird breeding success				will ask		
Seabird abundance (selected species)				will ask		
Total primary production				satellite based model		
Primary production needed to support fisheries removals				NA		
Crustacean zooplankton secondary production				NA		

Biological Environment/ Ecosystem resilience	Mean number of interactions per node				NA		
	Mean trophic links per species				NA		
	Diet diversity index				NA		
Exploitation of Living Marine Resources/ Fishing	**Total landings**	X	will ask	X	Yellow Sea and National waters	X from publication	X
	Mean trophic level of landings	X	will ask	X	Yellow Sea and National waters	X (selected species)	X
	Taxonomic diversity of landings	X	will ask	X	Yellow Sea and National waters	NA (no variability)	X
	Landings (biomass) of selected species	X	will ask	X	Yellow Sea and National waters	X from NPESR	X
Exploitation of Living Marine Resources/ Aquaculture	Aquaculture production (vertebrates, invertebrates)				coastal only		
Social and Economic/ Fishing effort	Annual number of vessels that fish				Yellow Sea and National waters		
	Number of days per calendar/fishing year the fishery is open				NA		

	Annual total number of days spent fishing (“fishing days”)				NA		
	Catch per unit of effort by gear and target fishery				NA		
	Numbers of commercial fishers	will ask	X	X	YES	will ask (likely can be calculated)	X (will ask)
	Number of fish processing plants				will ask		
	Per capita consumption of seafood				YES		
Social and Economic/ Landings revenue	Annual total ex-vessel revenue				NA		
	Average price (selected species)				NA		
	Revenue per fishing trip				NA		
	Revenue per fishing day				NA		
	Value and amounts of seafood exports and imports	will ask	X	X	YES	X, will ask	X (will ask)
Social and Economic/ other marine activities	Shipping				YES		
	Hydrocarbon-related activities				NA		

	Coastal engineering/length of shoreline hardening				will ask		
Additional considerations/ Top priorities from WG35 NPESR and HD committee	Quantity and value of catches and landings of seaweeds, fish, shellfish, and other invertebrates from inside and outside national EEZs	will ask	X	X	YES	X, will ask	X (will ask)
	Quantity and value of mariculture of seaweeds, fish, shellfish, and other invertebrates	will ask	aggregated by quantity, not necessarily value	X	YES	will ask	X (will ask)
	Number and power of fishing vessels by gear type, length, and tonnage	aggregated only	gear type, tonnage	X	NA	NA	X (will ask)
	CPUE by gear type and target fishery	aggregated only	X by target fishery	?	NA	NA	X (will ask)
	Employment in commercial fishing	will ask	X	X	YES	will ask (likely can be calculated)	X (will ask)
	Coastal population	will ask	will ask	X	YES	will ask	will ask

Appendix 4

The dynamics of the abundance of commercial fish in the Far Eastern seas and adjacent areas of the open part of the Pacific Ocean and factors influencing it

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In order to identify the effect of solar activity cycles and other environmental factors on the state of stocks of commercial fish species in the Far Eastern seas and the adjacent water area of the northwestern Pacific Ocean, long-term data on biomass and catch of 28 and 38 groups, respectively, were analyzed. The strength of the relationship between environmental factors and the abundance of fish was measured through the maximum information coefficient and was estimated both without a shift in the series and with a shift of the potential predictor to the past up to 5 years. The research results revealed significant relationships in the impact of solar energy on the abundance of the majority (21 stocks out of 28 for biomass and 26 stocks out of 38 for catch) of commercial fish. Among other environmental factors that have a decisive effect on the abundance of aquatic organisms, water temperature, ice cover, phytoplankton bloom and biomass of various fractions of zooplankton are noted. Abiotic factors are most susceptible to fish in the early stages of development. Peak biomass values of fish, mainly with a frequency of 3-5 and 8-13 years, formed the generation of high numbers, accounting for about 24% of the analyzed generations (data from 380 generations of 27 stocks were used). Due to the regional influence of heliogeophysical and other factors in the dynamics of the abundance of fish of different population groups of the same species, there is a distinct cyclicality in the formation of their abundance. The method for predicting catches used in this work by taking into account the interaction of heliophysical and other environmental factors and the revealed patterns in the frequency of formation of the biomass of population groups and species will increase the efficiency of using the raw material base of marine fish in the study area.

Appendix 5. FUTURE research theme questions

FUTURE's research theme questions addressed through WG36, and specifically TOR 4 and TOR 6, are highlighted in bold font.

1. What determines an ecosystem's intrinsic resilience and vulnerability to natural and anthropogenic forcing?
1.1. What are the important physical, chemical and biological processes that underlie the structure and function of ecosystems?
1.2. How might changing physical, chemical and biological processes cause alterations to ecosystem structure and function?
1.3. How do changes in ecosystem affect the relationships between ecosystem components?
1.4. How might changes in ecosystem structure and function affect an ecosystem's resilience or vulnerability to natural and anthropogenic forcing?
1.5. What thresholds, buffers and amplifiers **are associated with maintaining ecosystem resilience?**
1.6. What do the answers to the above sub-questions imply about the ability to predict future states of ecosystems and how they might respond to natural and anthropogenic forcing?

2. How do ecosystems respond to natural and anthropogenic forcing, and how might they change in the future?
2.1. How has the important physical, chemical and biological processes changed, how are they changing, and how might they change as a result of climate change and human activities?
2.2. What factors might be mediating changes in the physical, chemical and biological processes?
2.3. How does physical forcing, including climate variability and climate change, affect the processes underlying ecosystem structure and function?
2.4. How do human uses of marine resources affect the processes underlying ecosystem structure and function?
2.5. How are human uses of marine resources affected by changes in ecosystem structure and function?
2.6. How can understanding of these ecosystem processes and relationships, as addressed in the preceding sub-questions, be used to forecast ecosystem response?
2.7. What are the consequences of projected climate changes for the ecosystems and their goods and services?

3. How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?

3.1. What are the dominant anthropogenic pressures in coastal marine ecosystems and how are they changing?
3.2. How are these anthropogenic pressures and climate forcings, including sea level rise, affecting nearshore and coastal ecosystems and their interactions with offshore and terrestrial systems?
3.3. How do multiple anthropogenic stressors interact to alter the structure and function of the systems, and what are the cumulative effects?
3.4. What will be the consequences of projected coastal ecosystem changes and what is the predictability and uncertainty of forecasted changes?
3.5. How can we effectively use our understanding of coastal ecosystem processes and mechanisms to identify the nature and causes of ecosystem changes and to develop strategies for sustainable use?