2025 Intersessional Science Board Meeting

Report

Held online: May 12-14 (North America), May 13-15 (Asia)

(With GC decision to SB recommendation)

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

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Agenda Item 1: Welcome, Adoption of Agenda

Science Board Chair, Dr. Sukyung Kang, 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
Jennifer Boldt	Science Board Chair-Elect
Akash Sastri	Science Board Vice-Chair, BIO Chair
Steven Bograd	FUTURE SSC Co-Chair
Hanna Na	FUTURE SSC Co-Chair
Jackie King	FIS Chair
Mitsutaku Makino	HD Chair
Thomas Therriault	MEQ Chair
Lei Zhou	POC Chair
Sung Yong Kim	MONITOR Chair
Fangfang Wan	TCODE Vice Chair
Yury Zuenko	Representing Russia
Toru Kobari	BIO Vice-chair
*Governing Council	
Tetsuo Fujii	PICES Chair
Takashi Kamaishi	GC member
Se-Jong Ju	GC member
PICES Secretariat	
Sonia Batten	Executive Secretary
Sanae Chiba	Deputy Executive Secretary
Alexander Bychkov	Special project coordinator
Guests	
Yutaka Hiroe	F&A member
Tatsuki Oshima	F&A member
Sayaka Minamikawa	MOFA Japan
Kathryn Berry	BECI Science Director
Raphael Roman	AP-ECOP co-chair
Hana Matsubara	AP-ECOP co-chair
Vera Trainer	AP-SciCom

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

Agenda Item 2: FUTURE-SSC Report

FUTURE SSC Co-chairs, Hanna Na and Steven Bograd, presented the major activity update since PICES-2024 and planning in 2025 and beyond. One of the highlights was the FUTURE Symposium held on the opening day of PICES-2024. The symposium, consisting of several presentations and a panel session, aimed to review the accomplishments and gaps remaining in the FUTURE objectives, integrating PICES Science into the Social Environmental Ecosystem System frameworks. During the panel discussion and following the closing speech by Dr. Cisco Warner, direction and challenges toward the next phase of the PICES Integrated Science Program were emphasised to ensure the actionable science to inform regionally and internationally demanding issues. The full report of the Symposium is published in PICES Press.

FUTURE SSC held two business meetings on April 17/18 and April 30/May 1, to finalise FUTURE Synthesis Paper, which was submitted to ICES Journal of Marine Science (Takemura et al., in revision). The review study depicted the transition of PICES Science from the preceding PICES Scientific Program CCCC to FUTURE from disciplinary to inter- and multidisciplinary, and from basic to applied science.

With the valuable lessons learned over the past 16 years, FUTURE SSC will continue exchanging ideas for the new Integrated Science Program in the final year of its Phase III (2021-2025). They plan to disband the program at PICES-2026.

Agenda Item 3: SmartNet/AP-UNDOS Report

SmartNet/AP-UNDOS co-chairs Steven Bograd and Sanae Chiba presented the major activity update since PICES-2024 and planning in 2025 and beyond. See the “SmartNet 2024 Year in Review” (Appendix 1) for the details.

Agenda Item 4: SmartNet Implementation Plan

AP-UNDOS sought SB recommendation on the SmartNet Implementation Plan for its phase II (2025-2028) (Appendix 2) and established the status of SmartNet within the PICES, including SB representation of AP-UNDOS as the SmartNet steering committee of PICES. SB reviewed and unanimously endorsed the Implementation Plan. SB discussed the rationale for AP-UNDOS membership in SB and agreed to recommend that GC approve its representation on SB.

1. SB recommends GC approve the Phase II (2025-2028) SmartNet Implementation Plan
2. SB recommends GC grant AP-UNDOS representation on SB

GC approved the SmartNet Implementation Plan Phase II (2025-2028), and representation of AP-UNDOS on SB, with one vote (GC2025/S/2). **The decision takes immediate effect without waiting for the completion of FUTURE.*

Background and summary of SB discussion
At PICES-2023, SB had initially recommended that GC approve SmartNet to become a PICES Science Program after the completion of FUTURE, with representation of AP-UNDOS on SB. GC did not approve the SB recommendation and suggested that SmartNet develop an Implementation Plan.

Upon the publication of the Review Panel Recommendation urging the transformation of PICES—including the establishment of a new Integrated Science Program (ISP) and revision of organizational structure in the coming years—AP-UNDOS submitted the SmartNet Implementation Plan to SB-2024 and sought interim status as a PICES Scientific Program during the transition from FUTURE to ISP. SB deferred its recommendation on the proposal until

PICES' response to the Review Panel Recommendations became clearer.

At ISB-2025, as SG-ERRR (External Review Recommendation Response) is developing the idea of a new PICES Strategic Plan, SB acknowledged the unique role of SmartNet in linking the global initiative for ocean science with PICES in the UNDOS era, and the benefits of granting AP-UNDOS representation on SB. SB collectively agreed to recommend that GC approve the official representation of AP-UNDOS on SB. SB also discussed the potential schemes and timelines for granting this representation. Some suggested SmartNet serve as an interim ISP for a short term, from the completion of FUTURE to the establishment of the new ISP, but there were concerns about the timeline and alignment of SmartNet with the new ISP objectives and roles (see "Consolidated SB response to Review Panel Recommendations", Appendix 3). An alternative option - granting SB representation to AP-UNDOS SmartNet through the end of UNDOS in 2030, independent of ISP status - was also discussed. Given the current uncertainty surrounding the timeline of a new ISP establishment and PICES structural changes, SB found it difficult during the ISB to conclude the most appropriate protocol and timing for AP-UNDOS to be a SB member – whether it should take effect immediately, after FUTURE, or in the newly established PICES structure.

SmartNet Status (excerpt from SmartNet Implementation Plan)
We also seek to clarify and solidify SmartNet's role within PICES with an aim of positioning SmartNet as a key element of the organization's international scientific enterprise as we transition from the current (FUTURE) to a new flagship Scientific Program. The FUTURE Science Program will phase out over the next few years, initiating a transitional period of strategizing about the future of PICES science that coincides with the Ocean Decade (2021-2030). As articulated in the SmartNet proposal for IOC endorsement, the Ocean Decade provides a rare and unique opportunity to demonstrate ICES and PICES leadership on the global stage. We advise that ICES and PICES focus their energy and resources into SmartNet and Ocean Decade activities during this period (SmartNet Phase II, 2025-2028) to ensure success of the Programme and firmly position ICES and PICES as leaders within the Ocean Decade and global marine science.

The experiences and lessons learned from the implementation of SmartNet will inform new Expert Group(s) tasked with planning the next flagship PICES Science Program and will serve as a catalyst to more equitably share our science with the world. With this motivation, we request that Science Board and Governing Council that SmartNet be designated a PICES Program with representation on Science Board. Similarly, ICES could consider evolving SmartNet into a Strategic Initiative or Operational Group. We note that the plan outlined here is consistent with the recommendations for the future of PICES Science Programs made by the External Review Panel (Hofmann et al., 2024).

Agenda Item 5: Special Project Report:

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

FishPhytO Science Team co-Chair, Mitsutaku Makino, updated FishPhytO achievements since PICES-2024 and plans in 2025.

Update
Despite the FishPhytO project budget being halted by the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) after completion of Year 1 (March 31, 2024), at the FishPhytO Project Science Team meeting, convened in November 2024, in conjunction with PICES-2024, a workplan for 2025–2026 was adopted. This workplan is included below, and the status of various items is shown in orange.

Activities in Indonesia:
1. Develop a series of presentations for online General Lectures to be organized in 2025 and 2026;
   The General Lecture on "FishPhytO and Marine Environmental Monitoring for Disaster Mitigation of Harmful Algal Blooms (HAB) and Ciguatera Fish Poisoning (CFP): Dissemination of Technology to Increase the Human Resource Capacity of Indonesian Coastal and Small Islands Communities" will be held online on May 28, 2025,

by the Institute Technology of Indonesia (ITI). Co-organizers include: PICES and Indonesian partners – ITI, BRIN (National Research and Innovation Agency), BRIDA (Regional Disaster Office), UNRAM (University of Mataram) and UNPAD (University of Padjadjaran). The objective is, through a series of lectures by FishPhytO Project Science Team (PST) members and Indonesian scientists, to disseminate information about the FishPhytO project (a phytoplankton-fishery observing program for in Indonesian coastal waters) and new methodologies for marine environmental monitoring, and to introduce the ecological disaster mitigation model of HAB and CFP to a broad audience that includes stakeholders of coastal and small island communities, students, scientists and engineers from academia, research institutions and industry, policy makers, and government officials. The details on the presentations to be given at the General Lecture can be found under the "Meetings and Events" section on the FishPhytO webpage.

2. Play an active role in conducting an in-person knowledge dissemination workshop to be held in Indonesia in August 2026 (if a proposal submitted to IOC-WESTPAC is approved);

Indonesian colleagues have been informed that some funding (~3,000 USD) for this activity will be provided by IOC-WESTPAC, through their Working Group on Small Island Research and Development (SiRAD). With assistance from FishPhytO PST members in preparing a proposal, an attempt will be made to seek additional funding from APN (Asia Pacific Network) Indonesia and from the Research and Innovation Project for Advanced Indonesia, supported by the Ministry of Finance of the Republic of Indonesia.

3. Assist in analysis of data collected during 2024–2026 field surveys in Gili Matra Marine Tourism Park, Lombok, Indonesia.

In the period from May 2022 to February 2023, BRIN and the PICES/MAFF Ciguatera project jointly supported a total of five extended sampling surveys in the Gili Matra region conducted in different seasons. Two field surveys, funded through the BRIN-Ciguatera Indonesia project, were carried out in the Gili Matra Aquatic Tourism Park in 2024 – during rainy (March) and dry (August) seasons. Two more surveys in this area will be conducted in June 2025 and October 2025 to capture the transition phases from rainy to dry and dry to rainy conditions. In order to prepare scientific publications, FishPhytO PST members have been requested to participate in analysis of environmental and fisheries data collected during these surveys using smartphone-based monitoring tools (FishGIS and HydroColor applications) and the methodology for gathering socio-economic information (on-site surveys, questionnaires, and focus group discussions), developed and refined during the previous two PICES/MAFF projects (2017–2023) and the first year of the FishPhytO project.

Publications:

Prepare a scientific manuscript for a peer-reviewed journal summarizing findings from this project along with findings from two previous PICES-MAFF project (FishGIS and Ciguatera);

- An article titled "Risk Analysis of Harmful Algal Bloom and Ciguatera Fish Poisoning to Sustain Fisheries Resources and Ecotourism in Gili Matra Marine Tourism Park, Indonesia" will be published in Global Journal of Environmental Science and Management (through a paid fast-track program);
- An article titled "Morphological characteristics of unusual Mediophyceae diatoms, Lampriscus cf. shadboltianum var. crenulata, collected from Gili Meno, Indonesia" was submitted to Makara Journal of Science (minor revision requested);
- Prepare a publication, or publications, in the PICES Technical Report series detailing the operation of the FishGIS monitoring service along with broader insights gained from lessons learned on the implementation strategies for the FishPhytO project and preceding PICES-MAFF projects. The intent is to provide guidance for any future PICES projects planned for developing countries.

Observation tools:

1. Provide technical, hands-on training on the use of smartphone-based tools for monitoring of fisheries resources (FishGIS) and environmental health conditions (HydroColor), and on the use of Planktoscope for quantifying benthic

and pelagic phytoplankton during a practical workshop to be held by the Section on Harmful Algal Blooms (S-HAB) at the 2025 PICES Annual Meeting in Yokohama, Japan (if approved by PICES Science Board);

A practical workshop proposed by S-HAB was not approved for PICES-2025. A proposal will be submitted to convene this workshop in conjunction with PICES-2026.

2. Explore potential funding sources for the continued maintenance of the FishGIS server;

A half of the total amount required to maintain a FishGIS cloud server for Indonesia in 2024–2025 was paid in advance to Green Front Laboratory (GFL) from the FishPhytO Year 1 budget. To continue maintaining the server, limited funds have been successfully requested from a 3-year project developed between the Atmosphere and Ocean Research Institute (AORI) of the University of Tokyo and the National Federation of Fisheries Cooperative Association for the use of the FishGIS application to report unusual catches and phenomena in Japanese coastal waters. This project, funded by the Nippon Foundation, will cover expenses related to maintaining the FishGIS cloud server at least until March 31, 2026.

3. Seek potential users of the FishGIS application in PICES member countries and other developing Pacific nations.

Background

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.

Objective

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.

5. 2. Basin Events to Coastal Impacts (BECI) Report

BECI Science Director, Kathryn Berry, updated BECI achievements since PICES-2024 and plans in 2025 and beyond. The draft BECI Science Plan, with a rough timeframe of major activities and outputs, was issued in March 2025. It identifies seven Use Cases (applications): UC1: Learning From Marine Heatwave Impacts on Key Fisheries, UC2: Ecosystem-based Approaches to Climate Change to Inform Decision Making, UC3: North Pacific Ocean Color-Salmon Productivity Initiative, UC4: International Year of the Salmon Synthesis, UC5/6: North Pacific Ocean Ecosystem Status Report Framework, and UC7: Climate-Adaptive Spatial Conservation Planning.

Background: The BECI project (Basin-Scale Events to Coastal Impacts: An Ocean Intelligence System for a Changing World) was endorsed by the United Nations Decade of Ocean Science and Sustainable Development (UNDOS) in 2021. At the 2023 NPAFC Annual Meeting, the NPAFC adopted their new five-year science plan (2023 – 2027), which will complement BECI research and collaboration. BECI will build off the success of the International Year of the Salmon initiative's (2018 – 2022) High Seas Expeditions, which studied the winter ecology of salmon in the North Pacific Ocean. BECI Receives $1.1M in Funding from the B.C. Salmon Restoration and Innovation Fund (BCSRIF). The funding enables the establishment of a project office and the recruitment of key personnel,¢ such as a BECI Science Director to complete the science and implementation plans.

The objective of BECI is to develop a North Pacific Ocean Climate Knowledge Network (NPO-CKN) to connect diverse organizations across the basin—from research institutions to management bodies to coastal communities—

to enhance the synthesis of climate science and practical knowledge. By breaking down knowledge silos and fostering collaboration across boundaries, we work to create a holistic understanding of both climate change impacts and current research efforts. Our network aims to support informed decision-making, enhance ecosystem resilience, and promote sustainable management while helping organizations address shared challenges in our changing ocean.

Agenda Item 6: Collaboration with Strategic Partner Organization

6. 1. PICES-APN Collaboration highlight

PICES Secretariat Chiba updated the collaborative activities between PICES and the Asia-Pacific Network for Global Change (APN).

Background: PICES and APN signed a Collaborative Framework for scientific cooperation in February 2023. PICES-APN collaboration has been active on the common priority activity areas on ECOP capacity development and wider community engagement. These are recent and upcoming collaborative plans.

APN Workshop "The Future of Climate Change and Marine Environment" (March 18, 2025, Japan)
APN invited a PICES expert on marine plastic pollution to the workshop, and a S-MPP member, Dr. Susanne Brander from Oregon State University, participated in the workshop to give a talk on long-term monitoring of the North Pacific plastic pollution. APN fully funded her travel.

APN Training Workshop on "Proposal Development Training Workshop in the Temperate East Asian Region" (June 2-6, 2025, Jeju, Korea)
APN holds the workshop annually for ECOPs from APN countries to learn how to develop successful proposals for APN research funds. Through the open application process, PICES and APN agreed to jointly sponsor the travel of 2 ECOP participants from PICES countries (China and Russia).

Funding Proposal
SmartNet and APN collaborators submitted the funding request proposals "Empowering Early-Career Professionals and Amplifying Local Knowledge: Advancing the 2023 APN-PICES Collaborative Vision in the Pacific" to CAPaBLE, APN's capacity development programme. The proposal is currently under review. If the funding is successful, the team will invite multiple ECOPs from underrepresented nations to PICES/ICES/APN Joint Workshop: W8 Engaging with Local and Traditional Knowledge Holders to Co-Design Ocean Science in Pacific Small Island Developing States" at PICES-2025, and plan to hold an additional ad hoc workshop in Japan in conjunction with PICES-2025.

Agenda Item 7: PICES 2025 Update and 2026 Planning

7.1. PICES 2025 General Schedule

SB reviewed the basic schedule of PICES-2025.

Date: Nov 8 - Nov 16, 2025,
Venue and Location: Workpia, Yokohama, Japan
*Abstract submission opened on March 31 and will be closed on June 15

Pre-meeting timeline (tentative)	
– June 15	Confirmation of Invited speakers, Abstract submission & Financial support application
July - August	Confirmation of speakers, Finalization of Sessions / Workshop schedule
late Sept – early Oct	**Online** EG Business meetings to prepare; Activity Reports & Requests for SB-2025
mid Oct – late Oct	**Online** Committee/FUTURE business meeting to review; EGs Activity Reports & Requests for SB-2025

PICES-2025			
Nov 8 (Sat)	Day	4 Parallel Workshops	in-person EG business meetings (up to 3)
	Evening		Committee Business Meetings x 3 or 4 (hybrid)
Nov 9 (Sun)	Day	4 Parallel Workshops	in-person EG business meetings (up to 3)
	Evening		Committee Business Meetings x 3 or 4 (hybrid)
Nov 10 (Mon)	AM	Opening Ceremony	
	1100 -	Special panel? S1 Symposium	
	Evening	Welcome reception	
Nov 11 (Tue)	Day	4 Parallel Sessions	• in-person EG business meetings (1-2 per day) • F&A meeting (0.5 day) on Nov 11 and/or 12 (hybrid). • Mentor-Mentee program (3 day) • Introduction to PICES for ECOP (1 evening)
Nov 12 (Wed)	Day	4 Parallel Sessions	
	Evening	Poster Session	
Nov 13 (Thu)	Day	4 Parallel Sessions	
	Evening	Sports event ? (TBD)	
Nov 14 (Fri)	AM	4 Parallel Sessions	
	Noon	Closing Ceremony	
	PM		SB Meeting Day 1 (hybrid)
	Evening	Chair's reception	
Nov. 15 (Sat)	Day		SB Meeting Day 2, GC Meeting Day 1 (hybrid)
Nov. 16 (Sun)	Day		GC Meeting Day 2 (hybrid)

7.2. PICES 2025 In-person Business Meeting Request

SB reviewed the proposed in-person business meetings from Expert Groups (hereafter EG) and recommended GC for approval (see the table). Secretariat confirmed that rooms are available for all the requested business meetings. GC approved the business meetings as proposed (GC2025/S/1).

* All EGs are recommended to have at least one online business meeting to discuss items to request/propose to SB/GC approval before PICES-2025. EGs can additionally request an in-person meeting during PICES-*2025. Note that all Committees will also have an in-person business meeting during PICES-2025*

EGs	Duration	Note
AP-ARC	*3 day ICES-WGICA Joint meeting	Nov. 8 AM - 9:00-12:30: WGICA co-chairs business meeting Nov. 8 PM - 14:00-19:30: WGICA 10th anniversary meeting Nov. 9 AM (9:00-12:30) and PM (14:00-17:30): AP-ARC workshop (No WGICA meeting) Nov. 11 AM - 09:00-12:30: WGICA meeting for US Nov. 11 PM - 14:00-16:30: WGICA meeting in-person 17:00-19:30: WGICA meeting for EU
AP-CREAMS	0.5 day	We would like to request a 0.5 business meeting to discuss future activities regarding to recent changes in ToR
AP-ECOP	0.5 day	We would like to organize a half-day hybrid meeting between November 10 and 14, as many ECOPs are expected to arrive after the opening ceremony due to budget constraints.
AP-NIS	1 day	Please try to coordinate around AP-NIS workshop which will be Nov 8 or 9.
AP-NPCOOS	0.5 day	In addition to the workshop on mooring shelf data, we would like to request a 0.5 business meeting to further other objectives like the 2026 summer school.
AP-UNDOS	1 day	We would like to hold a one-day business meeting + coordination discussion with APN and other collaborating organizations
S-HAB	0.5 day	We will hold a zoom business meeting to cover the main reporting duties for MEQ, but a half-day in-person meeting is needed for considered discussions on new directions and emerging issues
S-MPP	0.5 day	Introductory meeting, as our section just began this year, to meet and organize our goals and objectives (ToR) for our upcoming year.
S-MBM	0.5 day	Request a half-day hybrid meeting.
WG-49	1.0 day	We would like to hold a one-day in-person business meeting (with a hybrid option if necessary) to share updates on extreme climate events in PICES member countries and to advance the activities of WG-49.
WG-50	0.5 day	We request a 0.5 business meeting to wrap up the activities for WG50
WG-51	0.5 day	We will hold a Zoom pre-AGM business meeting to review TOR progress and administrative duties. We would like to hold an in-person business meeting to share new results and plan next steps.
WG-53	Evening meeting x 2	Request to hold 2 evening session for the virtual participants from Europe , 6-8pm on Nov 11 (Tue), and Nov 13 (Thu)
FUTURE	0.5 day	

7.3 PICES-2026 Planning

Chiba reported that Canada has confirmed to host PICES-2026 from October 26 – November 1 in Nanaimo, BC. Meeting details will be updated in due course (GC2024/A/9). She noted that the selection of PICES-2026 Session/Workshop proposals will take place after the PICES-2025, following the new protocol agreed at PICES-2023 (see below). SB acknowledged the tentative selection schedule as proposed.

PICES-2026 Session/Workshop Selection Schedule (tentative)

Oct 2025: Session/Workshop Proposal application open
Late Nov: Session/Workshop Proposal application closes (after PICES-2025)
Early Dec: Committees to review/rank the proposals through a virtual meeting/review sheet
SB to hold a virtual meeting to make recommendations for the proposals
Year-end: GC to approve the SB recommendation.

New Protocol for Session/Workshop Selection

(GC2023/S/14) Council approved a new process for the session and workshop planning of PICES Annual Meeting whereby the Session and Workshop proposal deadline be set two weeks after the end of the annual meeting. Committees will work inter-sessionally/by correspondence to review, rank and report to SB by the end of November. SB will review and provide to GC in early December for approval before year-end.

Agenda Item 8: Structure of Future Annual Meeting

The structure of PICES Annual Meetings has transformed in recent years: from in-person only to hybrid EG business meetings, shorter and more densely-packed meeting duration (from 12 days to 9 days). While there is a GC suggestion to seek the possibility of even shorter duration in future (to 8 days by removing the final GC day), there are more ideas being proposed for holding special panels and side events, such as science-local policy dialogue, capacity development events, and engagement of wider communities. Given that 9-day (or shorter) duration is likely the future standard, SB members shared their thoughts on how PICES should prioritise these various options, what the best balance of components should be: sessions/workshops, business meetings, and other events. Given that Sessions and Workshops were already selected, assuming the 9-day model for PICES-2025, SB decided not to consider the shorter option for this year. However, SB will continue the discussion and develop the recommended schedule for PICES-2026 at SB-2025, before the selection of Session/Workshop proposals for PICES-2026.

Agenda Item 9: Scientific and Technical Mid-Year Reports

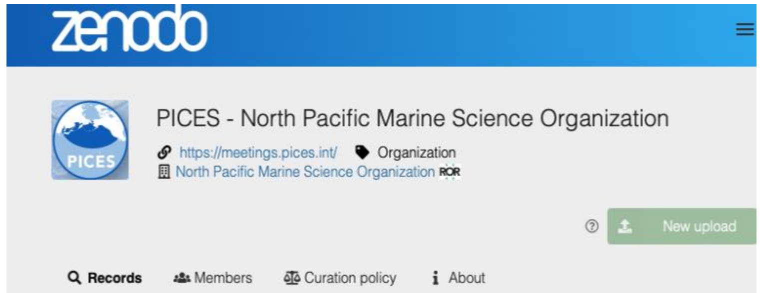
SB, FUTURE and Committees reported scientific achievements and progress of TOR of the respective Children Expert Groups since PICES 2023. The details of each EG report will be published online as a part of the PICES-2025 Annual Report.

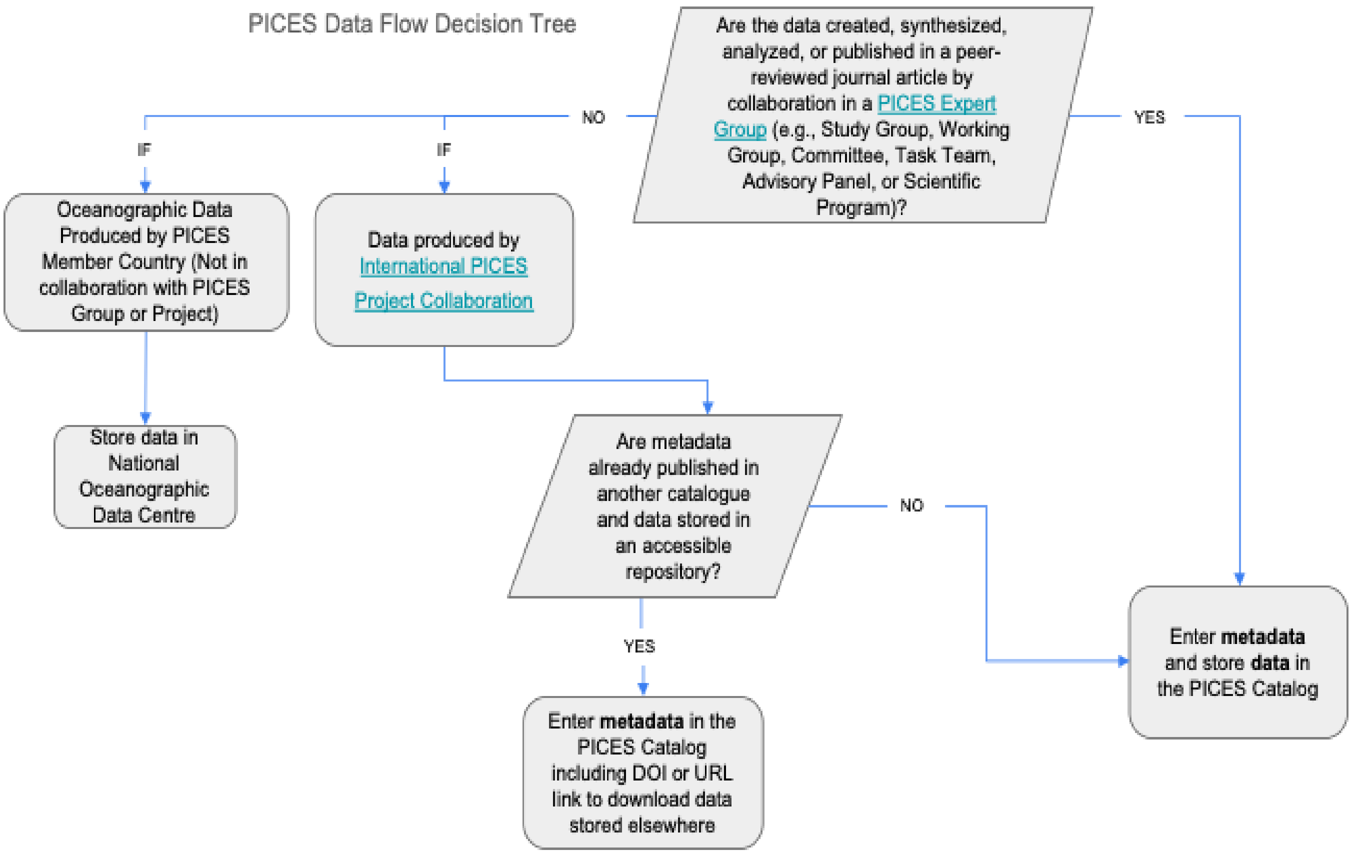
Agenda Item 10: PICES Data Reporting Protocol Update

TCODE Vice-Chair, Fangfang Wan, introduced the new PICES metadata catalogue under development on data repository hub Zenodo (approved at GC-2024). and updated the progress of EG Data Reporting Protocol being developed by WG52 (on Data Management) and TCODE. SB agreed to continue seeking how PICES could effectively encourage EGs to follow the protocol and report their data.

Their current tasks include;

- Transfer the past PICES metadata to the new data repository hub Zenodo.
- Create a guidance document and checklist for new PICES projects and/or the Expert Group to help adhere to PICES Data Policy, including data/metadata submission to Zenodo.
- Create a case study of using the new dataflow diagram and Zenodo data catalogue using a dataset from a current PICES expert group.





Agenda Item 11: SG-External Review Report Response (ERRR) progress update

PICES Executive Secretary, Sonia Batten, reported the progress of the SG-ERRR discussion on the new PICES roles and structure, responding to the External Review Report. Batten presented the tentative action roadmap toward 2027, suggesting that a few study groups and/or working groups will be established to review and develop new plans for respective components, including Mission, Strategic Plan, Integrated Science Program (ISP), and organizational and administrative structure. SB unanimously agreed that its perspectives should be considered in the development of ISP and organisational structure, and requested Batten to ensure that some SB members are involved in the relevant study group and/or working group.

Agenda Item 12: PICES Awards Selection

The Award Selection Committee (consisting of SB members and PICES Chair) chose the winner of the 2025 Wooster Award. SB members chose the awardees of POMA, PODA, and Zhu-Peterson Award. The awardees will be recognized during the awards ceremony during the opening ceremony of PICES-2025. Information on the awardees is confidential until PICES-2025.

Agenda Item 13: EG Proposals with Funding Implications

SB reviewed and ranked the priority of the funding requests shown below based on their relevance and importance to PICES Science. SB recommends GC approve the requests, considering the priority scores given by SB (High: 3 - Low: 1). GC approved the following support requests if the budget can accommodate them, noting Science Board's rankings (GC 2025/S/3).

13.1. Travel support request

The travel funding support scheme is for PICES scientists to convene or attend international meetings, etc. Priority is given to ECOPs as PICES has a limited amount of Trust Fund for travel support for ECOPs.

EG: AP-ARC (Arctic and Pacific Gateways) (SB)			
Conference inf.	Recipient(s)	Amount and rational of fund request	SB score
CIce2Clouds-BEPSII-CATCH sea-ice school February/March 2026, Saroma-lake, Hokkaido, Japan	A few ECOPs from PICES countries, support for travel and participation fee	(reference only: CA$ 4200) Important for PICES ECOPs to develop skills on field work through sea ice school with understanding climate change in Pacific Arctic.	1.7 (Low to Middle)

13.2. Open access fee

EG: S-HAB (Harmful Algae Bloom) (MEQ)		
Manuscript title	Rationale & Fee	SB score
"Controlling harmful algal blooms (HABs) in marine waters: current status and future prospects" Submitted to "Harmful Algae"	Requesting **partial support (US$2500)** of the online access fee (US$5000) to the manuscript. This joint work is the outcome of the TCODE/MEQ Topic Workshop GlobalHAB International Workshop on Solutions to Control HABs in Marine and Estuarine Waters (2023). Appendix 4: Manuscript	2.2 (Middle)

13.3 Support for PICES-2025 side events

AP-ECOP co-chair, Hana Matsubara, presented the proposal for beach cleaning and site visit to the local ocean science institutes during PICES-2-25. SB supported the proposal and suggested designing the plan, including the date and time, to allow the maximum participation of PICES ECOPs.

EG: AP-ECOP (FUTURE): Joint program with Japan ECOP (Full Proposal)		
Event information	Rationale & Fee	SB score

Beach cleanup Nov 15 (Sat) at nearby beach (TBC)	For consumables (garbage bags, gloves, etc.): Approximately CA$ 500. They will also seek LO support.	2.3 (Middle)
Site visit to local research institutes: Fisheries Research and Education Agency (FRA) and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) Nov 14 (Fri) PM	Transportation from the PICES Annual Meeting venue to FRA/JAMSTEC (e.g., bus): Approximately CA$ 1,200 They will also seek support from FRA and JAMSTEC	2.5 (Middle to High)

Full Proposal for ECOP Japan Joint Side Events at PICES 2025 Annual Meeting

1. Introduction
In light of the PICES 2025 Annual Meeting being held in Yokohama, Japan, ECOP Japan and AP-ECOP are planning to co-organize side events. These events aim to foster interaction between ECOPs, scientists, and other ocean professionals at all career stages participating in PICES, connect the PICES community with leading marine research institutions in Yokohama, as well as to provide opportunities for the general public to engage in marine science.

2. Objectives
- Promote networking and collaboration among ECOPs and researchers from various career stages participating in the PICES Annual Meeting.
- Facilitate exchange between international PICES participants and Japanese ECOPs.
- Plan visits or guided tours to leading marine research institutions in Yokohama (drawing on the successful experience of ECOPs who visited KIOST in Busan, Korea, in 2022).
- Create opportunities for the general public to experience and learn about marine science.

3. Event Details (Tentative)
We propose to organize one or both of the following events:

(1) Beach Cleanup and Beachcombing Event in Yokohama Area
This event will engage the general public in a hands-on experience of marine conservation. Participants will contribute to cleaning up a local beach and learn about the marine environment through beachcombing activities.

(2) Tour to FRA/JAMSTEC
Participants will have the opportunity to visit leading marine research institutions, the Fisheries Research and Education Agency (FRA) and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC).

4. Event Coordination
A task team will be formed by members from ECOP Japan and AP-ECOP to discuss event details and coordinate their implementation.

5. Participants
Participants of the PICES Annual Meeting (ECOPs, scientists, and other ocean professionals at all career stages), Japanese ECOPs, and General public (for the beach cleanup event)

6. Estimated Expenses
(1) Beach Cleanup and Beachcombing Event:
Consumables (garbage bags, gloves, etc.): Approximately 500 CAD

(2) Tour to FRA/JAMSTEC:
Transportation from the PICES Annual Meeting venue to FRA/JAMSTEC (e.g., bus):
Approximately 1,200 CAD

7. Conclusion

We believe these side events will be a valuable addition to the PICES 2025 Annual Meeting. They will promote productive exchanges among PICES attendees, and between ECOPs and other ocean professionals—whether PICES participants or researchers at JAMSTEC and FRA—enhance public communication regarding marine science, and contribute to achieving ToRs #2, #4, and #5 of AP-ECOP. We respectfully request your kind consideration of this proposal.

Agenda Item 14: EG Proposals without Funding Implications

14. 1 Membership Needs/Changes

SB acknowledged the membership requests of EGs and urged the national delegates to consider the appointment of new members at an appropriate time. GC acknowledged the member needs and respective national delegates to appoint these members.

EG (Parent)	Country	Names	Affiliation	e-mail
Carry over requests from PICES-2024				
TCODE	Russia	1~2 members		
AP-ARC	Russia	Yury Zuenko	TINRO	zuenko_yury@hotmail.com
AP-ARC	Russia	Kirill Kivva		kirill.kivva@gmail.com
AP-UNDOS (SB)	Russia	Evgenia Kostianaia	(IOC), ECOP leader in UNDOS	e.kostianaia@unesco.org
S-CCME	Russia	1-2 members. Potential candidate to suggest Russia: Kiril Kivva & Andrey Krovnin		
WG50 (POC)	Russia	Nikita Aleksandrovich Chikanov	St. Petersburg State University	prants@poi.dvo.ru
WG51 (HD)	Russia	Ekaterina Kurilova	VNIRO Khabarovsk	katy_k07@mail.ru
WG51 (HD)	Russia	Oleg N. Katugin	TINRO-Center	oleg.katugin@tinro.vniro.ru
WG52 (TCODE)	Russia	1~2 members		
New requests at ISB-2025				
AP-SciCom (SB)	China Korea	1~2 members 1~2 members		
AP-NPCOOS (MONITOR)	China	Need 1~2 engaged members		
AP-NIS (MEQ)	Russia	1 member with molecular expertise in NIS/at-risk species detection (emerging topic w/ past interest from NOWPAP)		
Members stepping down at ISB-2025				
AP-UNDOS AP-ECOP	Canada	Andrea White	DFO	

14. 2 Change of EG Chairs

SB acknowledged the appointment of the additional AP-CREAMS co-chair upon his membership appointment.

EG (Committee)	Current Chair to replace	New Chair Name/Country/Organization	SB Action
AP-ARC (SB)	(additional chair)	Dr. Hyoung Chul Shin *Confirmed to be a co-chair upon official membership approval (GC2024/S/2)	N/A

14. 3 Change of Action Plan – AP-CREAMS

Responding to GC decision 2024/S/21 (see below), AP-CREAMS (Circulation Research in the East Asian Marginal Seas) submitted the revised Action Plan. SB reviewed the Action Plan and agrees that it needs editing by SB members and its reporting parent Committee, MONITOR, before reporting to GC. SB will recommend GC approve the new AP-CREAMS Action Plan when AP-CREAMS revises it accordingly as suggested by SB and MONITOR, at the IGC before PICES-2025.

Background

At SB-2024, AP-CREAMS proposed the revision of its ToRs to expand its target area toward the wider western North Pacific. SB recognised the importance of understanding the interaction of physical, chemical and biological processes between the East Asian marginal seas, AP's core study area, and the wider western North Pacific regions, and recommended their proposals. However, GC requested a clearer rationale for the region the AP intends to expand in the revised AP Action Plan, and deferred the decision to IGC-2025.

GC Decision 2024/S/21. *AP-CREAMS revision. GC requested more detailed information on the rationale behind the proposed change, therefore it was determined that their term (with current ToRs) be extended for half a year, to enable them to submit a revised proposal to include: A rationale for the changes suggested including necessary revisions to the Action Plan, suggested membership needs (they may require additional USA members in an expanded area, for example) and a map using PICES eco-regions. This is to be presented at the next Intersessional Science Board meeting. It is expected that the fixed term will be removed when the proposal has been reviewed.*

Revised AP-CREAMS Action Plan with Rationale for extension of AP-CREAMS focus area and revision of Terms of Reference (ver. 2025-04-29)

1. AP-CREAMS tasks and their implementation

The AP-CREAMS (Advisory Panel on *Circulation Research in the East Asian Marginal Seas*) was established in October 2005 with the tasks:

1. To initiate and coordinate the studies on hydrography, circulation, and biology, as well as on variability of oceanographic and biological properties in the PICES area of the East Asian Marginal Seas;
2. To estimate climate-scale and long-term changes in abiotic and biotic environments of this region;
3. To facilitate the establishment of permanent observation and data exchange networks in this region;
4. To convene workshops/sessions to evaluate and compare the results of national and international research programs.

Primarily the activity of the AP-CREAMS is focused on the Northeast Asian marginal seas, which are sensitive to climate change and anthropogenic impacts, where intensive national activities take place, and where a strong need for international coordination and collaboration to study the variability of hydrodynamics, biogeochemistry, ecosystems, fisheries, and influence of human activities at multiple scales in the area exists.

Research activities among PICES member countries in the region of the North-East Asian marginal seas have a permanent character and need ongoing coordination, as the interests of different countries tightly overlap. Some ideas on further development of international surveys and observation networks have already been discussed by AP-CREAMS though specific details, such as joint standard sections, format of data exchange, operational information on planned and ongoing cruises, extension of the target area, *etc*., are not yet developed.

Meetings of the AP-CREAMS are organized 2-3 times each year, with exchange of results of international and national activities and plans. Results of the joint research in the CREAMS area have been published in leading scientific literature. AP-CREAMS is continuing the preparation of publications on the state of the regional ecosystem, namely on the PICES Scientific Report "Oceanography of the Yellow and East China Seas", and regional chapters (Areas 19 and 21) for the North Pacific Ecosystem Status Report-3.

During the most recent period (2023-2024) the AP convened the following workshops and scientific sessions:

- A workshop on "Changing social-ecological-environmental system of the North East Asian Marginal Seas: New challenges for integrative marine science" during PICES-2023 in Seattle, USA;
- CREAMS 30th Anniversary & CSK-II Joint-Workshop « International collaboration for science of East Asian Marginal Seas in a changing climate: circulation, biogeochemistry, and socio-economic research», July 25-26, 2024, Seoul, Korea;
- Scientific session "Past, Present and Future of CREAMS program: 30 years of international research in North East Asian Marginal Seas" at PICES-2024 in Honolulu, USA;
- Proposal of scientific session on "Changing Asian Marginal Seas: from marine science to societal needs, current challenges for integrative science and UN Ocean Decade is accepted for PICES-2025 in Yokohama, Japan.

AP-CREAMS maintains close contacts with leading regional international organizations, such as IOC/WESTPAC, UNEP/NOWPAP (CEARAC), IMBeR and others. Their representatives participate in the AP meetings and other activities. Information on their current programs and proposals for collaboration is provided and discussed at the AP meetings.

2. Revision of AP-CREAMS AP Terms of References

During recent years, in addition to the primary tasks, AP-CREAMS started activity in new directions, as a contribution to PICES/FUTURE and in response to their request:

i) to pursue an integrative approach, to include multiple disciplines beyond physics and chemistry to cover the whole social-ecological-environmental-system framework developed by FUTURE,

ii) to extend geographic coverage to include all North-East Asian Marginal Seas beyond the EAST-I and EAST-II regions, and

iii) to prioritize the involvement of ECOPs in its activity.

Correspondingly, the AP members drafted new terms of reference, as below (changes are highlighted in italics):

1. To coordinate programs to study the marine ecosystem and its variability in the *western North Pacific* and its marginal seas in the PICES area under global changes, both natural and anthropogenic; the effect of long-term and extreme changes in the abiotic and biotic environments of this region;
2. To facilitate the establishment of permanent observation and data exchange networks in this region;
3. To convene workshops/sessions/*mentoring* to evaluate and compare results from the program;
4. To enhance capacity building, knowledge dissemination, and cooperation with other international marine organizations/programs in the region.
5. *To provide more opportunities for ECOPs.to join*

3. Justification of the AP-CREAMS focus area

To understand the processes in the Asian Marginal seas and their impact on adjacent areas of the Pacific, it is important to consider the wider area, which would include the connection of the seas with the adjacent ocean. In addition to Northeast Asian marginal seas the proposed extension would cover the Okhotsk Sea, western part of the Northwestern Pacific and western part of the Bering Sea, including regions 16, 17, 18, 22 and narrow northwestern part of region 23 (Fig. 1). However the AP will keep its primary focus on the initial marginal seas to not dilute the specificity of CREAMS.

The extension will:

1. Provide more opportunities for the PICES community to be involved in the AP-CREAMS activity (e.g., bringing more attention to the workshops/sessions/mentorships the AP-CREAMS convenes),
2. Enhance the capacity of the AP-CREAMS to better coordinate programs to study the marine ecosystem, its variability in the core areas (19, 20, and 21), as well as the influence, exchange and interactions of ecosystem components between the core area and the extended areas. The extension will also facilitate the establishment of permanent observation and data exchange networks in a larger western North Pacific and its marginal seas, and disseminate more knowledge on the extended area.

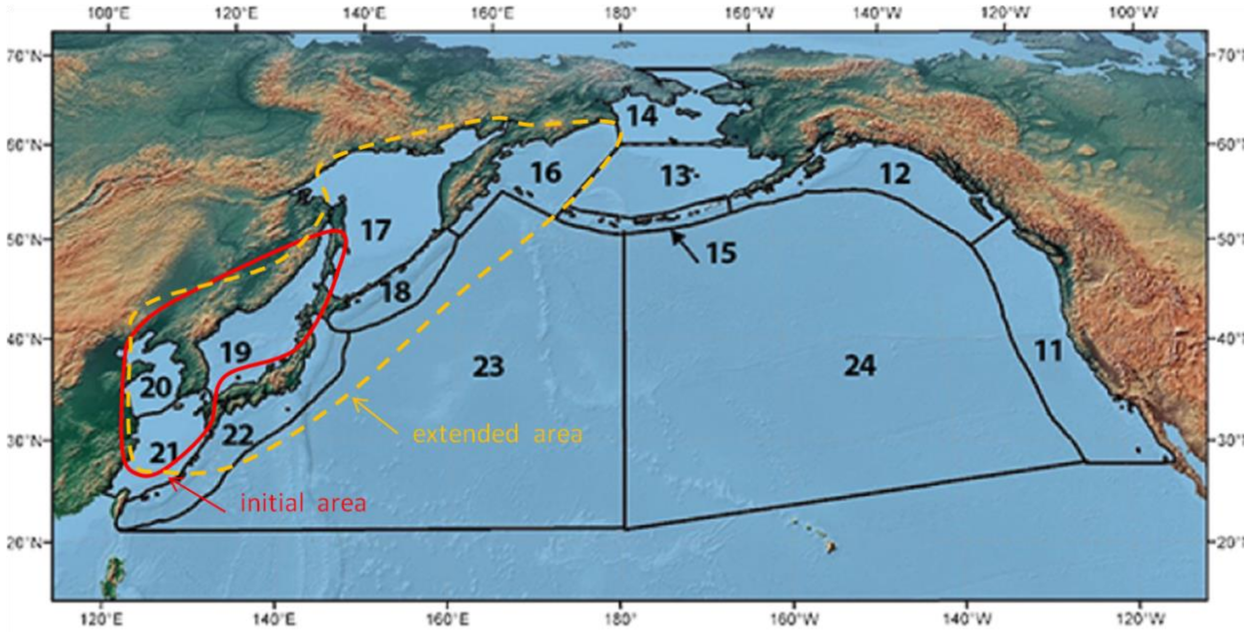


Figure 1 – AP-CREAMS initial focus area (red line) and proposals of its extension (yellow dashed line) overlapped on the PICES NPESR regions map.

Considering the goals of PICES, the extension will:

1. Better promote and coordinate marine research in the western North Pacific marginal seas (not limited to the core areas 19-21, but also the extended areas),
2. Advance more scientific knowledge about the ocean environment, global weather and climate change, living resources and their ecosystems, and the impact of human activities, focused on the western North Pacific marginal seas, and better promote the collection and rapid exchange of scientific information on various issues

Agenda Item 15. New Expert Group proposals

SB reviewed the new proposals, ICES/PICES WG-DLP and SG-NPESR4, and recommended GC approve them, once the suggested amendment has been addressed. GC approved WG-DLP (assigned as WG54) and SG-NPESR4 with the terms of reference as provided (GC2025/S/4).

SB also reviewed and commented on the draft proposals of WG-Ocean Acidification and WG-Finescale Processes, which are planned to seek approval at PICES-2026.

Name of EG	Proposed Parent Committee	Background and Goals
ICES/PICES WG-DLP (full proposal)	BIO	To develop best practices for using Deep Learning in processing Plankton images. Proposed by WG48: Plankton Imaging System. *SB suggestion* • *Consider sustaining data sharing platform available for all member countries.* • *Ensure to recruit members from Korea and Russia, also with proper expertise.*
SG-NPESR4 (full proposal)	SB	To plan next generation of PICES flagship ecosystem assessment report.
WG-Ocean Acidification *draft proposal*	POC, BIO	To understand basin scale states and ecosystem impacts of ocean acidification through establishment of NP monitoring network. Information only, the proposal to seek approval at PICES-2025
WG-Finescale Processes *draft proposal*	POC	Ideas developed upon accomplishments of WG38 Mesoscale processes, WG50: Sub-mesoscale processes. Information only, the proposal to seek approval at PICES-2025

Title and Acronym of the Group	
PICES/ICES Joint WG: Best Practices for Using Deep Learning in Processing Plankton Images (WGDLP)	
Term From .... To.... **WG: 3 yrs (with exception)*	**Proposed Parent Committee(s)** **Recommended to have no more than 2 committees*
From 2025 To 2028	BIO (Biological Oceanography)

Co-Chairs (Name, Country, Affiliation, Email address)
**consider appointing a chair from both Western and Eastern North Pacific*

Hongsheng Bi (USA, University of Maryland, hbi@umces.edu)
Paul Covert (Canada, Fisheries and Oceans Canada, pcovert@uvic.ca)
Xuemin Cheng (Tsinghua Shenzhen International Graduate School, chengxm@sz.tsinghua.edu.cn)

ICES Chair (WG on Zooplankton Ecology)
Sophie Pitois (UK, Centre for Environment, Fisheries and Aquaculture Science, sophie.pitois@cefas.co.uk)

Motivation, Goals and Objectives (max. 300 words)
**clarify scientific justification, societal outcomes, etc.*

Plankton are the foundation of marine ecosystems, playing a crucial role in oceanic food webs, biogeochemical cycles, and carbon sequestration. Monitoring plankton communities is essential for understanding ecosystem health, climate change impacts, and fisheries dynamics. The rapid increase in high-resolution plankton imaging systems has enabled the collection of massive datasets, requiring automated tools for efficient processing and analysis. Deep learning (DL) provides a transformative solution, offering fast and accurate plankton classification, yet there is no consensus on best practices for applying DL methods, leading to inconsistencies in data interpretation, model validation, and result comparability.

This working group addresses the urgent need for the best practices in DL-based plankton image processing. The lack of consistent guidelines has resulted in challenges such as model generalizability, dataset biases, and reproducibility issues. To ensure the robustness of DL models, it is essential to develop comprehensive training libraries, establish metadata best practices, and implement transparent evaluation metrics. By fostering international collaboration, this WG will harmonize DL-based image analysis methodologies across PICES and ICES member countries.

The scientific justification for this initiative lies in the growing demand for high-quality, standardized plankton monitoring data. With climate change driving shifts in plankton populations, monitoring changes in species composition, abundance and distribution is critical for ecosystem assessments. Developing best practices for DL-based plankton classification will significantly enhance the accuracy and efficiency of monitoring programs, enabling more precise ecological modelling and predictive analyses.

Improved plankton monitoring contributes to sustainable fisheries management, early detection of harmful algal blooms (HABs), and assessments of carbon flux and climate regulation services provided by the ocean. By ensuring high-quality, reproducible data, this WG will support environmental policies, conservation strategies, and blue economy initiatives. Additionally, this initiative will facilitate capacity building by engaging early-career researchers, providing training in DL applications, and fostering cross-disciplinary collaborations between oceanographers, ecologists, and computer scientists.

By integrating deep learning into plankton research in a standardized and transparent manner, this WG will enhance the consistency of plankton image processing, enable comparison among different regions, and contribute to the broader understanding of ocean health and climate change impacts. The outcomes of this WG will provide a foundation for future advancements in AI-driven marine monitoring and ecosystem-based management.

Relevance to the PICES Strategic Plan (max. 150 words)
This working group aligns with PICES' strategic goals by fostering international collaboration (Goal 1) among experts in deep learning, plankton ecology, and imaging systems. By developing best practices for DL-based image processing, it enhances the accuracy of plankton monitoring, contributing to ecosystem assessments and resilience studies (Goal 2). The group advances methods for analyzing marine ecosystem responses to climate change and human activities (Goal 3), supporting predictive modelling of plankton populations (Goal 4). By integrating AI with traditional oceanographic monitoring, it improves forecasting of ecological shifts, benefiting fisheries and conservation efforts. Additionally, the working group promotes open data-sharing practices and ensures accessibility of standardized scientific information (Goal 5). It also supports early-career scientists (Goal 6) by fostering interdisciplinary training and capacity building. Through these efforts, the group strengthens global cooperation and contributes to sustainable marine ecosystem management in the North Pacific and beyond.
Linkage(s) to Previous PICES Expert Groups Activities (if any) **See the link for the current and past PICES Expert Groups*
WGDLP builds upon the work of PICES WG 48, which focused on plankton imaging systems. By expanding into deep learning methodologies, this working group will further develop standardized image processing techniques, ensuring data consistency and comparability across regions.
Linkage(s) to Other Organizations and Programs (if any)
ICES: Collaboration with the ICES Working Group on Zooplankton Ecology (WGZE) aims to align best practices for deep learning (DL) applications in the North Atlantic and North Pacific. Dr. James Scott, the correspondent for TOR5 (plankton imaging), has joined the proposed working group to ensure that the scope of work remains consistent. CPR Program (Continuous Plankton Recorder): Coordination with plankton monitoring programs to integrate automated identification methods. MONITOR and AP-NPCOOS: Contributions to North Pacific Ocean observation systems through advancements in imaging-based monitoring.
Terms of References
1. Review current deep learning applications in plankton image processing. 2. Develop standardized DL model training, validation, and evaluation methodologies. 3. Establish a shared library of annotated plankton images and benchmarking datasets. 4. Foster collaboration between plankton ecologists, imaging specialists, and DL experts. 5. Organize workshops and symposiums to disseminate findings and enhance capacity building. 6. Publish a final report summarizing best practices for DL-based plankton image processing.
Time Line and Expected Deliverables ** **WG**: annual plan (year 1... Year 2...)*
Year 1 (2025) 1. WG meeting (Zoom meeting in July/August after the ISB/IGC approval in May/June) ✓ Discuss schedules, plans, and contributors for terms of reference and deliverables. ✓ Discuss schedules and plans of symposium during the next PICES/ICES annual meeting. 2. PICES/ICES workshop (during PICES/ICES annual meeting: Japan or Lithuania) ✓ Summarize developments and limitations of different plankton image processing procedures. ✓ Establish subgroups for processing pipeline, library/data, and case studies ✓ Develop work plan for each subgroup. 3. Contact information

- ✓ Make a list of experts on plankton imaging systems and plankton monitoring among PICES and ICES nations.

Year 2 (2026)

1. WG meeting (Zoom in March/April)
   - ✓ Revise schedules and discuss plans for terms of reference and deliverables.
   - ✓ Review available machine learning algorithms for plankton identification and enumeration.
   - ✓ Review different types of libraries
2. Special session on plankton image processing
   - ✓ Expand the list of experts on plankton imaging processing.
   - ✓ Further identify data availability for comparison among different imaging systems & processing procedures.
   - ✓ Review the applications of imaging processing.
3. PICES/ICES symposium (during PICES/ICES annual meeting)
   - ✓ Overview machine learning for plankton identification and enumeration.
   - ✓ Overview data/management needs for plankton image processing.
   - ✓ Develop protocols and standard libraries to test and compare the performance of different algorithms.
4. Contact information
   - ✓ Expand the list of contact information on experts on plankton imaging, image processing, and plankton monitoring in PICES and ICES nations.
5. Review articles
   - ✓ Review different machine learning algorithms for plankton identification and enumeration
   - ✓ Review different types of libraries, model training and potential ways to compare algorithms and output
6. Compare the performance of different algorithm using standard libraries.
   - ✓ Expand the collection of annotated plankton images to build a shared dataset.
   - ✓ Evaluate the performance of different DL algorithms using the dataset.
   - ✓ Organize a special session at the PICES Annual Meeting to present preliminary findings.

Year 3 (2027)

1. WG meeting (just before or after PICES/ICES annual meeting)
   - ✓ Make a draft of PICES/ICES scientific report, including the following information on plankton image processing
   - ✓ Review of different DLs for plankton image processing, advantages and limitation of different algorithms
   - ✓ Recommendations and best practices protocols for the utilization/selection of different algorithm based on the research purposes.
   - ✓ Recommendations and best practices libraries and protocols for comparing different machine learning algorithms for plankton identification and enumeration.
2. Sessions for PICES or ICES annual meeting
   - ✓ Integrate imaging systems, image processing into existing plankton monitoring programs.
   - ✓ Different platforms for monitoring plankton using imaging systems and plankton monitoring.
   - ✓ Standard protocol and library for comparing different plankton identification and enumeration procedures
3. Review articles
   - ✓ Submit, revise, and publish the review articles on monitoring plankton using imaging systems with results from case studies.
4. PICES/ICES scientific report
   - ✓ Submit a final scientific report to PICES/ICES.
   - ✓ Finalize and publish best practices for DL in plankton image analysis.
   - ✓ Submit a final report summarizing the WG's findings and recommendations.
   - ✓ Promote the adoption of best practices practices through international collaboration.

Expected Deliverables

- A comprehensive review of deep learning techniques in plankton image processing.
- Protocols for best practices DL model development and evaluation.
- A shared library of annotated plankton images for benchmarking DL algorithms.
- A final report summarizing the WG's findings, published as a PICES/ICES scientific report.

Data Management Plan (if applicable)

**see PICES Data Management Policy, PICES Data Flow Decision Tree (TBA)*

This working group is committed to adhering to the PICES Data Management Policy and ensuring the responsible collection, sharing, and dissemination of data, in alignment with the FAIR principles (Findable, Accessible, Interoperable, and Reusable).

Data Accessibility and Sharing

All best practices developed by this working group will be openly published in peer-reviewed journals and made publicly accessible to the scientific community. The image libraries compiled during the working group's activities will be hosted on **GitHub**, ensuring open access, transparency, and reproducibility. These libraries will include annotated datasets with appropriate metadata following PICES data-sharing guidelines to facilitate interoperability and broad usage.

Compliance with PICES Data Policy

The working group will ensure that all collected and processed data adhere to the PICES data policy by:

- Utilizing recognized open-access repositories and platforms for data storage and dissemination.
- Providing comprehensive metadata and documentation for reproducibility.
- Complying with data licensing and citation best practices.
- Ensuring that the datasets meet FAIR data principles.

Data Repositories

The working group encourages the use of well-established repositories for plankton image datasets, including:

- GitHub for dataset hosting and model sharing.
- Other recognized public repositories such as IEEE in compliance with international data-sharing policies.

Through these efforts, the working group aims to enhance data transparency, support international research collaboration, and facilitate the integration of deep learning methodologies into global plankton monitoring programs.

Suggested Members

** try to include experts from all PICES member countries (usually up to 3 members from each country).*
** recruitment of some ECOP (definition) members are highly encouraged.*
**Once the proposal was approved by SB and GC, suggested Co-chairs and members will officially be appointed by respective PICES National Delegate.*

Name	Country	ECOP? (Y or N)	Email Address
Hongsheng Bi	USA	N	hbi@umces.edu
David Kimmel	USA	N	david.kimmel@noaa.gov
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Ankita Ravi Vaswani	Germany	Y	ankita.vaswani@hereon.de

Any other information

This working group acknowledges several technical and logistical challenges and proposes mitigation strategies to address them:

- Variability in imaging systems: Establishing best practices for image processing will help ensure comparability.
- Bias in training data: Creating diverse annotated datasets will improve model generalization.
- Accessibility and computational requirements: Promoting open access and cloud-based deep learning solutions will enhance accessibility for researchers with limited resources.

In addition to these technical challenges, the working group recognizes **the difficulties faced by federal employees**, particularly NOAA scientists, due to budget cuts and widespread layoffs under the new administration. As a result, some participants are unable to make firm commitments at this time. **We are also actively working to engage scientists from Korea**. However, it is important to note that the primary users of imaging systems are currently from the U.S., European countries, Japan, and China, which is reflected in the current structure of this working group.

Title and Acronym of the Group	
Study Group on 4th North Pacific Ecosystem Status Report (SG-NPESR4)	
Term From .... To....	**Reporting body**
From IGC-2025 to PICES-2026 (1.5 year) *(considering the progress of new PICES mission/Science Plan, 1.5-year term is needed)*	SB and GC
Co-Chairs (Name, Country, Affiliation, Email address)	
TBC	
Motivation, Goals and Objectives (max. 300 words) **clarify scientific justification, societal outcomes, etc.*	
The North Pacific Ocean is experiencing unprecedented climate-driven changes and human-induced environmental degradation, negatively impacting marine ecosystems and fisheries across national boundaries. Although some monitoring programs are in place, they often remain fragmented in space and time, hindering basin-scale assessments and effective regional management. As a flagship assessment project of PICES, the North Pacific Ecosystem Status Reports (NPESR) were initiated in the early 2000s to provide an integrated overview of the status and trends of marine ecosystems, including the climate, oceanography, biology, and human dimensions. These reports provided member nations and their stakeholders with the large-scale understanding to improve fisheries and ecosystem management decisions by being open and transparent. A synthesis of variables across regions was included as a separate Chapter (NPESR-1 and 2) or stand-alone publication (NPESR-3), representing an important collaborative effort to synthesize basin-scale ecosystem variability. Past publications (NPESR-1, NPESR-2, and NPESR-3), revealed detailed changes across 14 distinct ecoregions, highlighting their unique ecological characteristics and responses to climate and human-induced pressures. However, despite this comprehensive geographic coverage, or cross-regional comparisons were limited due to varying data availability and analytical approaches across ecoregions. Although NPESR-3 attempted to promote standardized data contributions through an online data submission system, the protocol requiring additional effort from contributors was not widely adopted. Given the challenges of the coordination framework for NPESR, in addition to the lengthy process to obtain relevant data for each region, it remains unclear how effectively the NPESR has been used for supporting ecosystem-based management among member countries and other stakeholders. In 2024, the PICES External Review Recommendation Report encouraged the transformation of PICES to deliver “Actionable Science” in a more explicit manner. The report emphasized the need for the next NPESR to evolve to provide meaningful information to the users across PICES communities and beyond. We propose this SG to develop an implementation plan for the next NPESR, grounded in a more coordinated and efficient framework to enhance comparability across regions, improve detection of ecosystem-wide patterns, and integrate findings into management decisions in a timely manner.	
Relevance to the PICES Strategic Plan (max. 150 words)	
NPESRs are designed to implement PICES’ action plan to “Assess ecosystem status and trends and project future changes” to address its **Goal 2**: Understand the status and trends, vulnerability and resilience, of marine ecosystems, **Goal 3**: Understand and quantify how marine ecosystems respond to natural forcing and human activities, and **Goal 5**: Provide relevant scientific information pertinent to North Pacific ecosystems that is timely and broadly accessible. NPERS4 shall be developed in alignment with the new PICES mission and Science Plan, which is being formulated in response to the Review Panel Recommendation urging the PICES community to deliver actionable science.	
Linkage(s) to Previous PICES Expert Groups Activities (if any)	

- SG-NPESR-3: Study Group on *North Pacific Ecosystem Status Report*
  (Jan. 2015 - Oct. 2016)
- WG 35: Working Group on *Third North Pacific Ecosystem Status Report (WG-NPESR3)*
  (Term: May 2016 – PICES 2021) (Disbanded: March 1, 2024)
- Previous products: NPESR-1, NPESR-2, NPESR-3

Linkage(s) to Other Organizations and Programs (if any)

N/A

Terms of References

1. Review "lessons learned" from NPESR 3 process and ecosystem status reports of other organizations.
2. Establish a communication method with SG-ERRR, and other relevant SG/WG to ensure the contents of NPESR 4 will address new PICES missions and Science Plan.
3. Develop the structure and implementation of NPESR 4
   a) Select natural and social science variables and/or indices, taking into account the availability of qualified data and user needs, and previous PICES expert group final reports on this subject (e.g., WG 28 and WG 36).
   b) Determine the optimal NPESR reporting timeframe and frequency.
   c) Identify best practices for data standardization to enable meaningful regional comparisons in collaboration with TCODE.
   d) Develop a working protocol and timeline
4. Report on progress to SB-2025 (PICES-2025) and ISB-2026 to receive feedback from PICES community.
5. Develop the NPESR4 implementation plan and establish WG-NPESR4 at SB-2026 (PICES-2026).

Expected Deliverables

- Implementation plan of NPESR4 and establishment of WG-NPESR4 (Writing Team)

Data Management Plan (if applicable) **see PICES Data Management Policy,*

The links of the data source to be used for NPESR4 shall be registered to the PICES data hub following the PICES data sharing protocol which is under development by TCODE and WG52: Data.

Suggested Members *(TBC, any suggestion?)*

Name	Country	ECOP? (Y or N)	Email Address
Steven Bograd	USA	N	Sbograd@ucsc.edu
Thomas Therriault	Canada	N	
Jeanette Gann (or 1-2 TCODE or WG52 rep)	USA	N	
1-2 MONITOR rep.			
Other EG/CMTs? (HD, AP-SciCom?)			
2 GC members			
Sanae Chiba	Secretariat	N	
Kathryn Berry	BECI liaison	N	

Any other information

Title and Acronym of the Group	
WG on Comprehensive understanding of ocean acidification in the North Pacific	
Term (WG and SG only) From .... To.... **WG: 3 yrs (with exception)*	**Proposed Parent Committee(s)** **Recommended to have no more than 2 committees*
3 yrs, from PICES-2025 or IGC-2026	BIO, POC

Co-Chairs (Name, Country, Affiliation, Email address)
**consider appointing a chair from both Western and Eastern North Pacific*

Masahiko Fujii (Japan, Atmosphere and Ocean Research Institute, the University of Tokyo, mfujii@aori.u-tokyo.ac.jp)
Guang Gao (China, State Key Laboratory of Marine Environmental Science, Xiamen University, guang.gao@xmu.edu.cn)
Claudine Hauri (USA, International Arctic Research Center, University of Alaska Fairbanks, chauri@alaska.edu)

Motivation, Goals and Objectives (up to 300 words)
**clarify scientific justification, societal outcomes, etc.*

Ocean acidification and its biological effects are occurring on various spatial and temporal scales. Therefore, in order to accurately grasp the progress of ocean acidification (OA) and take effective measures, it is necessary for each country to conduct monitoring in various oceanic regions with different marine environments, analyze the data obtained, and share and mutually compare the results obtained. However, the methods used for monitoring and the degree of data sharing achieved have varied from country to country, and this has been a major challenge for the Integrative analysis and assessment of state and impacts of OA in the North Pacific region. Under the auspices of the Section on Carbon and Climate (S-CC), which has been uncovering carbonic acid inventory data, this working group aims to contribute to the comprehensive understandings of ocean acidification in the North Pacific by accelerating the sharing of OA monitoring data and information exchange on the biological effects of ocean acidification, in collaboration with international research organizations such as the Global Ocean Acidification Observation Network (GOA-ON), which has directly addressed these issues by establishing a data portal and other means.

Relevance to the PICES Strategic Plan (up to 150 words)

The aim of this WG is relevant to the PICES Strategic Plan from the following perspectives:
1) Foster collaboration among scientists with other multinational organizations such as GOA-ON and Integrated Marine Bioshere Research (IMBeR);
2) Help understand the status and trends of ocean acidification, and possible impacts on marine ecosystems and society, through loss of marine biodiversity;
3) Advance monitoring methods and tools of ocean acidification parameters;
4) Provide relevant scientific information of ocean acidification by compiling and synthesizing monitoring data in each country.

Linkage(s) to Previous PICES Expert Groups Activities (if any)
**See the link for the current and past PICES Expert Groups*

TBA

Linkage(s) to Other Organizations and Programs (if any)

TBA

Terms of References

- Assist member countries in establishing effective ocean acidification monitoring and the data sharing that is necessary for evaluating the current and projecting the future ocean acidification and the impacts on marine ecosystems and society;
- Ensure effective mutual communication with other international scientific groups that have experience and responsibility for the coordination of ocean acidification studies, such as GOA-ON and IMBeR;
- Communicate the needs of biologists to chemical monitoring programs to infer species and ecosystem responses, evaluate the needs and requirements of a biological monitoring program, and develop a theoretical framework linking chemical changes to biological response, with the GOA-ON Biology Working Group;
- Facilitate and promote the involvement of PICES members in marine carbon dioxide removal (mCDR) research to ensure the need for a trusted and comprehensive carbonate chemistry baseline and capability and the appropriate inclusion of ocean acidification expertise in mCDR research and management in the North Pacific, in collaboration with the GOA-ON mCDR Working Group;
- Recommend the establishment and strengthening of a monitoring and data-sharing network for ocean acidification in the North Pacific, in order to solve scientific and technical challenges and enable meaningful assessment, projection and mitigation measures of ocean acidification and its socio-ecological impacts;
- Organize webinars, symposia, or workshops on monitoring and data syntheses of ocean acidification, and the compound impacts on marine ecosystems and society along with ocean warming, deoxygenation, and other local stressors in the North Pacific.
- Assist member countries to meet their obligations to report data to the UN SDG14.3 reporting process, i.e., help countries that currently do not report, and help countries that do report improve their data collection and get more benefit from this activity and reporting process.
- Propose and promote activities addressing risks associated with maintaining monitoring capability, such as exploring issues in access to certified reference materials (CRMs) and the options for primary and secondary standards to be produced and distributed in the region.

Time Line and Expected Deliverables
** **WG**: annual plan (year 1... Year 2...)*

TBD
Year 1 (2026)
Webinar
WG meeting (just before or after PICES annual meeting)

Year 2 (2027)
Webinar
WG meeting (just before or after PICES annual meeting)

Year 3 (2028)
Webinar
WG meeting (just before or after PICES annual meeting)
Make a draft of PICES scientific report
Sessions for PICES annual meeting
PICES scientific report
Submit a final scientific report to PICES.

Data Management Plan (if applicable)
**see PICES Data Management Policy, PICES Data Flow Decision Tree (TBA)*

TBA

Suggested Members ** try to include experts from all PICES member countries (usually up to 3 members from each country). Contact Secretariat (sanae.chiba@pices.int) in advance if that is difficult.* ** recruitment of some ECOP (definition) members are highly encouraged.* **Once the proposal was approved by SB and GC, suggested Co-chairs and members will officially be appointed by respective PICES National Delegate.*			
Name	Country	ECOP? (Y or N)	Email Address
Tsuneo Ono Fei Chai Jan Newton …TBD	Japan China USA	N N N	ono_tsuneo65@fra.go.jp fchai@xmu.edu.cn janewton@uw.edu
Any other information			

Title and Acronym of the Group	
WG on Oceanic Finescale Processes: Impacts and Parameterizations	
Term (WG and SG only) From .... To.... **WG: 4 yrs (with exception)*	**Proposed Parent Committee(s)** **Recommended to have no more than 2 committees*
From PICES-2025 to PICES-2029	POC
Co-Chairs (Name, Country, Affiliation, Email address) **consider appointing a chair from both Western and Eastern North Pacific*	
Dr. Zhiwei Zhang, China, Ocean University of China, zzw330@ouc.edu.cn Dr. Bo Qiu, USA, University of Hawaii at Manoa, bo@soest.hawaii.edu	
Motivation, Goals and Objectives (max. 300 words) **clarify scientific justification, societal outcomes, etc.*	

Oceanic finescale processes are loosely referred to as dynamical processes with horizontal scales of O(0.1-100) km including mesoscale eddies, submesoscale processes, fronts, and internal waves, etc. These finescale processes play crucial roles in mediating oceanic energy cascade, biogeochemical and heat transport, and air-sea exchanges, and thus have significant impacts on the ecosystem dynamics and climate variations. For instance, the strong vertical motions induced by submesoscale processes can, on one hand, increase the primary productivity through upwelling and, one the other hand, facilitate the carbon export through downwelling, both of which having profound influences on biogeochemical cycles, ecosystems, and climate. However, the transient and small-size nature of finescale processes makes their observations and simulations challenging and critical gaps exist in understanding their mechanisms of energy cascade and tracer transport and their pathways in modulating the North Pacific ecosystems and climate. In particular, because the prevailing global models are still too coarse to resolve the finescale processes, their energy cascading and tracer transporting effects have to be parameterized in models. Improper parameterizations of finescale processes can lead to significant biases in projections of ocean warming, acidification, deoxygenation, and thus marine biodiversity and climate resilience.

The PICES Working Group 38 (WG 38) on "Mesoscale and Sub-mesoscale Processes" has ended in 2019, and the WG 50 on "Sub-mesoscale Processes and Marine Ecosystems" will be ended this year. While WG 38 and WG 50 have done a lot of work on meso- and submesoscale processes, additional finescale processes such as internal waves are not included. Furthermore, model parameterizations of finescale processes were not considered. It is timely and scientifically meaningful to transition from the tasks of the above two WGs to our proposed new WG: "*Oceanic Finescale Processes: Impacts and Parameterizations*".

The new WG aims to (1) collecting and integrating high-resolution observational datasets and simulation outputs and data analysis methods to better study finescale processes, (2) enhancing the understanding of finescale processes and their impacts on the North Pacific ecosystems and climate variations, (3) evaluating and developing parameterizations of finescale processes and (4) evaluating their influences on the models' performance in the North Pacific". The establishment of this WG helps to understand the status and changes of North Pacific ecosystems and climate and to improve the models' simulation and projection capabilities on these issues. It will also develop tight collaborations with international colleagues to promote studies on the relevant topics.

Relevance to the PICES Strategic Plan (approximately 100-200 words)

The proposed WG on Oceanic Finescale Processes and Model Parameterizations aligns closely with PICES' vision of fostering trans-disciplinary, multinational collaborations to advance understanding of North Pacific ecosystems and enhance resilience. By integrating high-resolution observations and simulations, the group directly supports PICES' mission to coordinate marine research through data exchange and methodological innovation. The PICES have 6 Goals in terms of "Advance Scientific Knowledge". The initiative fosters collaboration (Goal 1) by uniting observational oceanographers, ocean modelers, and ecosystem scientists across nations to address finescale dynamics. It advances understanding of ecosystem status, vulnerability, and resilience (Goal 2) by quantifying how finescale processes—such as mesoscale eddies, submesoscale processes, and internal waves—mediate responses to natural forcings and human activities (Goal 3). The usage and development of parameterizations enhance modeling tools (Goal 4), improving projections of climate variability and ecosystem shifts under anthropogenic pressures. By curating and disseminating datasets and analytical methods, the group ensures timely access to critical scientific information (Goal 5). Furthermore, engaging early-career scientists in cutting-edge data-model integration sustains a vibrant PICES community (Goal 6). Ultimately, this work bridges observational and modeling gaps, strengthening the scientific foundation needed to assess and mitigate ecological risks in a changing North Pacific—a core pillar of PICES' strategic priorities.

Linkage(s) to Previous PICES Expert Groups Activities (if any)
**See the link for the current and past PICES Expert Groups*

WG 38: Mesoscale and Submesoscale Processes
WG 50: Sub-mesoscale Processes and Marine Ecosystems

Linkage(s) to Other Organizations and Programs (if any)

N/A

43Terms of References

1. Review recent advances in finescale processes and their parameterizations in North Pacific to identify key knowledge gaps and innovation opportunities.
2. Assess the availability, accessibility, and interoperability of observation and simulation datasets to study finescale processes in the North Pacific.
3. Integrate multi-platform observational data (e.g., satellites, moorings, gliders, and drifters) with high-resolution model outputs to depict spatiotemporal variability of finescale processes in the North Pacific.
4. Identify the mechanisms and pathways how finesale processes modulate the North Pacific ecosystem dynamics and climate variations.

5. Evaluate the existing and develop new parameterization schemes for unresolved finescale processes in North Pacific models.
6. Evaluate the performance of numerical models with embedded finescale parameterizations under different climate scenarios.
7. Promote collaborations for data sharing, capacity-building workshops, and early-career mentorship to enhance research on finescale processes.

Time Line and Expected Deliverables

** **WG**: annual plan (year 1... Year 2...) * include information on the respective TOR(s) to be addressed.*

Time Line (from PICES-2025 to PICES-2029)

Year 1

(1) Convene an inaugural workshop (virtual/hybrid) to introduce the members and discuss the Terms of Reference (TOR) of the new WG.
(2) Review research advances in finescale processes in North Pacific and the relevant parameterizations (TOR 1).
(3) Assess the finescale datasets to study finescale processes in the North Pacific (TOR 2).

Year 2

(1) Convene a hybrid workshop focused on TOR 3–4.
(2) Integrate observational/model data to depict spatiotemporal variability of finescale processes in the North Pacific (TOR 3).
(3) Identify mechanisms linking finescale processes to ecosystem-climate interactions (TOR 4).

Year 3

(1) Convene a hybrid workshop focused on TOR 5–6.
(2) Evaluate existing parameterization schemes for finescale processes (TOR 5).
(3) Develop new parameterization schemes for finescale processes (TOR 5).
(4) Evaluate performance of numerical models with embedded finescale parameterizations (TOR 6).

Year 4

(1) Final workshop (in-person) to review TOR 1–6.
(2) Finalize collaborative frameworks (TOR 7) and compile project outcomes.

Expected Deliverables

(1) Annual progress reports to PICES, highlighting advancements against TOR objectives.
(2) Mentorship partnerships linking early-career scientists with modeling/observational experts on finescale processes.
(3) A review paper synthesizing research advances, current knowledge gaps, and innovation priorities in North Pacific finescale processes and parameterizations.
(4) A peer-reviewed article on finescale modulation pathways for North Pacific ecosystem dynamics and climate variations.
(5) (5) A report on best practices for finescale parameterization in North Pacific models with guidelines for integrating finescale processes into policy-relevant models.

Data Management Plan (if applicable)

**see PICES Data Management Policy, PICES Data Flow Decision Tree (TBA)*

TBD

Suggested Members ** try to include experts from all PICES member countries (usually up to 3 members from each country).* ** recruitment of some ECOP (definition) members are highly encouraged.* **Once the proposal was approved by SB and GC, suggested Co-chairs and members will officially be appointed by respective PICES National Delegate.*			
Name	Country	ECOP? (Y or N)	Email Address
Zhiwei Bo Qiu Takeyoshi Nagai Sung Yong Kim Takaya Uchida Lixin Qu Lia Siegelman	China USA Japan Republic of Korea Russian Federation China USA		zzw330@ouc.edu.cn bo@soest.hawaii.edu tnagai@kaiyodai.ac.jp syongkim@kaist.ac.kr takachanbo@gmail.com lixinqu@sjtu.edu.cn lsiegelman@ucsd.edu
Any other information			

Agenda Item 16: PICES Sponsored Conference/Symposia

Chiba updated information on PICES-Sponsored International Conferences and Symposia which are upcoming from 2025 to 2028.

1. Intergovernmental Panel on Harmful Algal Blooms (IPHAB-XVII), March 2025
2. One Ocean Science Congress (OOSC 2025), June 2025
3. UNOC3, June 2025
4. ESSAS OSM, June 2025
5. ICES Annual Science Conference, Sept 2025
6. International Conference on Marine Boinvasions (ICNB XII), October 2025
7. International Symposium on Small Pelagic Fish (SPF2026), May 2026
8. 5th Early Career Scientists Conference, 2027
9. ECCWO6

16.1. Intergovernmental Panel on Harmful Algal Blooms (IPHAB-XVII)

- Date/Location: 27-29 March 2023 at FAO Headquarters, Rome, Italy
- Pengbin Wang represented S-HAB (support approved by GC-2024)

16.2. One Ocean Science Congress (OOSC 2025): Science for Action

- Date/Location: 3-6 June 2025, Nice, France
- PICES supports travel of 2 ECOPs from PICES countries (approved by GC-2024)
- Sanae Chiba, Secretariat, is an OOSC International Science Committee member
- SmartNet Town Hall meeting "**Moving towards integrated evaluation approaches in support of ocean policy.** Conveners: David Reid, Furqan Asif, Sonia Batten, Mitsutaku Makino, Olivier Thebaud
- Deliver the voice from the science community to UNOC3

16.3. 3rd UN Ocean Conference (UNOC3)

- Date/Location: 9-13 June 2025, Nice, France
- PICES accredited for sending delegates (Sanae Chiba, and Sung Yong Kim to participate)
- 2025 UN Ocean Conference Declaration (zero draft)

16.4. ESSAS OSM 2025

- Date/Location: 24-26 June 2025, Tokyo, Japan
- PICES supports travel of a few ECOPs from PICES countries (approved by GC-2024)

16.5. ICES Annual Science Conference 2025

- Date/Location: 15-18 Sept, 2025, Klaipeda, Lithuania
- Conference style: Hybrid
- PICES Co-convening Sessions:
  Theme Session C: Climate-ready fisheries management in the UN Decade of Ocean Science for Sustainable Development: 'Best Practices' for decision support tools (co-sponsored by SmartNet).
  Conveners: Steven Bograd (US), Sanae Chiba (Canada), Kathy Mills (US), David Reid (Denmark)

  Theme session H: Managing for species distribution shifts (co-sponsored by S-CCME)
  Conveners: Kathy Mills (US), Kirstin Holsman (US)

  Theme session G: The human dimension in adaptive marine management
  Conveners: Rachel Seary (US), Erin Satterthwaite (US), Emily Ogier (Australia)(co-sponsored by PICES *relevant to WG51 and HD but not specifically noted)

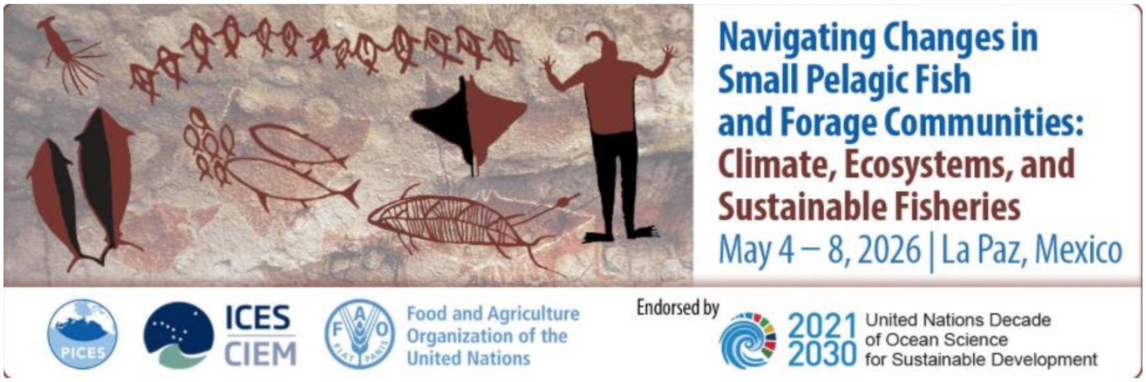
16.6. International Conference on Marine Boinvations (ICNB XII)

- Date/Location: 6-9 October 2025, Madeira, Portugal.
- PICES supports travel of a few ECOPs from PICES countries (approved by GC-2024)
- Abstract submission due: May 18, 2025.

16.7. ICES/PICES/FAO International Symposium on Small Pelagic Fish (SPF) 2026 Navigating Changes in Small Pelagic Fish and Forage Communities: Climate, Ecosystems, and Sustainable Fisheries

- Website Open, workshop proposal due: May 12
- Date/Location: 4-8 May 2026. La Paz, Mexico
- FAO, ICES and PICES (IGC-2023) confirmed their support.
- Local logistic support: CICIMAR, CIBNOR, CICESE, UABCS, etc.

- Local symposium convenor: Dr. Salvador Lluch-Cota (CIBNOR)
- ICES/PICES WG on SPF convened a 3-day workshop for the preparation of SPF-2026



16.8. 5th ICES/PICES Early Career Scientists Conference (ECS) 2027

ICES and PICES played as the main organisers of ECS in turn. As the 4th ECS was organized by ICES and held in Newfoundland, Canada, PICES will host the 5th ECS in an Asian nation in 2027.

16.9. ECCWO6: 6th International Symposium on the Effects of Climate Change on the World's Ocean

PICES and co-organizers are continuously seeking opportunities to hold ECCWO6 in South Africa in 2028 and communicating with potential local organizers.

Agenda Item 17: Capacity Development Events

Chiba updated information on Capacity Building Events proposed and/or organized by PICES EGs (17.1) and PICES partner organizations (17.2), upcoming from 2024 to 2026. SB reviewed the information and acknowledged the events.

17.1. PICES Events

Event title / Date / Location	Date/Location	Amounts and rationale of fund requested
Introduction to PICES - The goal is to provide a brief overview of PICES and its committees/EGs to help introduce new ECOPs/new PICES members to the organization.	PICES-2025 (2 hr)	Funding: N/A *Approved as regular event of Annual Meeting at PICES-2023*
Mentorship program orientation Similar to the program conducted at PICES-2023 and 2024.	PICES-2025 (2 hr x 3)	Funding: N/A During the core Annual meeting days *Approved as regular event of Annual Meeting at PICES-2023*

17.2. Events of PICES Partner Organization

17.2.1 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 SPF2026 (May 2026)

17.2.2. APN "Proposal Development Training Workshop in the Temperate East Asian Region" => *See Agenda Item 6*

- Date/Location: 2-6 June 2025, Jeju, Korea
- APN holds the workshop annually for ECOPs from APN countries to learn how to develop successful proposals for APN research funds. Through the open application process, PICES and APN agreed to jointly sponsor the travel of 2 ECOP participants from PICES countries (China and Russia).

17.2.3 GOOD-OARS Summer School 2025

- Date/Location: 4-11 Nov 2025, Penang, Malaysia
- PICES supports a few ECOPs from PICES countries (approved at PICES-2024)

Agenda Item 18: Publication update

18. 1. Peer-Reviewed Journal Papers (published)

The respective parent committees confirmed that the publications listed were the outcomes of their children Expert Groups' activities. SB endorsed committees' evaluations and recommended GC approve these publications to be posted on the PICES website. GC approved the addition of the following publications as PICES publications (GC 2025/S/5).

EG (Parent)	Citation	Comment	↓SB Action
PICES	Special collection: Effect of Climate Change on the World Oceans. (2025) ICES J. Mar Sci. vol 82, Issue 1. https://academic.oup.com/icesjms/issue/82/1?login=false#2103468-7985641	Products of ECCWO5, Bergen, 2023	→Recommend / not recommend.
PICES	Special collection: Zooplankton Production Symposium (2024-2025) ICES J. Mar Sci. vol 82, Issue 1-4. https://academic.oup.com/icesjms/pages/zooplankton-production-symposium?login=true	Products of ZPS7, Hobart, 2024	→Recommend / not recommend.
AP-UNDOS SmartNet (SB)	Purnomo, A. H., Sachoemar, S. I., Arifin, Z., Samiaji, J., Tanjung, R. H., Nurhayati, A., ... & Boschetti, F. (2025). Demographic dimension of ocean perceptions: Evidence from Indonesia. *Marine Policy*, *178*, 106706. https://doi.org/10.1016/j.marpol.2025.106706	Products of The Ocean We Want project	→Recommend / not recommend.

S-MBM (BIO)	Orben, R.A. et al. 2025. Collaborating with marine birds to monitor the physical environment within coastal marine protected areas. In Frontiers in Ocean Observing: Marine Protected Areas, Western Boundary Currents, and the Deep Sea.Oceanography 38: 32–37, https://doi.org/10.5670/oceanog.2025e115. E.J. Portner et al., 2025. Resource partitioning among pelagic predators remains stable despite annual variability in diet composition. Journal of Animal Ecology. DOI: 10.1111/1365-2656.70032. E.L. Hazen et al. Ecosystem Sentinels as Early Warning Indicators in the Anthropocene. Annual Review of Environment and Resources. DOI: 10.1146/annurev-environ-111522-102317.		→Recommend / not recommend
S-MPP (MEQ)	Savoca, M.et al. (2024). Monitoring plastic pollution using bioindicators: a global review and recommendations for marine environments. *Environmental Science: Advances*. **DOI** https://doi.org/10.1039/D4VA00174E		→Recommend / not recommend

18.2. PICES Official Publication

SB acknowledged that the listed reports and articles, which were already published in the PICES Official Publications, were the outcome of the respective expert group activities.

EG (Parent)	Type of publication & Title	Note
WG-42 (MEQ)	PICES Scientific Report 66	WG Final Report Previously approved, and WG disbanded
WG-44 (HD, FIS)	PICES Scientific Report 67	WG Final Report Previously approved, WG disbanded
WG46 (POC, BIO)	WG Final Report	Published on WG website, WG disbanded
AP-ECOP	Roman, R., Lin, Y., Matsubara, H., Lachance, H., Taylor, M., Jeong, S, W., Patil, V. (2025). International Open Science Training: An Ocean Decade-Endorsed Activity Co-led by PICES Early Career Ocean Professionals (ECOPs) PICES Press 33(1), 41-46.	
AP-CREAMS	SungHyun Nam and Vyacheslav B. Lobanov, 2025, CREAMS 30th anniversary & CSK-II Joint Workshop. PICES Press, Vol 33, No. 1, 47-50.	
AP-UNDOS AP-ECOP	Bograd, S.J., E. Curchitser, J. Hori, S.-I. Ito, K. Jhugroo, M. Makino, R. Roman, N. Saya, P., Weng, 2024. PICES at The Barcelona Conference of the UN Decade of Ocean	

	Science for Sustainable Development. PICES Press, 32(2), 14-17.	
AP-UNDOS AP-ECOP	Jhugroo, K., N. Sena, R. Roman, S.J. Bograd, 2024. PICES ECOPS at The Barcelona Conference of The UN Decade of Ocean Science for Sustainable Development. PICES Press, 32(2), 18-23.	
AP-UNDOS AP-ECOP	Lachance, H., and S. Bograd, 2024. W2- Sharing Capacity and Promoting Solutions for Marine Ecosystem Sustainability within the UNDOS. PICES Press, 32(1), 28-30.	
AP-UNDOS	Satterthwaite, E., S. Bograd, M. Makino, H. Na, S. Batten, S. Chiba, J. Schmidt, 2025. W5 - Exploring international knowledge co-production and the science-policy interface. PICES Press, 33(1), 21-23.	

18. 3. EG Final Report

SB reviewed and recommended the final product of SG-GREEN, and its disbandment

EG (Parent)	Type of publication & Title	Note
SG-GREEN (SB)	Final Report and Recommendation (to be posted on PICES website not in a form of PICES Scientific or Technical Report).	Appendix 5

18. 4. EG Final Report in Progress

Chiba reported the EG Final Reports in progress in various stages (1. In preparation, 2. Being reviewed by the parent Committee, 3. submitted to Secretariat, 4. previously approved by SB and nearly completed). SB acknowledged the progress, and the respective parent committees were committed to ensuring the completion of the reports without delay.

EG	Type of publication & Title	Stages	comments
WG39 (SB)	WG Final Report	4. previously approved by SB and nearly completed	Disbanded
WG47	PICES Scientific Report	1. In preparation	Need engagement of Korean and Chinese members
WG48	Journal review paper	2. Being reviewed by the parent Committee	

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Appendix 1

SmartNet 2024 Year in Review

SMARTNET: 2024 YEAR IN REVIEW

18 December 2024

Dear SmartNet Steering Committee and Friends,

We hope you have all had a wonderful and productive year in 2024. We wanted to highlight some of the activities and accomplishments of the **SmartNet Programme** over the past year, and to notify you of our plans for 2025. We look forward to working with you all to make SmartNet and the UN Decade of Ocean Science for Sustainable Development a success!

SmartNet Governance and Implementation

We had changes in the SmartNet leadership team in 2024. Our founding Co-Chair from ICES, Jörn Schmidt (**Figure 1**), has moved to a new position at WorldFish. We want to thank Jörn for his leadership in establishing SmartNet and guidance in getting SmartNet off the ground over our first three years. While Jörn has stepped down as Co-Chair, we expect to continue working together throughout the Ocean Decade and, hopefully, establish new collaborations between WorldFish, ICES and PICES. Thank you Jörn!

While we will miss Jörn, we are very excited to welcome Dave Reid (**Figure 1**), the ICES Science Committee Chair, as our new SmartNet Co-Chair. Dave has a long history working in ICES and in the international marine science sphere and has already been very active in SmartNet activities this year, including playing a key role in our activities at PICES-2024 Annual Meeting in Honolulu in November. Welcome Dave!

Figure 1: Former and current ICES Co-Chairs of SmartNet, Jörn Schmidt (l) and Dave Reid (r).

Steven Bograd (NOAA, USA) and Sanae Chiba (PICES Secretariat) continue to serve as the PICES Co-Chairs of SmartNet. An important accomplishment of the SmartNet Co-Chairs this year was the completion of the **SmartNet Implementation Plan**, which is under review at PICES Science Board and Governing Council.

A note on SmartNet governance and nomenclature: Since establishing SmartNet in early 2021, we have used the name ICES-PICES Ocean Decade (IPOD) to refer to its Steering Committee, composed of members from ICES and PICES. In Spring 2022, PICES Science Board and Governing Council approved the formation of a new Advisory Panel on the UN Decade of Ocean Science (AP-UNDOS), with Steven Bograd and Sanae Chiba as Co-Chairs. Members of AP-UNDOS will form the PICES-based membership of the SmartNet Steering Committee; See **Appendix A** for AP-UNDOS Terms of Reference. ICES does not currently have an Ocean Decade-specific Expert Group but retains members on the Steering Committee. To avoid confusion, we will no longer refer to IPOD but instead refer to our leadership team as the **SmartNet Steering Committee**. SmartNet will continue to work within our strategic framework involving knowledge production, knowledge sharing, networking with Ocean Decade Actions, and engagement with diverse communities, as outlined in our Implementation Plan (**Figure 2**).

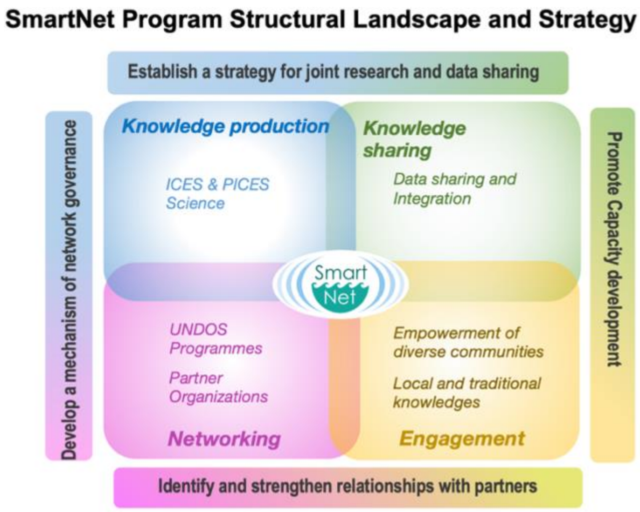

Figure 2: SmartNet structural landscape and strategy.

2024 Accomplishments

SmartNet had its most productive and successful year by far in 2024. SmartNet was active in the production of scientific output, in hosting workshops to our scientific enterprise, and in fostering networks of collaborators. A list of SmartNet 2024 accomplishments is presented in **Appendix B**.

Scientific Production

SmartNet led or contributed to three peer-reviewed scientific publications and an Ocean Decade-published document in 2024:

(A) A review of UN Ocean Decade efforts around the ‘climate-biodiversity-fisheries’ nexus and recommendations for new Actions, published in *ICES Journal of Marine Science*. This paper developed from a SmartNet-led Workshop held at the Effects of Climate Change on the World’s Oceans (ECCWO) Conference held in Norway in April 2023.

https://academic.oup.com/icesjms/article/81/9/1705/7736706

(B) A review of SmartNet’s strategies for sharing knowledge and capacity with ECOPs from Small Island Developing States, published in *Oceanography*. This paper summarizes our efforts to provide leadership opportunities for ECOPs from SIDS with the goal of supporting sustainable scientific development in SIDS. AP-UNDOS members Khush Jhugroo (Mauritius) and Naya Sena (Cabo Verde) are providing leadership for SmartNet in these activities.

https://tos.org/oceanography/assets/docs/38-1-chiba.pdf

(C) A synthesis of the Ocean Decade Vision 2030 Working Group 2 focusing on Challenge 2: Protect and restore ecosystems and biodiversity, published in *ICES Journal of Marine Science*. SmartNet Co-Chair Steven Bograd served on this Working Group, whose objective was to assess the resources, infrastructure, partnerships, capacity development and technology solutions necessary to effectively address this Challenge by 2030, and to provide specific recommendations to achieve the Decade’s objectives.

(D) UN Ocean Decade review of 'success stories' in support of COP16 on Biodiversity, published as an IOC publication. In this document, SmartNet contributed a summary story of our outreach and capacity sharing activities with SIDS.

https://unesdoc.unesco.org/ark:/48223/pf0000391687

(E) SmartNet also contributed a 'success story' focused on our SIDS capacity sharing activities for a planned UNESCO-IOC document to be published in association with the UN Oceans Conference-3 (UNOC3), to be held in Nice, France, in June 2025.

Networks and International Outreach

SmartNet has also been very active in strengthening collaborations with other UN Ocean Decade Actions, building a broader Network around the 'climate-biodiversity-fisheries' nexus, and co-designing science with partners:

(A) SmartNet is a founding partner in a Community of Practice that hosts a monthly webinar series on '*Topics at the nexus of climate change, fisheries and blue foods*' (**Figure 3**). The series is hosted by our partner Actions SUPREME, FishSCORE2030, Blue Food Futures, BECI and FishMIP, and highlights current efforts and challenges at the climate-fisheries nexus. The webinars, scheduled at various times to accommodate different time zones, are well attended by a global audience and are contributing to building a Network of practitioners to address the Decade's identified challenges around the 'climate-fisheries nexus'.

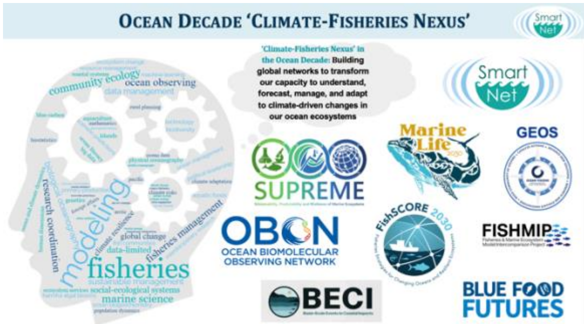

Figure 3: UN Ocean Decade 'climate-fisheries nexus'.

(B) PICES participation and leadership at the UN Decade of Ocean Science Conference in Barcelona, Spain, in April 2024 (**Figure 4**). PICES scientists participated in the Conference in many capacities, including leading a side event (see C) and serving as panelist at several sessions and events. A full description of SmartNet and PICES participation in the Ocean Decade Conference can be found in the Summer 2024 issue of *PICES Press*:

https://meetings.pices.int/publications/pices-press/PICES-Press-2024-Vol32No2.pdf#page=14

Figure 4: PICES representatives at the UN Ocean Decade Conference in Barcelona, Spain, April 2024.

(C) SmartNet hosted a Side Event at the UN Decade of Ocean Science Conference titled '*What is the Ocean We Want? A Global Survey to Understand Perspectives on Ocean Decade Outcomes*' and led by Mitsutaku Makino (**Figure 5**). The 'Ocean We Want' Survey is one of the key SmartNet contributions to the Ocean Decade. The theme of the Ocean Decade is 'the science we need for the ocean we want', but what exactly is the ocean we want, and who are 'we'. This global survey, with pilot surveys already completed in USA, Japan, France and Australia, seeks answers to this question from the general public. Outcomes will include regionally specific assessments of the key issues facing our oceans and their resources, and recommendations for meeting the Decade-identified challenges to support sustainable oceans and ecosystems.

Figure 5: Illustrations (by Bass Kohler) from the SmartNet 'Ocean We Want Survey' side event at the UN Ocean Decade Conference in Barcelona, Spain, April 2024.

(D) As in past years, SmartNet also co-hosted a Workshop at the PICES-2024 Annual Meeting in Honolulu, USA, titled '*Exploring International Knowledge Co-Production: Lessons Learned from International Marine Science Organizations at the Science-Policy Interface*', which was led by AP-UNDOS member Erin Satterthwaite (UCSD, USA) (**Figure 6**). Speakers and panelists representing different inter-governmental organizations, NGOs and RFMOs participated in the Workshop, which aimed to (1) understand how other international organizations conceptualize the process of working at the science-policy interface; (2) identify effective strategies and practices for knowledge co-production in international organizations; and (3) evaluate the current use of PICES information and explore opportunities for enhancing its application. A full description of this SmartNet-supported Workshop can be found in the upcoming Winter 2025 issue of *PICES Press*.

Figure 6: Participants at the SmartNet-sponsored Workshop on the 'science-policy interface' at the PICES-2024 Annual Meeting in Honolulu, USA, in October 2024.

(E) Sharing capacity with Small Island Developing States (SIDS). One of the primary objectives of SmartNet is to leverage the ICES-PICES networks, infrastructure and scientific capacity to share our collective knowledge and capacity beyond our convention areas. A specific focus in on career development of ECOPs from SIDS, which is being led by AP-UNDOS members Khush Jhugroo (Mauritius) and Naya Sena (Cabo Verde), as outlined in the *Oceanography* article linked above.

Ocean Decade Relationships

In addition to continued development of our Ocean Decade Community of Practice on the 'climate-biodiversity-fisheries nexus', we will also continue our relationship with relevant Decade Collaborative Centers (DCCs). Our original sponsor DCC, the Ocean Visions Decade Collaborative Center, will cease to operate at the end of 2024. SmartNet has a relationship with the Italy-hosted Coastal Resilience Decade Collaborative Center (CR-DCC) and will herein have this as our primary DCC. The CR-DCC will help SmartNet with coordination and planning activities, as it does with the SUPREME Programme, which will be tremendously helpful in making SmartNet a success. We are looking forward to working closely with the CR-DCC and our umbrella Projects in the coming year.

SmartNet will continue to integrate Decade-endorsed Projects, and welcome new ones, into our Network. We currently have 7 Projects under the SmartNet umbrella, with two others recommended for endorsement.

2025 Plans and Tasks

SmartNet will continue to our primary activities: scientific production, networking and outreach, and capacity sharing. A list of SmartNet 2025 planned activities is presented in **Appendix C**.

SmartNet is anticipating having an especially active year in terms of networking and outreach. In addition to co-hosting the monthly webinar series on the 'climate-fisheries nexus', SmartNet has proposed to co-host a session at the ICES-2025 Annual Meeting in Lithuania in September 2025 titled '*Climate-Ready Fisheries Management in the UN Decade of Ocean Science for Sustainable Development: 'Best Practices' for Decision Support Tools*'. The proposal has been accepted to be a part of the Meeting. As a planned follow-up, SmartNet has proposed a workshop for the PICES-2025 Annual Meeting in Yokohama, Japan, in November 2025 titled '*Climate-Ready Fisheries Management: Reviewing Effective Strategies for Developing Decision Support Tools*', which is under review by PICES Governing Council. This Workshop will also seek to follow on the suggestion from the PICES-2024 Workshop. Finally, Co-Chair Steven Bograd will also give an oral presentation reviewing the 'climate-biodiversity-fisheries nexus' paper at the One Ocean Science Congress in Nice, France, in June 2025. SmartNet has also proposed to conduct a Town Hall meeting at the Congress with the 'climate-fisheries nexus' Actions titled '*Navigating the Climate-Fisheries Nexus: A Global Perspective*'. We hope to see many of our SmartNet members and collaborators at these events in 2025!

SmartNet will continue to build our Networks with other Ocean Decade Actions, with the CR-DCC, and with our Decade-endorsed Projects. Networking will continue to be a primary activity in 2025.

We hope to see many of you at our upcoming SmartNet and ICES/PICES events, and we welcome ideas and thoughts from all of you on how best to move SmartNet forward in the coming year. Thank you all for your support of SmartNet in 2024, and we look forward to a productive and rewarding 2025!

Happy New Year from your SmartNet Co-Chairs!

Steven Bograd, Sanae Chiba, Dave Reid

Appendix A

PICES AP-UNDOS Terms of Reference

1. Define and promote the joint scientific activities of PICES and partner organizations (including ICES) that will contribute to UN Ocean Decade societal outcomes.

2. Implement the SmartNet Programme (in partnership with ICES), organize its activities and partnerships, monitor its progress, and communicate updates to the PICES community.

3. Implement a strategy that prioritizes engagement with early career ocean professionals, indigenous communities, developing nations, and recognizes the importance of promoting diversity and gender equity in our activities; Coordinate with FUTURE SSC, AP-ECOP and AP-SciCom to develop these strategies.

4. Develop recommendations for new UN Ocean Decade activities for endorsement by UNESCO-IOC, with new and existing partners, allowing for participation of additional partners throughout the Decade.

5. Develop recommendations for new and existing PICES Expert Groups to implement and maintain SmartNet and UN Ocean Decade activities and encourage and support Expert Group participation in all aspects of the UN Ocean Decade.

Appendix B

SmartNet 2024 Accomplishments

Completed

1. Email exchanges with several potential UNDOS Project proposals (**Jan 2024**)
2. SmartNet survey & joint ECOP satellite events accepted for UNDOS conference (**Jan 2024**)
3. Reviewed and provided endorsement recommendations for new UNDOS Project proposals (**Mar 2024**)
4. Co-Chairs planning call (Steven, Sanae, Jörn; **Mar 2024)**
5. Participation in numerous capacities in the UN Decade of Ocean Science Conference, including SmartNet satellite event on the 'Ocean We Want Survey' (Steven, Makino; **Apr 2024)**
6. AP-UNDOS presentation at ISB (Steven; **Mar 2024)**
7. Prepared *PICES Press* articles on UNDOS Conference (Steven, Makino; **May 2024)**
8. SmartNet Chairs call (**Jun 2024**)
9. Complete publication of UNDOS climate-biodiversity-fisheries white paper (**Jul 2024**)
10. Prepared draft SmartNet Implementation Plan, disseminated to Secretariats, AP-UNDOS (**Jul 2024**)
11. Call to discuss SmartNet-SIDS capacity building with Khush, Naya, Raphael; plan for SIDS workshop at PICES-2025 (**Aug 2024**)
12. Submitted SmartNet theme session proposal for ICES-2025; session accepted (**Aug 2024**)
13. Completed and disseminated SmartNet Phase II Implementation Plan (**Aug 2024**)
14. Submitted Project and Contribution solicitation requests for SmartNet, SUPREME for 08/2024 Call for Decade Actions (**Aug 2024**)
15. Complete publication of article on capacity sharing for *TOS Oceanography* (**Sep 2024**)
16. Prepared and submitted Smartnet & SUPREME 7th Call Project proposal reviews (**Sep 2024**)
17. Submitted SmartNet & SUPREME contributions to Ocean Decade publication for Biodiversity COP16 (**Sep 2024**)
18. Conducted pre-PICES-2024 AP-UNDOS virtual business meeting (**Oct 2024**)
19. Participated in DCC-OV call with Program affiliates, presented on SmartNet updates (**Oct 2024**)
20. Preparation for PICES-2024 (AP-UNDOS, SmartNet IP, SB) (**Oct 2024**)
21. Prepared SmartNet, SUPREME slides for DCC-CR Program Committee call (**Oct 2024**)

22. Hosted SmartNet Workshop (W5) on science-policy interface at PICES-2024 (Erin, Makino; **Oct 2024**)
23. Presented SmartNet updates to Committees at PICES-2024 (**Oct 2024**)
24. Represented AP-UNDOS/SmartNet at 'future PICES science' panel at PICES-2024 (**Nov 2024**)
25. Conducted AP-UNDOS business meeting, report out to Science Board, SmartNet IP discussion at PICES-2024 (**Nov 2024**)
26. Submitted climate-biodiversity-fisheries abstract for OOSC; talk accepted (**Nov 2024**)
27. Submitted SmartNet-sponsored workshop proposals (climate-ready fisheries, SIDS) for PICES-2025 (**Nov 2024**)
28. Submitted *PICES Press* article on W5 (Erin; **Dec 2024**)
29. Submitted SmartNet SIDS capacity sharing 'success story' for DCU UNOC3 communications (**Dec 2024**)
30. Submitted APN-CaPABLE proposal to facilitate ECOP engagement in SmartNet and PICES activities (Rafael; **Dec 2024**)
31. Gave SmartNet, SUPREME updates for NOAA TFOD quarterly call (**Dec 2024**)
32. Submitted OOSC Town Hall proposal for 'climate-fisheries nexus' (Claire et al; **Dec 2024**)
33. Submitted SmartNet, SUPREME updates for DCC-CR newsletter (**Dec 2024**)

Appendix C

SmartNet 2025 Task List

Active

1. IPOD Chairs call (**Dec 2024**)
2. Update IPOD membership (AP-UNDOS, ICES) (**Dec 2024 – Feb 2025**)
3. Integrate SmartNet intern (**Dec 2024 – Feb 2025**)
4. OOSC registration (**Jan 31, 2025**)
5. SmartNet Project initiation and network calls (**Jan-Feb 2025**)
6. Consolidate task teams on priority actions (**Jan-Feb 2025**)
7. Revise/maintain SmartNet web presence (intern): (**Jan-Feb 2025**)
   https://forum.oceandecade.org/ventures?block-filters%5Bfulltext%5D=SMARTNET
8. Develop criteria for SmartNet Project endorsement ala ML2030 (**Jan-Feb 2025**)
9. DCC-CR Program Committee activities (SmartNet, SUPREME) (**2025**)
10. DCC and endorsed Projects collaborations & activities (FishGLOB, GPIB, etc) (**2025**)
11. Follow up on SmartNet-SIDS engagement (Khush, Naya) (**2025**)
12. Contribute to UNDOS National Surveys (Makino) (**2025**)
13. Planning and organization of Workshops on community engagement (ITK; community-supported observation), with DCC support (**2025**)
14. SmartNet & SUPREME network meetings (**2025**)

Appendix 2

SmartNet Implementation Plan

SUSTAINABILITY OF MARINE ECOSYSTEMS THROUGH GLOBAL KNOWLEDGE NETWORKS (SMARTNET): PHASE II (2025-2028) IMPLEMENTATION PLAN

Steven Bograd, Sanae Chiba, Mitsutaku Makino, David Reid, Jörn Schmidt

Co-Chairs, ICES-PICES Ocean Decade (IPOD)

9 August 2024

Draft for Science Board, Secretariat Review; Approval at ICES-2024, PICES-2024

1. MOTIVATION, PLANNING AND ENDORSEMENT

The UN Decade of Ocean Science for Sustainable Development (Ocean Decade; 2021-2030), sponsored by the Intergovernmental Oceanographic Organization (IOC), provides an unprecedented opportunity to strengthen and expand the collaborative science between ICES and PICES and with other partner organizations. ICES and PICES are scientific organizations that interact and engage with an array of different groups, from academia, policy, civil society, industry, and foundations throughout the Northern Hemisphere, and through partnerships and specific agreements we are also increasing our presence in the Southern Hemisphere. Our two organizations play leading roles in advancing and communicating scientific understanding of marine ecosystems for societal outcomes. Our partnership brings together diverse networks to increase the overall capacity to conduct ocean science in support of sustainable development and to foster the range of skills necessary to support broad and overarching marine science goals. Furthermore, the strategic plans and objectives of both organizations are well-aligned with Ocean Decade objectives, positioning ICES, PICES and their associated networks to play a leading role in addressing Ocean Decade priorities and societal outcomes. With this motivation, an ad-hoc group of ICES and PICES scientists began bilateral discussions in October 2019 to develop a strategic plan to bring about transformational science during the Ocean Decade by building upon our long history of successful partnerships in advancement of marine science.

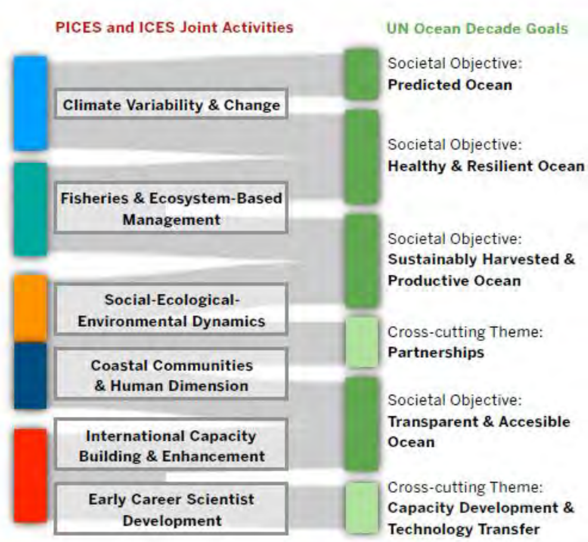

Figure 1: Mapping of ICES and PICES core activities and focus areas onto UN Ocean Decade societal objectives and cross-cutting themes.

Our strategic partnership was formalized in a joint Study Group on the UN Decade of Ocean Science (SG-UNDOS; 2020-2021), which aimed to (a) establish a common strategy for joint activities and provide regional leadership in support of the Ocean Decade; (b) identify and strengthen relationships with partner professional and multilateral organizations to facilitate Ocean Decade engagement; and (c) develop a UN Ocean Decade Programme[1] for endorsement by the IOC. The resulting Programme proposal, titled 'Sustainability of Marine Ecosystems Through Global Knowledge Networks' (SMARTNET), was submitted to the first Ocean Decade Call for Actions in January 2021 (see **Supplement A**), and was among the first set of Actions endorsed by the IOC in June 2021 (see **Supplement B**). SMARTNET aims to support, leverage and expand upon ICES, PICES, and member countries' priorities and initiatives related to the Ocean Decade, by emphasizing areas of mutual research interest and policy needs, including climate change, fisheries and ecosystem-based management, social, ecological and environmental dynamics of marine systems, coastal communities and human dimensions, and communication and capacity development (**Figure 1**). SMARTNET also aims to incorporate strategies to facilitate Ocean Decade cross-cutting inclusivity themes relating to gender equality, early career ocean professional (ECOP) engagement, and significant involvement of indigenous communities and developing nations in the planning and implementation of joint activities.

2. SMARTNET OBJECTIVES AND GOVERNANCE

SMARTNET has two primary objectives: (1) **To convene global partners through knowledge networks to facilitate research, knowledge generation and capacity sharing** in support of sustainable marine ecosystems in a changing climate; and (2) **To leverage and build upon joint ICES-PICES collaborations** to expand our networks and increase resilience of marine & coastal resources and the communities that depend on them. These objectives are closely linked to the Ocean Decade's ten Challenges and seven Desired Outcomes, with a particular emphasis on 'A Productive Ocean', 'A Healthy and Resilient Ocean', 'A Predicted Ocean', and 'An Inspiring and Engaging Ocean'. More broadly, SmartNet objectives are congruent with several of the UN's Sustainable Development Goals: SDG 14 ('Life Below Water'), SDG 13 ('Climate Action'), SDG 2 ('Zero Hunger') and SDG 5 ('Gender Equality').

Figure 2: Intersection of SMARTNET activities within ICES/PICES infrastructure: PICES FUTURE Scientific Steering Committee, and Advisory Panels on UN Decade of Ocean Science, Science Communications, and Early Career Ocean Professionals; and ICES Advisory Committee (ACOM).

[1]A Decade programme is global or regional in scale and will contribute to the achievement of one or more of the Ocean Decade Challenges. It is long-term (multi-year), interdisciplinary and multi-national. A programme will consist of component projects, and potentially enabling activities

To build upon the ICES-PICES enterprise, SMARTNET requires a joint governance structure within the ICES and PICES infrastructure. This is accomplished through the ICES-PICES Ocean Decade (IPOD), which serves as the joint Steering Committee for SMARTNET. In the first phase of SMARTNET (2021-2024), IPOD members were drawn entirely from the broader ICES and PICES communities (**Supplement C**). IPOD members from PICES also serve on PICES' Advisory Panel on the UN Decade of Ocean Science (AP-UNDOS; 2022-present). The terms of reference of AP-UNDOS (**Supplement D**) include the development and governance of SMARTNET, ensuring active collaborations within the Programme across the PICES member nations. In addition, AP-UNDOS has the broader remit of advising and implementing more comprehensive PICES engagement with the Ocean Decade. Within PICES, SMARTNET will facilitate collaboration across several Expert Groups: FUTURE, the flagship Science Program, and the Advisory Panels on the Ocean Decade, ECOPs and Science Communications, all of whose contributions are required for SMARTNET to succeed. The ICES Advisory Committee will also work closely to facilitate SMARTNET engagement across ICES Expert Groups (**Figure 2**).

The objectives of SMARTNET will be achieved through the development and operation of a Global Knowledge Network (GKN) to generate and share knowledge and capacity. This framework has four functional, intersecting components: knowledge production, knowledge sharing, networking and engagement (**Figure 3**), which provides the strategic guidance to implement SMARTNET activities.

- *Knowledge production* comprises the ICES and PICES scientific enterprise and leverages collective organizational infrastructure to advance key scientific topics in marine science. This is exemplified by joint ICES-PICES Expert Groups such as those focused on climate change effects on marine ecosystems (ICES SICCME, PICES S-CCME); impacts of warming on growth rates and fisheries yield (ICES WGGRAFY, PICES WG-45); and sustainable pelagic forage communities (ICES WGSPF, PICES WG-53). SMARTNET will facilitate creation of new joint Expert Groups to address emerging challenges and priorities throughout the Ocean Decade (see Section 3).

- *Knowledge sharing* also leverages the organizational and scientific infrastructure of ICES and PICES, with scientific information communicated through sponsored meetings (ICES/PICES Annual Meetings and associated Workshops and Sessions, International Symposia) and publications (peer-reviewed scientific manuscripts, Scientific Reports, Special Publications, and newsletters such as *PICES Press* and *ICES Cooperative Research Reports*). In addition to the dissemination of scientific knowledge and products, SMARTNET works with Expert Groups to facilitate dissemination of data through Findable, Accessible, Interoperable and Reusable (FAIR) principles (e.g. PICES Technical Committee on Data Exchange, TCODE, aims to establish dialogue to support the Ocean Decade, in particular, its societal outcome of a "transparent and accessible ocean"; similarly for the ICES Data Science and Technology Steering Group, DSTSG).

- *Networking* fulfills the key SMARTNET objective of creating a functioning Global Knowledge Network (GKN) to generate scientific knowledge and share capacity around marine ecosystem sustainability. The long history of ICES and PICES partnerships with national, international and inter-governmental organizations (e.g., PICES MOUs) provides the foundation for this GKN, which SMARTNET will expand beyond the Convention Areas of the North Atlantic and North Pacific represented by ICES and PICES, respectively (although ICES has links with countries in the Global South). A key objective of SMARTNET is to identify new partners and expand the GKN to the Global South, to least developed countries (LDCs) and to Small Island Developing States (SIDS). The Ocean Decade provides new networking opportunities amongst endorsed Actions (Programmes, Projects) which encompass Communities of Practice around key themes (see Section 3).
- *Engagement* focuses on the cross-cutting Ocean Decade objectives of empowering diverse communities, ensuring geographic and gender equity in knowledge generation and capacity sharing, facilitating the career development of ECOPs, and incorporating local and traditional forms of knowledge. By striving for global equity in the generation and sharing of scientific knowledge and implementation of ocean solutions, this element of the Ocean Decade has the potential to be most transformative. SMARTNET actively pursues these cross-cutting themes through developing and sharing capacity with new partners (see Section 3).

The objectives and governance structure described above have guided the activities of SMARTNET since its Ocean Decade endorsement in 2021, leading to substantial progress in fulfilling its goals.

Figure 3: The strategic framework governing the SMARTNET Global Knowledge Network.

3. SMARTNET *PHASE I*: 2021-2024

From Ocean Decade endorsement in June 2021 through 2024, SMARTNET has refined its objectives and governing structure, initiated new partnerships, established an identity, and generated and shared new scientific knowledge through a variety of activities:

A. BUILDING THE GKN

SMARTNET has imitated the building of its GKN through three pathways: (1) expanding or developing new relationships with ICES and PICES network partners; (2) developing informal and formal Communities of Practice amongst endorsed Ocean Decade *Programmes* with overlapping interests and objectives; and (3) bringing in new endorsed Ocean Decade *Projects* under the SmartNet umbrella. SMARTNET representatives participated in the joint PICES-Asia Pacific Network (APN) Study Group on Scientific Cooperation in the Pacific Ocean (SG-PICES-APN; Aug 2021-Feb 2023), culminating in an MOU that outlines avenues of collaboration that incorporate many of the goals and activities of SMARTNET and the Ocean Decade more broadly (**Supplement E**). Additionally, SMARTNET representatives provide leadership to FUTURE, the PICES flagship Science Program. The FUTURE Scientific Steering Committee recently completed the FUTURE Phase III (2021-2025) Science Plan Addendum which explicitly links FUTURE and orients its activities towards the UN Ocean Decade, particularly through SMARTNET (see Section 2 and Figure 2). ICES is also completing an updated 2024-2029 Science Plan, which will articulate links to SMARTNET and Ocean Decade activities. In general, ICES and PICES network partners are inherently part of the SMARTNET GKN and receive updates and other communications through the knowledge sharing activities described above.

The Ocean Decade provides a critical global platform to facilitate global communication and cooperation around marine science and ocean sustainability. SMARTNET has taken advantage of this platform to develop close collaborations with several Ocean Decade endorsed Programmes, including Sustainability, Predictability and Resilience of Marine Ecosystems (SUPREME), Marine Life 2030, Fisheries Strategies for Changing Oceans and Resilient Ecosystems by 2030 (FishSCORE2030), Blue Food Futures, Global Ecosystem for Ocean Solutions (GEOS) and Ocean Biomolecular Observations Network (OBON). These Programmes have formed a Community of Practice around the 'climate-biodiversity-fisheries' nexus, with the aim of sharing scientific advances and tips on navigating Ocean Decade logistics, co-designing collaborative activities, and integrating our individual networks. Four of these Programmes (SmartNet, SUPREME, FishSCORE, BFF) have hosted a monthly webinar series since November 2023 on 'Topics at the Nexus of Climate Change, Fisheries, and Blue Foods'. These webinars reach a global audience and facilitate the co-design of new Ocean Decade activities amongst the four participating Programmes and their networks.

Several newly endorsed Ocean Decade Projects are sponsored by SMARTNET and are explicitly part of the SMARTNET GKN (**Table 1**). These Projects span broad geographic and disciplinary ranges, but all have a focus on finding solutions to critical regional or global issues, in line with the Ocean Decade Challenges. These issues include managing for multiple pressures in regional marine ecosystems, reducing and mitigating the effects of bycatch, disseminating marine and climate information to regional stakeholders, and developing methodologies to quantify the effects of plastic ingestion in marine species.

B. Knowledge Generation and Sharing

SmartNet has taken advantage of scheduled international fora to gather partners at meetings, workshops and satellite events, using these events as the primary pathway to consolidate the GKN and co-design Ocean Decade activities with partners (**Table 2**). In addition to the monthly webinar series described above, these events – both virtual and in-person – have been the primary tool to introduce SmartNet to a global audience and to facilitate the collaborations needed to meet our objectives. The 'climate-biodiversity-fisheries' Community of Practice was formed through the planning and implementation of these events. SmartNet also had a strong presence at the first UN Ocean Decade Conference, held in Barcelona, Spain, in April 2024 – hosting a side event and co-sponsoring two others in collaboration with the Ocean Decade ECOP Programme (Table 2).

A second avenue to widely share SmartNet information is through publications. An early article introduced the objectives of SmartNet in an Ocean Decade-themed special issue of *ECO Magazine* (Trainer et al., 2021), while a more recent publication describes the knowledge- and capacity-sharing strategies of SmartNet in a special issue of *Oceanography* magazine (Chiba et al., in review). A recent SmartNet-led publication, with Community of Practice collaborators, describes the collective capacity and key knowledge gaps within the 'climate-biodiversity-fisheries' nexus, and provides recommendations for future Ocean Decade Actions (Bograd et al., 2024b). Additionally, several articles in *PICES Press* have described the proceedings and outcomes of several of the SmartNet-led and -supported events (Bograd et al., 2023a, 2023b, 2024a; Satterthwaite et al., 2023; Jhugroo et al., 2024).

SmartNet has also contributed to knowledge generation in the Ocean Decade through its global survey on the 'What is the Ocean We Want?'. The refrain of the Ocean Decade is 'The Science We Need for the Ocean We Want'. The SmartNet-led survey seeks to understand 'The Ocean We Want' relative to the 7 Ocean Decade Outcomes, recognizing that there are widely different priorities and

Figure 4: Sketch from the SmartNet 'Ocean We Want Survey' satellite event at the Ocean Decade Conference in Barcelona, Spain, April 2024.

policy needs across cultures and ecosystems. Based on questionnaires designed from the Ocean Decade Implementation Plan, pilot surveys of the general public were conducted in 4 countries (Australia, France, Japan, USA) in 2023, with additional surveys planned in other countries (see Section 4). The expected outcomes from the global survey are threefold: (1) to provide an empirical basis for assessing progress on the Decade Objectives in different regions; (2) to inform SMARTNET'S capacity building strategy to address priority themes for each country, with an emphasis on SIDS and LDCs; and (3) to partner with stakeholders to co-design country-specific ocean advocacy strategies for promoting ocean sustainability. A description of the survey and initial results from the pilot surveys were presented at the SMARTNET-hosted side event at the Ocean Decade Conference in April 2024 (**Figure 4**).

Small Island Developing States (SIDS) have been the focus of SMARTNET'S initial capacity building strategy during *Phase I*. SMARTNET ECOPs from SIDS (Mauritius and Cabo Verde) have led these outreach efforts and developed a list of recommendations to prioritize future activities. These recommendations include inclusion and recognition of SIDS partners; creation of a positive policy environment, with emphasis on empowerment of women and ECOP engagement; improved technical development and science communication to local communities; and financial support from external sources. The initial outreach conducted during *Phase I* will guide SMARTNET capacity-sharing activities in *Phase II* (see Section 4).

C. ECOP DEVELOPMENT

A key objective of SMARTNET from its planning stages was to facilitate active participation by ECOPs in all of its activities. This has arguably been the most successful activity during *Phase I*. ECOPs have contributed leadership to the planning and execution of all of the SMARTNET workshops and events (Table 1), the development of SMARTNET publications, and Programme planning and organization through IPOD, ICES SICCME, and PICES AP-UNDOS and AP-ECOP. PICES ECOPs are members of the IPOD SMARTNET Steering Committee and have taken the lead in SMARTNET'S outreach to SIDS. PICES supported the participation of two PICES ECOPs to the UN Ocean Decade Conference in Barcelona, Spain, in April 2024, where they represented SMARTNET and PICES in several capacities (**Figure 5**). ICES has a Strategic Initiative on Early Career Scientists (SIIECS), and both

Figure 5: PICES delegation at the Ocean Decade Conference in Barcelona, Spain, April 2024. PICES ECOPs Khush Jhugroo (2nd from left), Raphael Roman (3rd from left) and Naya Sena (not shown) represented SMARTNET and PICES in various capacities.

organizations provide significant support for the joint Early Career Scientist Conferences and ECOP/ECS travel support to international fora.

D. ICES-PICES Expert Groups

SmartNet leverages the organizational infrastructure of ICES and PICES to advance work around key scientific themes. During *Phase I*, this has taken the form of incorporating objectives of SmartNet and the Ocean Decade into the goals, terms of reference or anticipated outcomes of relevant Expert Groups. PICES Working Groups 49 (*Climate Extremes and Coastal Impacts in the Pacific*), 50 (*Sub-mesoscale Processes and Marine Ecosystems*), 51 (*Exploring Human Networks to Power Sustainability*), and 52 (*Data Management*) all explicitly mention the Ocean Decade as a motivating influence on their activities. Indeed, the Ocean Decade Challenges and the objectives of SmartNet were motivating factors in the development of WG-49, which is taking a trans-disciplinary approach to understand, predict and communicate the impacts of climate extremes such as marine heat waves and harmful algal blooms. While some of these Expert Groups have a PICES focus, SmartNet provides linkages to ICES and other partners of the GKN and will provide the foundation for new joint ICES-PICES Expert Groups (see Section 4).

4. SmartNet *Phase II*: 2025-2028

In *Phase I*, SmartNet built its organizational structure, developed a strategic framework, expanded its Global Knowledge Network, and initiated activities to meet the objectives of the Programme and the UN Ocean Decade. SmartNet is poised to expand upon these accomplishments during *Phase II*.

A. Programme Objectives and Governance

The *Phase I* SmartNet objectives and governance structure will largely be retained during *Phase II*. The primary objectives remain:

- **To convene global partners through knowledge networks to facilitate research, knowledge generation and capacity sharing** in support of sustainable marine ecosystems in a changing climate;
- **To leverage and build upon joint ICES-PICES collaborations** to expand our networks and increase resilience of marine & coastal resources and the communities that depend on them.

Likewise, the ICES-PICES Ocean Decade (IPOD) will continue to serve as the Steering Committee for SmartNet. In Fall 2024, updates to IPOD membership will be implemented to ensure a balance between ICES and PICES representation as well as geographic, disciplinary, gender and career-stage diversity.

To facilitate the prioritization and completion of SmartNet activities, we will fully implement a set of IPOD Task Teams:

- **Writing Team**: Prepare periodic SmartNet updates for the ICES/PICES communities; Prepare review articles highlighting SmartNet events; Prepare peer-reviewed publications; Update and revise the SmartNet Implementation Plan as needed.
- **Survey Team**: Execute the global 'What is the Ocean We Want?' surveys; analyze, interpret and disseminate survey results in presentations and publications.
- **Outreach Team**: Plan, organize and execute SmartNet meetings, workshops, webinars and training sessions; Maintain a responsive and informative SmartNet web presence.
- **Network Team**: Facilitate communications and engagement with the GKN, including the IOC Decade Coordinating Unit, the Decade Collaborative Centers, and Ocean Decade partner Actions and Communities of Practice.
- **Capacity-Sharing Team**: Facilitate communications and engagement with partners beyond the ICES/PICES convention areas; Develop an engagement strategy with

SIDS; Develop an engagement strategy to incorporate traditional knowledge into SMARTNET activities.

Task Teams will be populated with the revised IPOD membership in Fall 2024.

B. PICES PROGRAM STATUS

We also seek to clarify and solidify SMARTNET's role within PICES with an aim of positioning SMARTNET as a key element of the organization's international scientific enterprise as we transition from the current (FUTURE) to a new flagship Scientific Program. The FUTURE Science Program will phase out over the next few years, initiating a transitional period of strategizing about the future of PICES science that coincides with the Ocean Decade (2021-2030). As articulated in the SMARTNET proposal for IOC endorsement, the Ocean Decade provides a rare and unique opportunity to demonstrate ICES and PICES leadership on the global stage. We advise that ICES and PICES focus their energy and resources into SMARTNET and Ocean Decade activities during this period (SMARTNET *Phase II*, 2025-2028) to ensure success of the Programme and firmly position ICES and PICES as leaders within the Ocean Decade and global marine science. The experiences and lessons learned from the implementation of SMARTNET will inform new Expert Group(s) tasked with planning the next flagship PICES Science Program and will serve as a catalyst to more equitably share our science with the world. With this motivation, we **request to Science Board and Governing Council that SMARTNET be designated a PICES Program with representation on Science Board**. Similarly, ICES could consider evolving SMARTNET into a Strategic Initiative or Operational Group. We note that the plan outlined here is consistent with the recommendations for the future of PICES Science Programs made by the External Review Panel (Hofmann et al., 2024).

C. BUILDING THE GKN

Expansion of the **SMARTNET Global Knowledge Network** is the Programme's primary objective. Our focus in *Phase I* was to entrain partners from within the long-established ICES and PICES Networks. In *Phase II*, we will emphasize expansion of the GKN to include organizations and individuals beyond the ICES and PICES Convention Areas, with a particular focus on the Global South and SIDS. Co-design of activities with the Asia-Pacific Network (APN) will be emphasized as an opportune starting point. Networking with SIDS will follow the recommendations identified in *Phase I* (described in Section 3B) and may include jointly-sponsored workshops at relevant international symposia (e.g. ICES/PICES Annual Meetings) and training sessions focused on relevant themes such as the design of observing systems, data processing and dissemination, and linking science products to policy needs. We anticipate the Network and Capacity Sharing Task Teams will work jointly to expand the GKN and facilitate active participation and will also work closely with the Outreach Task Team to optimize communications about SMARTNET activities and opportunities (see below). Attention to the career development of ECOPs – a *Phase I* emphasis - and diversity and inclusion within the GKN will be paramount.

D. Scientific Foci

The scientific themes identified during *Phase I* included the broadest scientific categories for which ICES and PICES have long had expertise and conducted joint activities. These broad themes included climate effects on fisheries and ecosystem-based management, social-environmental-ecological systems, and human dimensions of coastal systems. During *Phase II*, SmartNet will leverage existing ICES-PICES joint activities to concentrate on a limited number of specific scientific foci. This concentration will ensure that activities respond to identified priorities, have a defined organizational structure, and are likely to produce useful, tractable outcomes that respond to the Ocean Decade Challenges. Initial scientific foci will include:

- Research on the **effects of climate variability and change** on the dynamics of coastal and **marine ecosystems and their living marine resources**, including both historical analyses and climate projections (*leverage Section/Strategic Initiative on Climate Change and Marine Ecosystems; PICES Advisory Panel on Arctic Ocean and Pacific Gateways*).

- Research and advice on the physical forcing, biological impacts and mitigation/adaptation strategies associated with **climate extremes** such as marine heat waves and HABs (*leverage PICES Working Group on Climate Extremes and Coastal Impacts in the Pacific*).

- Research on the **effects of ocean warming on fish growth** and population dynamics (*leverage joint ICES/PICES Working Group on Impacts of Warming on Growth Rates and Fisheries Yields; Working Group on Sustainable Pelagic Forage Communities*).

- Translation of climate information into **ecosystem management frameworks**, including Ecosystem Status Reports, Integrated Ecosystem Assessments, and Management Strategy Evaluations (*leverage joint ICES/PICES Working Group on Integrated Ecosystem Assessment for the Northern Bering Sea - Chukchi Sea*).

- Research on public perceptions of and priorities for the Ocean Decade Outcomes based on the SmartNet **'Ocean We Want' surveys**, which will inform new priority activities.

- **Capacity-sharing** of ICES/PICES science with SIDS and other GKN partners, through scientific fora, scientist exchanges and training sessions (*leverage PICES Working Group on Exploring Human Networks to Power Sustainability*).

The Writing and Survey Task Teams will play key roles in producing and disseminating these scientific activities, with key roles for the other Task Teams as well.

These scientific foci are neither static nor limited, and SMARTNET will retain a nimbleness to pivot to emerging issues as needed. New issues and priorities will be informed through interactions with the GKN. Recommendations and proposals for new joint Expert Groups will be one of the primary tools for SMARTNET to address identified scientific gaps.

E. COMMUNICATIONS AND OUTREACH

SMARTNET will continue to pursue the *Phase I* avenues of communication and outreach established during *Phase II*: the SMARTNET website, informal activity reports (e.g. *PICES Press*), peer-reviewed publications, and network correspondence. An important initial priority will be the expansion of the SMARTNET website to include new content: (a) news and highlights of activities; (b) general Ocean Decade news and updates; (c) descriptions of and links to upcoming meetings, workshops and training sessions; (d) links to reports and publications; and (e) links to Ocean Decade endorsed Projects and other Actions within the GKN, including the 'climate-biodiversity-fisheries nexus' Community of Practice. The Outreach Task Team will have primary responsibility for these activities, along with the organization of meetings, workshops and training sessions.

A key element of *Phase II* will be the recruitment of a **Programme Coordinator** to oversee communication and outreach, which will be supported through the Ocean Decade International Cooperation Center, CHINA. Anticipated responsibilities of the Coordinator include:

- Lead and facilitate progress of the Outreach and Networking Task Teams.
- Lead development of a functional SMARTNET website.
- Facilitate communication and engagement with the GKN.
- Connect ICES/PICES Expert Groups with the activities of SMARTNET and other Ocean Decade Actions.
- Organize workshops, webinars and training sessions.
- Liaise with the IOC Decade Coordinating Unit, Decade Collaborative Centers, and the national Decade committees of ICES and PICES member countries.

Dedicated SMARTNET coordination will result in a higher profile for ICES and PICES within the Ocean Decade and more visible leadership. It would provide a mechanism to facilitate access to ICES/PICES infrastructure to deliver Ocean Decade objectives and result in more effective communication of our activities and outputs. A more rapid awareness of relevant Ocean Decade activities will result in a more effective use of our limited resources and more tangible progress toward meeting the Ocean Decade Challenges than would occur without this coordination. In addition, member countries would benefit through a clearly defined connection between national efforts and international Ocean Decade activities.

F. Anticipated Outcomes

Our current task is to build from the momentum initiated during SmartNet *Phase I* and make significant progress towards our Programme and the Ocean Decade objectives. It is important to recognize that the Ocean Decade is meant to transcend 'business as usual' and to facilitate 'transformative' science with a focus on developing and equitably implementing solutions to the Ocean Decade Challenges (UNESCO-IOC, 2021). With this obligation in mind, SmartNet during *Phase II* will strive for the following **outcomes**:

- Discernable progress towards addressing the Ocean Decade Challenges and implementing the UN Sustainable Development Goals, represented primarily through scientific products.
- Transformation of ICES/PICES science into a stronger global leadership role, with a new emphasis on strategizing and implementing ocean solutions.
- Successful sharing of knowledge and capacity across the Global Knowledge Network, with an emphasis on the Global South and SIDS.
- Successful career development of a new cadre of ECOPs representing gender, geographic and disciplinary diversity.
- Establishment of a stable and functional Global Knowledge Network with the capacity to contribute to ocean research and sustainability beyond the period of the Ocean Decade.

By implementing this plan, we are confident that SmartNet will get us closer to a productive, predicted, healthy and resilient ocean, that is, to the 'Ocean We Want'.

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Table 1: UN Ocean Decade endorsed Projects sponsored by SMARTNET. List as of July 2024.

Endorsement Date	HOST COUNTRY	PROJECT TITLE / DESCRIPTION
March 2023	Germany	sustainMare: Analyses and classifies use of and pressures on marine spaces to provide a scientifically sound basis to create decisions by politics, authorities and the economy.
March 2023	Italy	Cost Action (MAF World): Provide the scientific basis for understanding and preserving Marine Animal Forests (MAFs), to unify different protocols (e.g. mapping, restoration, ecosystem services) to tackle climate change, natural disasters, & food crisis.
June 2023	USA, Global	Global Plastic Ingestion Bioindicators (GPIB): Aims to move beyond baseline assessments of plastic pollution to evaluate trends, risks, and effects to species and ecosystems.
July 2024	Norway	Ghost Fishing Solutions (GFS): Aims to prevent ghost gear, abandoned fishing gear that harms marine life and ecosystems, through innovative technology and practices.
July 2024	Denmark	Klimaatlas: Conveys climate information about future changes and extremes in temperature, precipitation, wind, evaporation, sea level and storm surges in Denmark and serves as one of the primary sources of climate information on land in Denmark.
July 2024	Brazil	INCT Biodiversity of the Blue Amazon (INCT-BBA): A vast Brazilian Project that has established a broad national network of researchers with international collaborators from different fields of knowledge to address specific goals, including basic and applied research, training of human resources qualified in Marine Sciences and scientific dissemination and outreach.
July 2024	Spain	SAFETURTLES: Collaborates with governments and fisheries along the Pacific American coast to facilitate the development of a regulated training system of fishers in best handling and release practices of captured turtles.

Table 2: SMARTNET sponsored or co-sponsored events during Phase 1.

DATE	VENUE	EVENT
April 2022, Washington, DC	Consortium for Ocean Leadership Meeting	Workshop to 'Coordinate Biological Observing Programs in the UN Ocean Decade'
June 2022, Virtual	UN Ocean Decade Satellite Event on 'A Productive Ocean'	SMARTNET: Establishing Global Knowledge Networks to Achieve 'A Productive Ocean' during the UN Decade of Ocean Science for Sustainable Development
September 2022, Busan, Korea	Workshop at PICES-2022 Annual Meeting	SMARTNET: Promoting PICES and ICES Leadership in the UN Decade of Ocean Science for Sustainable Development
April 2023, Atlanta, GA USA	Ocean Visions Biennial Summit	Panelist for 'Leveraging the UN Ocean Decade Framework for Ocean-Climate Solutions'
April 2023, Bergen, Norway	Workshop at Effects of Climate Change on the World's Oceans Conference	The Climate-Fisheries Nexus within the UN Decade of Ocean Science for Sustainable Development: Co-Designing Actions and Solutions for a Productive, Healthy and Resilient Ocean
October 2023, Seattle, WA USA	Workshop at PICES-2023 Annual Meeting	Sharing Capacity and Promoting Solutions for Marine Ecosystem Sustainability within the UN Decade of Ocean Science
April 2024, Barcelona, Spain	UN Ocean Decade Conference	Hosted Side Event on 'What is the Ocean We Want: Global Survey to Understand Perspectives on Ocean Decade Outcomes'
April 2024, Barcelona, Spain	UN Ocean Decade Conference	Co-Sponsored Side Event on 'The Inclusivity We Need for the Ocean We Want', with ECOP Programme
April 2024, Barcelona, Spain	UN Ocean Decade Conference	Co-Sponsored Side Event on 'Building Ocean Leadership: Fostering Networking, Creativity, and Resilience', with ECOP Programme
October 2024, Honolulu, HI USA	Workshop at PICES-2024 Annual Meeting	Exploring international knowledge co-production: Lessons learned from international marine science organizations at the science-policy interface

SMARTNET sponsored event

SMARTNET co-sponsored event

SMARTNET participation at event

SUPPLEMENT A: SMARTNET Proposal submitted to the Intergovernmental Oceanographic Commission for Ocean Decade endorsement in January 2021.

UN Decade of Ocean Science
ICES/PICES Decade Programme
FINAL

Sustainability of Marine Ecosystems through global knowledge networks
(SMARTNET)

Summary description

SMARTNET will establish a global knowledge network (GKN) for ocean science by strengthening and expanding the collaboration of ICES/PICES and partner organizations. It will support and leverage ICES/PICES member countries' activities related to UNDOS, by emphasizing areas of mutual research interest including climate change, fisheries and ecosystem-based management, social, ecological and environmental dynamics of marine systems, coastal communities and human dimensions, and communication and capacity development. It also incorporates strategies to facilitate UNDOS cross-cutting inclusivity themes relating to gender equality, early career engagement, and involvement of indigenous communities and developing nations in the planning and implementation of joint activities.

Countries in which the Programme will be implemented

ICES and PICES Member Countries*, as well as countries and organizations with which we have formal affiliations (e.g. Australia, New Zealand, Chile, Peru, South Africa, UN, FAO, IOC, Regional Fisheries Management Organizations, and Regional Seas Conventions)

The ICES and PICES international scientific platform and cooperation thus goes far beyond our Member Countries, and with potential for this programme to be implemented in countries in both the Northern and Southern hemisphere. We expect to develop partnerships with countries in Africa (e.g. Angola, Mozambique, Sao Tomé and Principe and Cabo Verde), Caribbean and Asia, as well as island nations (e.g., East Timor and Palau), Brazil, and India.

*ICES Member Countries; Belgium, Canada, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Russian Federation, Spain, Sweden, United Kingdom, United States of America

* PICES Member Countries; Canada, China, Japan, Republic of Korea, Russian Federation, United States of America

High-level objectives

Develop and implement a global knowledge network to support knowledge production and dissemination on the status and future of marine social-ecological systems in support of the UN Sustainable Development Goals.

This knowledge will be used to advance and share scientific understanding of marine ecosystems and the services they provide. We will use this knowledge to generate state-of-the-art advice and evidence for meeting conservation, management, and sustainability goals.

The Strategic Plans and Objectives of both organizations are well-aligned with the objectives of the Ocean Decade and our established networks and existing infrastructure will allow us to build on our experience in successfully conducting joint research across our organizations and scientific communities.

During the latter part of 2020, the Governing Councils of ICES and PICES agreed to establish an ICES–PICES Ocean Decade Steering Committee (IPOD SC) to identify activities central to the science objectives of our organizations and the Ocean Decade.

Key expected outcomes

We will increase understanding of the current state and future development of marine social-ecological systems through collaboration of scientists with diverse partners, including under-represented communities, indigenous populations, and early career ocean professionals. We aim to establish a programmatic infrastructure to facilitate transformative scientific research and exchange of information and technical capacity from developed to developing countries as a key outcome. Science will be communicated in a clear, concise manner to achieve solution-based goals for the “ocean we want”.

The ICES–PICES Decade programme – SMARTNET - will identify and facilitate engagement of partner organizations to implement joint UN Ocean Decade activities and enhance communication and outreach to diverse stakeholders. In particular, we acknowledge the

‘Coastal Indigenous Peoples’ Declaration at OceanObs’19’, and similar initiatives, to “establish meaningful partnerships with indigenous communities, organizations, and Nations to learn and respect each other’s ways of knowing; negotiate paths forward to design, develop, and carry out ocean observing initiatives; and share responsibility and resources”. We will engage with organizations that have capacity to bring traditional/indigenous knowledge into our activities. We will also develop partnerships with organizations active in regions outside our formal membership, working in conjunction with the IOC Decade Coordination Unit.

Activities that will be implemented as part of the proposed Decade Programme

There is a long and productive history of collaboration through joint ICES-PICES working groups (see the list below) working on a wide range of topics including climate change impacts on fish and shellfish, biologically-driven ocean carbon sequestration, and regional integrated ecosystem assessments. SMARTNET will leverage the experience and momentum of these joint working groups to expand our work thematically and geographically. Some working groups have also included other organizations, such as the Arctic-oriented Working Groups, and this practice will be extended under the Decade programme to southern hemisphere organizations to deliver the required expansion. We will also coordinate with Global Stakeholder Fora at an early stage to identify and prioritize programme activities. Working group terms of reference are typically updated after 1-5 years to accommodate changing priorities and emerging issues. This iterative process will allow the Decade programme to be dynamic and to evolve as the Decade progresses. Many current joint working groups already have relevance to the planned Decade Outcomes because they were developed with the SDGs in mind. The IPOD Steering committee will develop initial programme priorities and set update Terms of Reference during 2021.

The programme will also leverage ongoing efforts in ICES and PICES to develop a network of Early Career Ocean Professionals (ECOP). We have already jointly-hosted three international Early Career Scientist Symposia to encourage the participation of ECOP in international scientific investigations and to promote their involvement in the management and stewardship of the marine environment. The fourth in the series is scheduled to be held in Canada in May 2022 and will have an Ocean Decade theme. The Scientific Steering Committee, comprising 9 ECOPS from both organizations and the local host, is meeting in January 2021 to develop the programme for this Symposium.

Plans are underway for a first joint ICES/PICES conference in the autumn of 2023, hosted by the USA, in place of separate organizational annual meetings. We propose that this conference be designated as a formal Decade event which will evaluate the early scientific accomplishments and plan further activities that will be conducted during the Decade. Consistent with the goals of the Decade and ICES/PICES shared priorities, the joint conference will also play an important role in furthering development of ECOP, will include representation from indigenous communities and developing nations, and will recognize the importance of gender equality. A second ICES/PICES event is anticipated, likely in the Southern Hemisphere, towards the later stages of the Decade (2028) to review and synthesize accomplishments, and to identify remaining gaps and needed activities.

Ongoing initiatives:

Joint Working Groups:

Joint ICES/PICES Working Group on Small Pelagic Fish

ICES/ PICES Working Group on Ocean Negative Carbon Emission (WG ONCE)

ICES/PICES Working Group on Impacts of Warming on Growth Rates and Fisheries Yields (WG GRAFY)

ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean

Joint ICES/PICES Working Group on Integrated Ecosystem Assessment of the Northern Bering Sea-Chukchi Sea

ICES/PICES Strategic Initiative on Climate Change Impacts on Marine Ecosystems

ICES Council Strategic Initiative/PICES Study Group on the UN Decade of Ocean Science

Symposia:

ICES/PICES/NOAA Marine Socio-Ecological Systems Symposium 2021

ICES/PICES Symposium on Small Pelagic Fish: New Frontiers in Science and Sustainable Management 2022.

ICES/PICES Early Career Scientist Conference 2022

Joint ICES/PICES Conference 2023

Joint multiyear programmes:

International Year of the Salmon (ICES (via NASCO)/PICES/NPAFC/other partners)

Please describe the theory of change that underpins your proposed Decade Programme i.e. how will the activities being carried out achieve the outcomes and objectives that you envisage

The Decade of Ocean Science for Sustainable Development offers a unique opportunity to align efforts and link up with partners outside the current constituency. The IPOD Steering Committee will develop and consolidate a strategic plan to bring about transformational science during the Decade by building upon our long history of successful partnerships in advancement of marine science which have included Regional Fisheries Management Organizations (RFMOs), Regional Conventions and member countries. Beyond that, we anticipate close coordination with a range of stakeholders to identify and prioritize programme activities. Establishment of joint working groups provides opportunities to bring together experts and knowledge holders from different organisations, disciplines and backgrounds in a sustained structure that supports the development of joint publications, activities and projects, but is partly dependent on external funding. In addition, we will use and extend our current evaluation processes for these groups to guide the action or project planning, design and implementation, and to monitor and assess activities to identify impact and achievements. Groups report to the steering structures on a yearly basis and produce science reports in open access report series. These evaluation processes have been enabled us to be resilient and adapt to change over many years of individual and collaborative endeavors.

How will the proposed Decade Programme enhance the sustainability of ocean science initiatives, including infrastructure or individual / institutional capacity, in light of the current Covid-19 pandemic

SMARTNET will support and encourage establishment of joint working groups, workshops and symposia with partners of ICES and PICES in the Southern Pacific and Southern Atlantic and will extend cooperation in the Arctic. The international programme will embrace new working cultures, with emphasis on remote meetings, aimed at greater accessibility with reduced travel to reduce greenhouse gas emissions. The infrastructure to allow these groups to work remotely is already available, and has been greatly enhanced through our actions to transfer marine science training, cooperation, and development activities to remote platforms during 2020.

We acknowledge the educational and economic setbacks brought on by the COVID-19 pandemic and will accelerate our efforts to engage programme partners and stakeholders to accomplish our objectives. This includes the development of an international joint graduate education program and extending our training (short-course) programme.

Coordination / management structure for the proposed Decade Programme

ICES and PICES are international scientific organizations that interact and engage with a diverse range of entities, including academia, government agencies, policy-makers, industry, and NGOs throughout the Northern Hemisphere. Our presence in the Southern Hemisphere through partnerships and agreements is already strong and will increase substantially through the SMARTNET Programme. Our organizations play leading roles in advancing and communicating scientific understanding of marine ecosystems for societal outcomes. They are supported by national contracting parties, have established and sustainable infrastructures, and have demonstrated many decades of success in developing and advancing ocean science. Our partnership brings together diverse networks to increase the overall capacity to conduct ocean science in support of sustainable development and to foster the range of skills necessary to support broad and overarching marine science goals.

The IPOD Steering committee will have initial oversight of joint programme activities. Its terms of reference include identifying strategic partners and activities to be carried out within the programme, and establishing a more permanent oversight body after 2021 that will include international partners. The joint oversight expert body will evolve with the Decade, via periodic review of its terms of reference, assessments of where the programme outputs should be better aligned with the Decade as it matures, and the regular rotation of new personnel into the group. Wide geographic representation is assured through the working group membership policies of both organizations. In accordance with ICES and PICES commitments to increase the involvement of Early Career Ocean Professionals (ECOPs) in working groups, ECOPs will form part of the membership of the oversight body which will confer several advantages: mentorship and career development of the ECOPs by senior scientists, ensuring continuity during the Decade and a lasting legacy when the circle is completed as the ECOPs transition into established scientists and new ECOPs begin to participate in the Programme.

To which Sustainable Development Goal(s) (SDG) will your proposed Decade Programme contribute? Please select a maximum of three SDGs

GOAL 1: No Poverty.

GOAL 2: Zero Hunger

GOAL 3: Good Health and Well-being

GOAL 4: Quality Education

GOAL 5: Gender Equality

GOAL 6: Clean Water and Sanitation

GOAL 7: Affordable and Clean Energy

GOAL 8: Decent Work and Economic Growth

GOAL 9: Industry, Innovation and Infrastructure

GOAL 10: Reduced Inequality

GOAL 11: Sustainable Cities and Communities

GOAL 12: Responsible Consumption and Production

GOAL 13: Climate Action

GOAL 14: Life Below Water

GOAL 15: Life on Land

GOAL 16: Peace and Justice Strong Institutions

GOAL 17: Partnerships to achieve the Goal

How will your proposed Decade programme will contribute to the SDGs selected?

All SDGs are intrinsically interlinked. The proposed framework, in collaboration with partner organisations and the financial support of member countries and donors, will develop and support activities, including working groups, workshops and symposia, which produce and synthesize marine scientific and other knowledge which support SDG 13 with focus on target 13.2 (integrate climate change measures into national policies, strategies and planning), and SDG 14, with focus on 14.2 (sustainably manage and protect marine and coastal ecosystems), 14.4 (effectively regulate harvesting and end overfishing), 14.7 (increase the economic benefits to Small Island Developing States), 14a (increase scientific knowledge, develop research capacity and transfer marine technology). Through this process we will also support targets of other SDGs. The implementation will explicitly focus on gender equality, and more broadly on diversity, equality and inclusion. By extending into regions beyond our traditional regional focus we will enhance knowledge exchange and develop capacity for knowledge production, the SMARTNET Programme will be directly responsive to SDG 17, target 17.6 (Enhance North-South, South-South and triangular regional and international cooperation) and 17.18 (By 2020, enhance capacity-building support to developing countries, including for least developed countries and small island developing States).

How will your proposed Decade Programme contribute to the vision and mission of the Decade?

Both ICES and PICES are uniquely positioned to develop and synthesize science to provide the evidence base to support policy and decision makers to achieve a productive, healthy, safe, and resilient ocean. Their experience in communicating with recipients of advice and extending this expertise in engaging with stakeholders and other ocean actors, will concretely support the identification of both the science we need and the joint objectives for the ocean we want. Both organisations have a commitment and strategies in place to build capacity through engagement with ECOPs and less developed countries which will be expanded and emphasised through the Decade Programme. The joint projects and activities that are already active within the SMARTNET Programme and those to be initiated will produce the knowledge base needed to bring about transformational science and facilitate tractable solutions. Partnering RFMOSs and RSCs are already using scientific evidence and advice provided by existing Working Groups. We will also work with international programmes such as Future Earth to facilitate and promote transdisciplinary research and sustainability studies.

In addition, the SMARTNET Programme will be proactive in recommending and seeking resources to improve ocean observing and ecosystem monitoring activities, particularly in regions around least developed and developing countries. Products developed through SMARTNET activities will assist in the identification of key observing gaps and the promotion of emerging technologies.

To which Decade outcome(s) will your proposed Decade Programme contribute?

Outcome 1: A clean ocean where sources of pollution are identified and reduced or removed.

Outcome 2: A healthy and resilient ocean where marine ecosystems are understood, protected, restored and managed.

Outcome 3: A productive ocean supporting sustainable food supply and a sustainable ocean economy.

Outcome 4: A predicted ocean where society understands and can respond to changing ocean conditions.

Outcome 5: A safe ocean where life and livelihoods are protected from ocean-related hazards.

Outcome 6: An accessible ocean with open and equitable access to data, information and technology and innovation.

Outcome 7: An inspiring and engaging ocean where society understands and values the ocean in relation to human wellbeing and sustainable development.

How will your proposed Decade Programme contribute to the Decade outcomes selected?

ICES and PICES Science Plans encompass the goals of UNDOS, with science priorities directly addressing the expected societal outcomes. ICES and PICES have existing capacity and well-developed institutional infrastructures supporting marine science research, responding to societal needs. This is made possible through legally binding conventions and commitments from member countries, recognizing the importance of scientific research and coordination of effort, the importance of relating scientific work to national, regional, and global management objectives, and where possible reconciling resource management and biodiversity conservation objectives. This is evident through the unique and collaborative work of our two organizations, which is further strengthened through cooperation with other partners. This extended network has global reach covering the North Atlantic, North Pacific and Arctic and broad thematic scope within and beyond areas of national jurisdiction. We have developed and continue to develop science in areas such as climate change effects on marine ecosystems, fisheries and ecosystem-based management, the human dimension, and capacity building to improve understanding, estimation and prediction (Outcomes 4, 5, 6) to provide evidence to support a clean, healthy, safe, productive, and resilient ocean (Outcome 1, 2, 3) and promoting work ensuring an accessible, inspiring and engaging ocean (Outcome 7).

To which Ocean Decade Challenge(s) will your proposed Decade Programme contribute?

Challenge 1: Understand and map land and sea-based sources of pollutants and contaminants and their potential impacts on human health and ocean ecosystems, and develop solutions to remove or mitigate them.

Challenge 2: Understand the effects of multiple stressors on ocean ecosystems, and develop solutions to monitor, protect, manage and restore ecosystems and their biodiversity under changing environmental, social and climate conditions.

Challenge 3: Generate knowledge, support innovation, and develop solutions to optimise the role of the ocean in sustainably feeding the world's population under changing environmental, social and climate conditions.

Challenge 4: Generate knowledge, support innovation, and develop solutions for equitable and sustainable development of the ocean economy under changing environmental, social and climate conditions.

Challenge 5: Enhance understanding of the ocean-climate nexus and generate knowledge and solutions to mitigate, adapt and build resilience to the effects of climate change across all geographies and at all scales, and to improve services including predictions for the ocean, climate and weather.

Challenge 6: Enhance multi-hazard early warning services for all geophysical, ecological, biological, weather, climate and anthropogenic related ocean and coastal hazards, and mainstream community preparedness and resilience.

Challenge 7: Ensure a sustainable ocean observing system across all ocean basins that delivers accessible, timely, and actionable data and information to all users.

Challenge 8: Through multi-stakeholder collaboration, develop a comprehensive digital representation of the ocean, including a dynamic ocean map, which provides

free and open access for exploring, discovering, and visualizing past, current, and future ocean conditions in a manner relevant to diverse stakeholders.

Challenge 9: Ensure comprehensive capacity development and equitable access to data, information, knowledge and technology across all aspects of ocean science and for all stakeholders.

Challenge 10: Ensure that the multiple values and services of the ocean for human wellbeing, culture, and sustainable development are widely understood, and identify and overcome barriers to behaviour change required for a step change in humanity's relationship with the ocean.

How will your proposed Decade Programme contribute to the Decade Challenges selected?

Sustainability of a healthy and resilient ocean for the benefit of future generations requires evidence-based decision-making. Through an ecosystem-based approach, our Decade programme will facilitate science to develop and implement tools and assessments to support decision-making including the evaluation of cumulative effects and analyses of trade-offs among ocean users (Challenge 1, 2, 3, 4, 10). It will provide ecosystem, fisheries, and aquaculture assessments in new areas (ecosystem description, identification of human pressures, and their effect on key ecosystem components), and will advance good practice in including local, traditional, and stakeholder knowledge (Challenge 2, 3, 5, 10). ICES and PICES already coordinate Northern Hemisphere efforts to understand, estimate and predict the impacts of climate change on marine ecosystems. This work is substantive, diverse and includes themes such as: i) global assessment of the implications of climate change on the spatial distribution of fish and fisheries, and forecasting, ii) seasonal to decadal prediction of marine ecosystems, iii) development and evaluation of socio-economic scenarios, and iv) development of scientific evidence to support decision-making. Current efforts in survey design and technology, data analysis and curation will be extended in cooperation with partners, i.e. regional organisations, stakeholders and member countries (Challenge 6, 7, 8, 9).

To which Decade Objective(s) will your proposed Decade Programme contribute?

Objective 1: Identify required knowledge for sustainable development, and increase the capacity of ocean science to deliver needed ocean data and information

Objective 2: Build capacity and generate comprehensive knowledge and understanding of the ocean including human interactions, and interactions with the atmosphere, cryosphere and the land sea interface.

Objective 3: Increase the use of ocean knowledge and understanding, and develop capacity to contribute to sustainable development solutions.

How will your proposed Decade Programme contribute to the Decade Objective(s) selected?

ICES and PICES have extensive and effective infrastructures and networks of expertise to efficiently develop, synthesize and translate scientific information and products which inform management through a transparent, unbiased, impartial, and independent process, providing the evidence base to inform about status and change of marine ecosystems (Objective 1 and 3). We are already key providers of advice for a broad range of organisations and countries and will expand this expertise in collaboration with existing and new partners (Objective 3). Working groups cover ecosystem science, impacts of human activities, seafood production, conservation and management, emerging technologies and the relationship between sea and society (Objective 2). We will extend these activities to include social and economic information in integrated ecosystem assessments, exploration of tools to evaluate marine socio-ecological systems and develop good practice for the co-creation of the evidence base, including development and evaluation of scenarios and solutions with indigenous people, coastal and local communities, and stakeholders as full partners (Objective 1, 2, 3). Strengthened emphasis on science communication and ocean literacy, as well as ECOP development will be leveraged to disseminate the knowledge and products developed in the programme (Objective 3).

With respect to the Decade Objectives selected above, to which Decade Sub-Objective(s) will your proposed Decade Programme contribute?

1.1: Provide the scientific basis for regular integrated assessments of the state of the ocean and identify priority gaps at different scales and in different geographies to frame efforts in exploration, observations and experimentation.

1.2: Promote new technology development and enhance access to technology to generate ocean data, information and knowledge.

1.3: Enhance and expand existing ocean observing systems across all ocean basins to deliver information on standardized essential ocean variables including social and economic, geological, physical, chemical, bathymetric, biological, ecological parameters, and observations on human interactions with the ocean.

1.4: Develop mechanisms that support community-led science initiatives and the recognition and inclusion of local and indigenous knowledge as a fundamental source of knowledge.

1.5: Undertake regular assessments of the state of ocean science capacity to identify and overcome barriers to generational, gender and geographic diversity, and promote sufficient and sustainable investment.

2.1: Generate a comprehensive inventory, mapping, and understanding of the role and function of ocean components including their human interactions and interactions with the atmosphere, cryosphere and the land sea interface.

2.2: Generate a comprehensive understanding of thresholds and tipping points for ocean components, including human interactions.

2.3: Innovate and expand the use of historical ocean knowledge to support sustainable development solutions.

2.4: Improve existing, and develop new generation ocean models for improved understanding of the past, current and future states of the ocean, including human interactions.

2.4: Improve prediction services and increase predictive capability for oceanic hazards or events including extreme weather and climate.

2.5: Expand cooperation in ocean-related education, training, capacity development and transfer of marine technology.

3.1: Broadly communicate and promote the role of ocean science for sustainable development across diverse stakeholder groups including through formal and information education and an expansion of ocean literacy approaches across stakeholder groups.

3.2: Develop interoperable, open access platforms and applications to share data, information and knowledge in a format that connects knowledge generators and users.

3.3: Undertake interdisciplinary, multi-stakeholder co-design and co-delivery of ocean solutions including policy, decision making, integrated ocean management frameworks, applications and services, and technology and innovation.

3.4: Expand and enhance spatial planning processes to contribute to sustainable development across regions and scales.

3.5: Expand and enhance inclusive and integrated management frameworks and tools, including nature-based solutions, to maintain ecosystem functioning, provide for adaptive processes under changing ocean conditions, and incorporate community values and needs.

3.6: Expand and enhance services, applications and management tools for building and mainstreaming preparedness and adaptive responses to multiple stressors and hazards.

3.7: Expand and enhance tools, applications and services that integrate and facilitate use of data, information, and knowledge on ocean-related natural capital including the social, cultural, environmental, and economic characteristics of the ocean.

How will your proposed Decade Programme contribute to the Decade sub-objectives selected?

ICES and PICES are established intergovernmental platforms for science cooperation with an extended scientific network spanning more than 60 countries, 700 institutes, and a pool of more than 6000 experts (1.1). Science is developed through working groups, annual science meetings and symposia. Activities span across all marine science disciplines, improving the understanding, integrated assessment and prediction of marine socio-ecological systems (2.1, 2.2, 2.3, 2.4). Education and training programmes will be further developed in cooperation with partner organizations to improve capacity development (2.5, 3.1). Mechanisms already allow participation of observers and stakeholders and we will develop a process for including indigenous and local actors (1.4). We will also develop processes to ensure ensuring a diverse, inclusive, and gender balanced working environment and to transfer knowledge and technical capacity from ICES and PICES member countries to least developed and developing countries (1.4, 1.5). ICES and PICES have extensive experience in coordinating joint monitoring programs and developing data and technology science (1.2, 3.2). Our Data Centres already provide data services to a range of organizations, with data, data tools, and data products available online and compliant with commitments to ensure open data access and FAIR principles (1.3, 3.7).

Please check which of the following criteria are relevant to your proposed Decade Programme as far as they are relevant to your proposal:

Accelerate the generation or use of knowledge and understanding of the ocean, with a specific focus on knowledge that will contribute to the achievement of the SDGs and complementary policy frameworks and initiatives.

Is co-designed or co-delivered by knowledge generators and users, and does it facilitate the uptake of science and ocean knowledge for policy, decision making, management and/or innovation.

Will provide all data and resulting knowledge in an open access, shared, discoverable manner and appropriately deposited in recognized data repositories consistent with the IOC Oceanographic Data Exchange Policy[1] or the relevant UN subordinate body data policy. (If you check this criteria, please provide in the question below details of where data will be deposited and where it exists, attach a data management plan.)

Strengthen existing or create new partnerships across nations and/or between diverse ocean actors, including users of ocean science.

Contribute toward capacity development, including, but not limited to, beneficiaries in Small Island Developing States, Least Developed Countries and Land-locked Developing Countries.

Overcome barriers to diversity and equity, including gender, generational, and geographic diversity.

Collaborate with and engage local and indigenous knowledge holders.

How will your proposed Decade Programme contribute to the Decade criteria selected?

Collaborative integrated projects and activities initiated under the SMARTNET Programme will be developed and implemented through partnerships and collaborations in to substantially advance our understanding of processes and phenomena in ocean ecosystems. Access to data will be based on the principle of open data and an adherence to the FAIR principles (Findable, Accessible, Interoperable, Reusable), acknowledging the need to exclude some data from unrestricted access due to sensitivities, such as sensitive location information (e.g. vulnerable marine ecosystems).

Emerging conservation activities will be addressed, including a focus on marine biodiversity in areas beyond national jurisdiction, microplastic pollution, and further advancing a better understanding on the ocean ecosystem functioning under progressive climate change and human impacts.

This will be accomplished with full participation of the new generation of marine researchers, supporting involvement in large-scale international research projects, by invitations to (co-)author publications. This inclusion and participation will extend across international research communities, in an overall effort to promote career prospects and develop the future leadership. All activities will recognize our commitment to pursue a diverse, inclusive, and gender balanced working environment and to ensure transfer of knowledge and technical capacity from developed countries within ICES and PICES to least developed and developing countries.

Please describe how you plan to communicate about your proposed Decade Programme including the main target audiences and methods of communications.

Science communication and ocean literacy are integral components of the work of ICES and PICES. Developing tailored outputs for target audiences using appropriate media will be an important objective for the programme.

Programme progress will be communicated broadly using available Ocean Decade mechanisms, as well as established and developing ICES and PICES channels.

Programme outputs will pursue peer-reviewed publications. Outputs may also be peer-reviewed and quality assured translation of science into policy and management relevant advice (e.g. ICES Viewpoints, see for example here: http://ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/vp.2020.01.pdf)

Specific messages resulting from these publications and outputs will be tailored for target audiences at all levels, and across sectors: policymakers; management bodies, scientific community, and the informed public.

Social media will be leveraged to amplify the messages and communicate broadly.

PICES has recently established a Study Group in Science Communications with a specific goal of enhancing the communication of PICES sciences, especially within the context of the Ocean Decade, by broadening the scope of its scientific community to include communication specialists (e.g., designers, journalists, videographers, artists, educators) and policy makers. Specific deliverables include establishing international transdisciplinary opportunities to enhance communication capacity of PICES science, promoting ”green” science and highlighting carbon reduction, especially developing a strategy for PICES meetings to become carbon neutral within the next decade.

ICES has a dedicated Communications team that will be engaged to help convey agreed outcomes and messages, using appropriate media including the ICES website and social media channels.

SUPPLEMENT B: SMARTNET Ocean Decade endorsement letter from the Intergovernmental Oceanographic Commission.

INTERGOVERNMENTAL OCEANOGRAPHIC CO
COMMISSION OCÉANOGRAPHIQUE INTERGO
COMISIÓN OCEANOGRÁFICA INTERGUBERN
МЕЖПРАВИТЕЛЬСТВЕННАЯ ОКЕАНОГРАФИ

UNESCO - 7 Place de Fontenoy - 75352 Paris Cedex 07 SP, France
http://ioc.unesco.org - contact phone: +33 (0)1 45 68 03 18
E-mail: v.ryabinin@unesco.org

Ref. : IOC/VR/21.134/JB/AC/ic 7 June 2021

Dear Madam, Sir,

It gives me a great pleasure to inform you of the endorsement of the Decade Action entitled "No. 90 - Sustainability of Marine Ecosystems through global knowledge networks", which you submitted in response to the Call for Decade Actions No. 01/2020 as a programme of the UN Decade of Ocean Science for Sustainable Development. Please accept my sincere congratulations on this achievement.

The endorsement of your programme is a milestone in your involvement in the Ocean Decade. I would cordially request you to please undertake the following steps:

(i) Please review the attached Charter for Endorsed Decade Programmes, which includes further information on their functioning and roles as part of the Ocean Decade.
(ii) Please review the information on the Ocean Decade Communities of Practice at this link and sign up to one or more of the Communities of Practice that are relevant to your programme. Via that link you will also be asked to respond if you would be willing to play a lead role in co-organising a virtual "meet and greet" between Community of Practice members in coming months.
(iii) Please review the Communications Welcome Pack and provide the name and contact details of a focal point for communications within your team. In coming weeks we will be reaching out to you regarding the official announcement of your Decade Action, and it would be greatly appreciated if you could provide the information requested in the Welcome Pack to allow us to develop social media assets and a factsheet for your programme as soon as possible.
(iv) Please provide the name and contact details of an Early Career Ocean Professional (ECOP) focal point within your team that can be put in contact with the Ocean Decade ECOP Informal Working Group.
(v) Finally, please review, print on your institutional letterhead, and then sign and send the attached acknowledgement letter confirming receipt of this letter and the information contained herein.

…/…

International Council for the Exploration of the Sea (ICES)
Copenhagen V, Denmark
The North Pacific Marine Science Organization (PICES)
Sidney, British Columbia, Canada

Due to formal legal reasons, please kindly be aware of the following disclaimer. Endorsement of your programme does not imply endorsement by the IOC/UNESCO of any business type, product or service. Nothing in or relating to this letter and its attachment shall be deemed a waiver of any of the privileges and immunities of UNESCO. All disputes arising out of or in connection with this letter and its attachment and your acceptance thereof shall be settled by mutual understanding. However, if no amicable settlement can be arrived at, any dispute shall be arbitrated according to the rules defined by the United Nations Commission on International Trade Law (UNCITRAL).

In coming weeks we will also be in touch with you to request additional information to aid in the development of a consolidated resource needs assessment for Decade Actions and to discuss the process of identifying and endorsing projects that will form part of your programme. In the meantime, if you have any questions or require any additional information on the above please do not hesitate to contact us at oceandecade@unesco.org.

Again, on behalf of the entire Ocean Decade Team, please accept my heartfelt congratulations on the endorsement of your Decade Action. Together, let us work towards the ocean we want!

Sincerely,

Vladimir Ryabinin
Executive Secretary, IOC

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

CHARTER FOR ENDORSED DECADE PROGRAMMES

Congratulations! After a thorough review process following the process outlined in the Ocean Decade Implementation Plan, the Executive Secretary of the Intergovernmental Oceanographic Commission of UNESCO (IOC) has endorsed your Decade Programme as part of the UN Decade of Ocean Science for Sustainable Development (the Ocean Decade).

This endorsement is a recognition that your programme will play a central role in supporting the Ocean Decade mission to catalyse transformative ocean science solutions for sustainable development, connecting people and the ocean, in order to achieve the Ocean Decade vision of 'the science we need for the ocean we want'.

This Charter document sets out the responsibilities of the partners responsible for implementing the programme, as well as providing other useful information and conditions pertaining to the endorsement.

I. DURATION AND SCOPE OF ENDORSEMENT

1. The endorsement of the programme will be valid for the duration that you identified in your submission. If there is a change in the duration of the implementation period of more than six (6) months, please notify the Decade Coordination Unit in writing so that we can determine whether a subsequent endorsement evaluation is required.
2. The endorsement of the programme is for the scope that was detailed in the submission to the Decade Coordination Unit, any subsequent supplementary information provided to the Decade Coordination Unit during the evaluation process, and any conditions or requirements identified in the endorsement letter from the Executive Secretary of the IOC. If you plan any significant changes to the programme, including its strategy, plan and/or partners, please advise the Decade Coordination Unit as soon as possible to that we can determine whether a subsequent endorsement evaluation is required.

II. RESPONSIBILITIES OF AN ENDORSED DECADE PROGRAMME

3. As a Decade Programme, your programme will play a prominent role in delivering against the ambitions of the Ocean Decade and contributing to one or more Ocean Decade Challenge[s]. Specifically, the endorsed programme will be responsible for:

   i. Playing an active and lead role in relevant Communities of Practice via the Global Stakeholder Forum to optimise synergies and collaboration with other Decade stakeholders and thus contribute to the collective impact of the Decade.

   ii. Ensuring close and regular coordination and communication with the relevant Decade coordination structures nominated by the Decade Coordination Unit including Decade Coordination Offices, Decade Collaborative Centres and Decade Implementing Partners. This includes, amongst other issues, provision of information on attached Decade projects, as well as information needed for gap analyses, resources needs assessments, work planning, and annual monitoring and reporting. The Decade Coordination Unit will provide information on the Decade coordination structures relevant to your programme.

   iii. Ensuring coordination across partners in the endorsed Programme. This will include facilitating co-design and co-delivery of programme initiatives to meet the Programme's stated objectives, as well as coordinating work planning, implementation of activities, collation of information on resource needs and monitoring, and contributing to communications and outreach.

   iv. Contributing to gap analyses processes led by the Decade coordination structures and coordination of programmatic input to the development of Calls for Decade Actions at the project level. We may also ask you to provide recommendations and advice to the Decade

Coordination Unit in relation to the requests for endorsement for Decade projects that apply to join the endorsed programme.

v. Working with Decade coordination structures and relevant Network Programmes to catalyse the co-design and co-delivery of new Decade Actions and partnerships that could be attached to the endorsed programme as projects or activities. This will include actively fostering and creating a structure within which new projects can be identified and attached to the endorsed programme once endorsed by the Decade Coordination Unit.

vi. Coordinating communication and collaboration with leads of attached Decade projects in order to ensure coherence in activities and contribution to overall work planning, implementation and monitoring. This will include supporting Decade projects to deliver required monitoring information, and collecting information to inform resource needs assessments and communications products.

vii. Consolidating annual monitoring information at the programme level for sharing with the Decade Coordination Unit in line with the requirements of the Decade Monitoring & Evaluation framework that will be provided to the lead partner of the endorsed programme. The Decade Coordination Unit will provide information on the annual monitoring information that you will need to provide.

viii. Providing regular information on resources needs and gaps for operational and coordination activities. Playing a lead and active role in resource mobilisation efforts for the endorsed programme, and ensuring close and regular coordination and communication with Decade coordination structures in relation to resource mobilisation efforts, achievements and opportunities.

ix. Contributing to communications and outreach activities to engage new partners and new projects and raise awareness of the impact and achievements of the endorsed programme and its component projects.

x. Contributing to regular review processes led by the Decade coordination structures that are envisaged in the Implementation Plan.

III. BENEFITS OF AN ENDORSED DECADE PROGRAMME

4. Your programme will be recognized and showcased on the Ocean Decade website (oceandecade.org), included in Ocean Decade communications materials and assets (e.g. social media channels, reports, Ocean Decade events).

5. As a Decade Programme, you will be able to use the Ocean Decade logo in line with the Ocean Decade Branding Guidelines in relevant materials and assets, including, but not limited to, peer-reviewed papers, reports, programme website, programme materials, press materials and/or social media channels. Please note that you can cannot grant or authorise use of the logo by any third party.

IV. SUSPENSION OR TERMINATION OF ENDORSEMENT

6. Please note that the IOC may terminate this endorsement on the basis of advice from the Decade Advisory Board if there is a failure to fulfil the responsibilities outlined in this Charter or if annual resources needs assessments indicate that despite the best efforts of the Programme Lead and the Decade coordination structures the programme has failed after a reasonable period of time to mobilise sufficient resources to operate as a Decade Programme.

7. Should the endorsement be terminated, you will no longer be able to use the Ocean Decade logo and it must be removed from any programme materials and assets.

8. The Programme Lead may also indicate in writing to the IOC at any time that it no longer wishes to be recognised as an endorsed Decade Programme.

Thank you for your engagement in the Ocean Decade and we look forward to creating the ocean we want by 2030!

ACKNOWLEDGEMENT LETTER – PLEASE PRINT ON YOUR INSTITUTIONAL LETTERHEAD AND SEND A SIGNED COPY TO j.barbiere@unesco.org with copy to a.clausen@unesco.org and oceandecade@unesco.org

Dear Executive Secretary,

I confirm receipt of your letter dated [INSERT DATE] advising of the endorsement of [INSERT PROGRAMME NUMBER AND NAME] as an endorsed programme of the UN Decade of Ocean Science for Sustainable Development. I have read and acknowledge my understanding of the information contained in the letter and the Charter for Endorsed Decade Programmes in the attachment.

I am pleased to advise the name and contact details of:

1. Communications Focal Point
   a. [NAME]
   b. [EMAIL ADDRESS]

2. Early Career Ocean Professionals Focal Point
   a. [NAME]
   b. [EMAIL ADDRESS]

Sincerely,

[SIGNATURE REPRESENTATIVE OF THE LEAD PARTNER OF THE DECADE CONTRIBUTION]

Name: [INSERT NAME]

Title: [INSERT TITLE}

Institution: [INSERT NAME OF LEAD PARTNER INSTITUTION]

Date: [INSERT DATE]

SUPPLEMENT C: ICES-PICES Ocean Decade SMARTNET Steering Committee Membership (July 2024). PICES members serve on the Advisory Panel on the UN Decade of Ocean Science (AP-UNDOS).

Kathryn Berry (BECI, ex-officio)

Steven Bograd (USA, Co-Chair)

Sanae Chiba (SECRETARIAT, Co-Chair)

Emanuele Di Lorenzo (USA)

Kirstin Holsman (USA)

Jennifer Jackson (CANADA)

Khushboo Jhugroo (CANADA)

Sukyung Kang (KOREA, Science Board)

Emily Lemagie (USA)

Li Li (CHINA)

Hyung-Gyu Lim (Korea)

Mitsutaku Makino (JAPAN)

Hanna Na (KOREA)

Fangli Qiao (CHINA)

Raphael Roman (CANADA)

Hiroaki Saito (JAPAN)

Erin Satterthwaite (USA)

Vera Trainer (USA)

Andrea White (Canada)

Sinjae Yoo (Korea)

Silvana Birchenough (UK)

Alan Haynie (SECRETARIAT)

David Reid (SECRETARIAT, Co-Chair)

A. Miguel Santos (PORTUGAL)

Olivier Thibaud (FRANCE)

SUPPLEMENT D: PICES Advisory Panel on the UN Decade of Ocean Science (AP-UNDOS) Terms of Reference (July 2024).

1. Define and promote the joint scientific activities of PICES and partner organizations (including ICES) that will contribute to UN Ocean Decade societal outcomes.

2. Implement the SMARTNET Programme (in partnership with ICES), organize its activities and partnerships, monitor its progress, and communicate updates to the PICES community.

3. Implement a strategy that prioritizes engagement with early career ocean professionals, indigenous communities, developing nations, and recognizes the importance of promoting diversity and gender equity in our activities; Coordinate with FUTURE SSC, AP-ECOP and AP-SciCom to develop these strategies.

4. Develop recommendations for new UN Ocean Decade activities for endorsement by UNESCO-IOC, with new and existing partners, allowing for participation of additional partners throughout the Decade.

5. Develop recommendations for new and existing PICES Expert Groups to implement and maintain SMARTNET and UN Ocean Decade activities, and encourage and support Expert Group participation in all aspects of the UN Ocean Decade.

SUPPLEMENT E: Memorandum of Understanding between PICES and the Asia Pacific Network.

September 14, 2022

APN-PICES Collaborative Framework for Scientific Cooperation

Executive Summary

The Asia-Pacific Network for Global Change Research (APN) and North Pacific Marine Science Organization (PICES) are Intergovernmental Organizations with shared goals, particularly in terms of supporting international cooperation in research and capacity development, and partly overlapping geographic regions of focus. The joint APN-PICES Study Group for Scientific Cooperation in the Pacific Ocean (SG-PICES-APN) developed a framework that strives to enhance collaboration between the two organizations. This collaborative framework identifies several broad areas of joint interest to PICES and APN on which progress could be made over the next five years. Research areas relating to climate change (for example; sustainable fisheries, ecosystem services and food security, impacts of extreme events on coastal communities and the need for adaptation and disaster risk reduction) as well as marine plastic debris and microplastics, and downscaling of regional climate models are current foci for both organizations. Two common types of activity that spanned these research areas were also identified, one being the capacity development of early career professionals and the second being the engagement of Local and Traditional Ecological Knowledge (LTEK), a cross-cutting theme for the climate change research areas, in particular.

The framework identifies various mechanisms for implementing enhanced collaboration between PICES and APN including workshops and joint working groups, topic sessions at PICES Annual Meetings, representation at each other's meetings and/or workshops. As areas of interest and priorities change over time, the joint areas for collaboration may be updated.

Following approval from both organizations, routine monitoring of the progress of activities will be completed jointly by the Secretariats of PICES and APN and reported to the PICES Science Board annually, and APN's Intergovernmental Meeting (IGM) and Steering Committee (SC) on a regular basis, respectively.

Background

The Asia-Pacific Network for Global Change Research (APN) and North Pacific Marine Science Organization (PICES) are Intergovernmental Organizations with shared goals, particularly in terms of supporting international cooperation in research and capacity development, and partly overlapping geographic regions of focus.

APN was established in 1996 as an intergovernmental network working towards an Asia-Pacific region that is successfully addressing the challenges of global change and sustainability. A list of the member countries of APN can be found here.

APN's mission is to support a cohesive and interactive community of global change researchers, policymakers, practitioners and civil society across the Asia-Pacific region through innovative and transdisciplinary approaches that draw upon the extensive network of science-policy practitioners. An integral part of its mission is to support and promote the scientific investigations of changes in the Earth's life support systems and their implications for sustainable development in the Asia-Pacific region. The APN contributes to the realization of these investigations through:

September 14, 2022

1. Supporting research and science-based response strategies.
2. Effectively linking scientific outcomes with policy mechanisms applicable to all levels of governance and societal sectors in each country.
3. Scientific capacity development within and beyond governments, including affected communities and other members of civil society.

PICES was established in 1992 to:

- **I.** promote and coordinate marine scientific research in order to advance scientific knowledge of the area concerned and of its living resources, including but not necessarily limited to research with respect to the ocean environment and its interactions with land and atmosphere, its role in and response to global weather and climate change, its flora, fauna and ecosystems, its uses and resources, and impacts upon it from human activities;
- **II.** promote the collection and exchange of information and data related to marine scientific research in the area concerned.

The Organization receives recommendations on the science program from the Science Board Executive Committee, which is supported by a number of permanent scientific and technical committees, along with an assemblage of "expert groups" with various life-spans. The PICES Convention Area is defined as "the temperate and sub-Arctic region of the North Pacific Ocean and its adjacent seas, especially northward from 30 degrees North Latitude, hereinafter referred to as the "area concerned". Activities of the Organization, for scientific reasons, may extend farther southward in the North Pacific Ocean."

The present PICES members are Canada, Japan, People's Republic of China, Republic of Korea, the Russian Federation, and the United States of America. All PICES countries, except Canada, are currently also members of APN.

Development of Collaboration

Reciprocal participation in annual meetings of both organizations in 2020 prompted the recognition of shared priorities and that closer ties, and planning of joint activities, would be mutually beneficial. A joint Study Group (SG) to develop a Framework for Scientific Cooperation was developed and approved by PICES Governing Council in 2021 [GC Decision 2021/S/3] with a Terms of Reference that can be found here: study-groups - PICES - North Pacific Marine Science Organization. Identification and approval of members was hampered by the COVID-19 pandemic, which prevented any in-person meetings and took some time, however, the Study Group had its first online meeting in February 2022. The SG met virtually three more times through 2022 and corresponded online to draft the present Collaborative Framework which was presented to PICES Science Board and Governing Council at PICES-2022. Representatives of both organizations also met in-person at PICES-2022 to discuss next steps. The present Collaborative Framework will be presented for consideration and approval to the APN Steering Committee either via email or on the occasion of its 51st Meeting in early 2023.

Collaborative Framework

APN Science Priorities

Through support of regional and international cooperation in research on inter- and transdisciplinary global change and sustainability issues particularly relevant to the Asia-Pacific region, APN aims to produce policy–relevant scientific knowledge that can contribute to the implementation of international agendas, such as the UNFCCC's Paris Agreement, Sustainable Development Goals, Sendai Framework for Disaster Risk Reduction, Post-2020 Global Biodiversity Framework, UN Decade of Ocean Science (2021-2030), and the accumulation of scientific knowledge in science-policy assessment bodies such as IPCC, IPBES, etc.

Global change affects all countries, and its impacts and the ability to measure and understand these impacts intersects different disciplines. Therefore, APN strives to address global change and sustainability in a holistic manner that involves active participation of all member countries across a broad spectrum of thematic areas under the global environmental change umbrella, including:

- Climate;
- Biodiversity and ecosystems;
- Air, land, coasts and oceans;
- Food, water and energy;
- Risk and resilience; and
- Human dimensions.

Capacity development of early-career scientists and professionals, and members of other societal groups is vital to enable APN member countries to formulate scientific evidence-based policies. Therefore, APN continuously stives to improve its capacity development agenda through:

- Enhancing efforts in providing support to early-career professionals through tailored research activities;
- Enhancing efforts in providing capacity development to early-career professionals that meet their specific needs, for example, by training them in developing high-quality scientific proposals;
- Continuing to strengthen APN's capacity development programme, CAPaBLE.
- Creating holistic and transdisciplinary capacity development activities on topics of relevance in the Asia-Pacific region.

PICES Science Priorities

PICES promotes transdisciplinary, multi-national collaborations to further collective understanding of the North Pacific's natural systems. As part of its vision, PICES aspires to be a leading contributor to global marine science and to be sought as a valued collaborator in addressing current and future management issues. The first goal of the 2016 PICES Strategic Plan is to "*Foster collaboration among scientists within PICES and with other multinational organizations, particularly with those that have common goals*".

PICES activities have been further guided by its current 10+-year integrated research program FUTURE (Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems). FUTURE is an integrative science program with a goal to understand and communicate the future of North Pacific ecosystems and the potential impacts from human use. More specifically, the program seeks to understand how marine ecosystems in the North Pacific respond to climate change and human activities, to forecast ecosystem status based on contemporary understanding of how nature functions, and to communicate new insights to its members, governments, stakeholders, and the public. FUTURE is in its synthesis phase and is due to end in 2024.

In January 2021 the United Nations launched a Decade of Ocean Science for Sustainable Development (UNDOS), which was seen as a valuable opportunity for PICES to expand its horizons, building on FUTURE's achievements and providing a new iteration of integrated activities. A joint program proposal (SmartNet) was submitted with our sister organization, ICES, in the Atlantic, and was endorsed by the Intergovernmental Oceanographic Commission. SmartNet now forms a major focus within PICES which will last until 2031. It will establish a global knowledge network (GKN) for ocean science by strengthening and increasing the collaboration of ICES/PICES and partner organizations. It will support and leverage ICES/PICES member countries' activities related to UNDOS, by emphasizing areas of mutual research interest including climate change and ecological forecasting, fisheries and ecosystem-based management, and the social, ecological and environmental dynamics of marine systems, including coastal communities. It also incorporates strategies to facilitate UNDOS cross-cutting inclusivity themes relating to gender equality, early career engagement, and involvement of indigenous communities and developing nations in the planning and implementation of joint activities. The governance structure and implementation plan for Smartnet is currently being developed and will develop recommendations for new and existing Expert Groups.

Scientific Areas of Joint Interest

The criterion used to determine topics that are of mutual interest and which to focus on in the short-term was a shared relevance to both Organization's objectives or priority areas. Research areas and activities where collaboration would be desirable were identified (**Table 1**) together with the priority for each organization.

Collaboration Mechanisms

Potential mechanisms for enhancing collaboration between APN and PICES include:

1. Workshops or Topic Sessions at PICES annual meetings

Joint sessions at PICES annual meetings, typically held in October, are an excellent potential mechanism for cooperation between PICES and APN. Most past annual meetings include examples of sessions that PICES has co-convened with other organizations, such as CLIVAR (Climate and Ocean: Variability, Predictability and Change), ICES (International Council for the Exploration of the Sea), IMBER (Integrated Marine Biogeochemistry and Ecosystem Research), NOWPAP (Northwest Pacific Action Plan), and SOLAS (Surface Ocean Low Atmosphere Study), among others. The benefits of sharing research findings in a theme session or sharing expertise in workshops have been demonstrated by these examples.

Topic session proposals from PICES scientists and co-sponsoring organizations should be submitted to the PICES website by the deadline, typically September 1 of the calendar year before the Annual Meeting of interest. Proposals should include: a title, duration (full or half day), session description, list of conveners, sponsoring PICES Scientific Committee(s), co-sponsoring organizations (if any), and whether (and where) a publication is intended. At the Committee meetings at the Annual Meeting in the fall (the year before the meeting of interest), recommendations for which session proposals to support are finalized. The Committee Chairs then present the recommendations to the Science Board (SB) who will evaluate and agree on co-sponsoring of sessions. The agreement will consider not just the scientific excellence and appropriateness of the proposals, but also the financial constraints of funding such sessions. The final list is then submitted to PICES Governing Council for final approval.

2. Joint Working Groups

Similar to the current joint APN-PICES Study Group on Scientific Cooperation in the North Pacific Ocean to develop the present Collaboration Framework, there may be a need to form other joint expert groups to address research priorities. Joint working groups represent one of the most effective mechanisms for collaboration and cooperation when there is a need to focus on a specific topic with specific deliverables defined by terms of reference. In general, joint working groups would be formed following one or a series of meetings and/or workshops that are organized on a common theme. Thus, effective planning is a crucial element in successfully establishing a new and productive working group. Typically, in PICES, a working group has a duration of three years. A proposal for a new working group should be submitted by one of the Committees to PICES Science Board for their review.

3. Conferences and Symposia

Normally, PICES organizes one major symposium per year in addition to its annual meeting. Typically, this symposium is jointly sponsored because of the financial commitments required to organize a major symposium. Organizations seeking co-sponsorship of a symposium by PICES should direct a letter of invitation to the Executive Secretary of PICES that describes the scientific rationale, other co-sponsoring organizations and a summary of roles and financial/in-kind contributions expected of PICES. Significant commitments of resources typically require 2–3 years advance planning. A potential example that may be an opportunity for co-sponsorship by APN is the next in the series of Early Career Scientist conferences (these alternate between ICES and PICES leadership), which would be expected to take place in a PICES country in 2027.

4. Representation at meetings and/or workshops

PICES and APN have a history of having representatives from other organizations participate in the annual meeting, including business meetings of relevant expert groups and workshops, where they can report on their organization's activities of interest and so foster collaboration. It is recommended that both organizations consider inviting one or more representatives from the other organization to participate in the meetings of, for example, the Steering Committee and Subregional Committee for the Pacific (for APN) and Science Board (for PICES) to update those bodies on ongoing research activities and research priorities for the future.

While hindered by the COVID pandemic, APN conducts at least one in-person subregional workshop to train early-career professionals on how to develop and submit effective proposals to APN for funding. In its current round of 2021 proposals, early-career professionals are leading 69% of projects funded by APN. This is a good indicator of its success. As APN's Pacific subregional Proposal Development Training Workshop (PDTW) is expected to be held in the coming year or two and as PICES and APN collaboration is engaging Pacific subregional members of APN, there is a potential opportunity to have a joint Proposal Development Training Workshop on one or more of the topics identified in the introduction. A similar opportunity may also be relevant for North Pacific Countries as well as APN and PICES members overlap. This is an area worth exploring further.

Monitoring and Reporting

Following the approval and implementation of this collaborative framework by the respective bodies of PICES and APN (i.e., the Science Board and the Steering Committee), this framework will continue for a period of five years at which time it will be reviewed to assess the progress on the areas identified in Appendix 1, and to identify new areas for collaborations. The review should also assess the collaboration mechanisms by identifying which ones were employed, the utility of those mechanisms in achieving desired results, and identify new mechanisms for future joint collaboration.

On an annual basis, there will be a progress report prepared by the Secretariat of each organization that is available for its members. This progress report should be common for both organizations, be a summary of joint activities between PICES and APN (including status and actions required to make progress on objectives), and be prepared in collaboration by both Secretariats. Further, this progress report will be presented annually at the PICES Science Board and the APN ~~annual~~ Steering Committee meetings as part of a standing item on their agendas. If modifications/alterations are required to joint activities to enable enhanced productivity and success, these recommendations will be approved by both the PICES Science Board and APN Steering Committee (via correspondence if necessary). For any joint activity that is completed, the co-convenors will prepare a summary report of the activity and it will be available for all members of both organizations.

Table 1. Recommended joint PICES-APN focus areas with associated rankings and mechanism to achieve progress within 5 years.

Activity or Research Area	PICES Rank	APN Rank	PICES Focus	APN Focus	Mechanism and potential platforms	Priority in next 5 years
Activity: Capacity Development of ECOP. i. UNDOS cross-cutting theme	High	CD of ECPs: high	Major objective of SmartNet (UNDOS program). Major focus area for PICES recently with Advisory Panel on ECOP advisory-panels - PICES - North Pacific Marine Science Organization approved in 2021	One of the goals of APN's 5th Strategic Plan is capacity development, particularly that of early career professionals (ECPs)	1. APN – Capacity development programme (CAPaBLE) is one of the two main pillars of APN's activities; 2. APN's Proposal Developing Training Workshop (PDTW) in the Pacific region may benefit from PICES input if there is a marine theme. 3. Next ICES-PICES ECS Symposium planned for 2027	High, Relevant to UNDOS
Activity: Engaging Local and Traditional Ecological Knowledge i. UNDOS cross-cutting theme ii. Indigenous knowledge in the context of adaptation and disaster risk reduction iii. Indigenous Knowledge in the context of food and water security	High	High (for the Pacific SRC)	Major objective of SmartNet. Some activity at PICES-2022 (W6 for Bering Sea), Also planned for PICES-2023	"Global and indigenous knowledge" was one of the high priority topic areas of P-SCR for the 2021 call for proposals.	Workshops at upcoming events Will be discussed at PICES-APN side meeting in Busan, Sept 2022	High, relevant to UNDOS
Research area: Climate change; sustainable	High	Climate Change:	Major objective of SmartNet, and several	1. Food security (and habitat value)		High, priority research area

fisheries		high	PICES Expert Groups	2. Ecosystem services (non-food related) including cultural services		
Research area: Climate change; impacts of extreme events on coastal communities	High	High	New Working Group (WG49)	Adaptation and disaster risk reduction	Review WG plans as they develop. Look for opportunities to share outputs. Add an APN Ex-officio member	High, priority research area
Research Area: Marine plastic debris and microplastics	High	High	WG42 working-groups - PICES - North Pacific Marine Science Organization will end in 2022 but have indicated there should be a follow-on expert group (possibly a Section) to continue the work and link to Global initiatives	Marine plastic debris and microplastics are one of the focused areas under Goal 1 “Research” of APN’s 5th Strategic Plan.	Include APN members in a new Expert Group? Review WG plans as they develop. Look for opportunities to collaborate and share outputs.	Med-high, awaiting outcome of PICES Science Board recommendation on new EG
Research Area: Regional climate model downscaling in the Pacific	High	High	Active area of research in PICES nations; theme of S-CCME; theme of SUPREME and BECI (UNDOS Program/Project)	“Regional climate downscaling in the Pacific” was one of the high priority topic areas of P-SCR for the 2021 call for proposals.	“Regional climate downscaling in the Pacific" will remain a high priority topic of P-SRC for the APN FY 2022 Call for Proposals	High
Research Area: Circular and Ecological Economy	Med	High	Likely of interest to PICES Human Dimensions Committee.	CEE is one of the focused areas under Goal 1 “Research” of APN’s 5th Strategic Plan. Circular and Ecological Economy (CEE) is an initiative to enhance sustainable socio-economic activities by drawing on locally		Med-high

				available energies, natural resources, infrastructure, industrial conglomerations, as well as the indigenous culture, particularly in rural areas.		

The Asia Pacific Network-North Pacific Marine Science Organisation (PICES) Collaborative Framework for Scientific Cooperation

The Collaborative Framework for Scientific Cooperation between the APN and PICES comes into effect when signed below by both parties, and will continue for a period of five years at which time it will be reviewed to assess progress.

The Collaborative Framework may be revised at any point as agreed by both parties, and may be renewed for a further period if approved by both the PICES Science Board and APN Steering Committee.

冨坂隆史

__________________ 17 February 2023

Signature **Date**

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Appendix 3

Science Board Feedback on Review Report Recommendation

GC-2024 request to SB
GC requested SB to revisit and discuss their response to the External Review Committee recommendations, focusing on considerations based on the science perspective only for each recommendation, and to provide a report to GC as soon as practicable in the new year (GC2024/S/19).

Science Board Feedback on Review Report Recommendation to submit to the Governing Council

January 2025

Summary

- Science Board (SB) agrees that PICES should clarify and emphasise its role in promoting evidence-based decision-making for stakeholders, including member countries. SB calls for the establishment of an organisational mechanism to accelerate co-design and co-production, enabling the delivery of Actionable Science with the Governing Council (GC).
- SB agrees on the need for committee restructuring to make PICES science fit-for-purpose operationally and calls for careful consideration of the new structure to balance discipline-specific knowledge to enhance interdisciplinary collaboration to address urgent societal issues.
- SB suggests the new Integrative Science Program be established based on a Socio-Environmental-Ecological-Systems (SEES) framework, with focused themes, clear timelines and tangible deliverables.
- Across all three subjects above, SB requests the new "Study Group (SG) on Review Recommendation Response (tentative name)", comprising the selected members of GC, to facilitate sufficient communication with SB to ensure the co-design and co-production of new PICES science.
- SB recognises PICES capacity development efforts have been strengthened in recent years and are on track to achieve the Recommendation.

1. PICES Role

1.1. On Implementation of Actionable Science

Understanding that "Actionable Science" is the science to urge evidence-based decision and policy-making to solve social, environmental, and ecological challenges facing the world ocean, SB agrees to emphasise the PICES' role in implementing "Actionable Science".

Although not explicitly stated as its role in the Convention, PICES science has been practising "Actionable Science" on issues such as climate–ocean interactions, biodiversity conservation, and fisheries management. We have addressed societal needs by producing scientific outcomes and products, including tools (mobile app of Ciguatera project), model projections, and indicator development. Ecosystem/environmental assessments including NPESR and ADRIFT Report have provided useful information to Regional Fisheries Management Organisations (RFMOs) and for the regional management of member countries. We have provided North Pacific perspectives to international bodies such as the IPCC and IPBES, contributing to policy-setting under international treaties, which our member countries are committed to achieving. However, these contributions have primarily been made through the activities of individual Expert Groups (EGs) and/or on an ad hoc basis (e.g., special projects). To implement "Actionable Science" more operationally and proactively, PICES needs to establish an organisational mechanism to enable the co-production and co-design of the science plan.

1.2. Needs for co-design/co-production mechanism

To effectively implement and deliver actionable science, SB believes that improved communication with GC members is essential. Because there will be differences of opinion in member countries as to how far we go, having national delegates and scientists from each member country meet and discuss can only go so far. In PICES, science plans are developed through a bottom-up process, driven by the creative and free ideas of groups of scientists, which is a valuable tradition. However, in the current structure, SB lacks opportunities to receive input from the GC during this process. As a result, the scientific community is informed of GC decisions on their plans without understanding the specific needs of respective member countries. Establishing mechanisms to enhance communication between SB/EGs and the GC—such as ad hoc dialogues or the creation of an EG to conduct a systematic survey on national demands—could help address this issue (e.g., SG on Actionable Science or co-production).

1.3. On useful products for stakeholders

PICES EGs have recently held workshops focusing on stakeholder engagement and science-policy interface (e.g. W5 at PICES-2024), inviting guests from partner organisations such as ICES and RFMOs. We have heard their clear and increasing demand for more useful and findable PICES information resources, including scientific reports, assessment reports and data. SB strongly agrees with the Review Report Recommendation on the need to revise the NPESR format to be more user-oriented, thereby strengthening their engagement and communication. SB will establish a new SG to design NPESR IV in 2025 to address the stakeholders' needs. We would like to ensure GC's thoughts on NPESR IV (if any) will be shared with the SG from the early phase of the planning to allow the co-design of the report (e.g., including a few GC members in SG).

As for the PICES role as a data provider, PICES has already begun transforming in recent years. TCODE and WG52 on Data Management revised the PICES data management policy to align with the global data sharing principles. They are developing the PICES metadata repository protocol and data portal/hub to make our data findable for users while respecting feasibility and member countries' data-sharing policies, e.g. development of usable data interface via collaboration with BECI project. SB hopes for continued support of member countries in establishing a new PICES data protocol.

1.4. On the basic but Innovative science

There will be various paths forward to strengthen the PICES capacity for Actionable Science. While learning from cases of similar intergovernmental organisations, including ICES, SB believes PICES should develop its own model, considering the unique nature of the North Pacific and the diverse perspectives and business practices of our member countries. Although the focus of PICES science has already shifted from basic to applied science (Takemura et al., submitted), SB still sees the value in the PICES role in fostering international collaboration on basic and focused disciplinary science, too. Innovative scientific findings and technologies derived through basic science can bring game-changing solutions to regional and global challenges.

2. PICES Structure

2.1 On restructuring Committees: discipline basis to thematic basis

The FUTURE study reports the transformation of PICES science from a primarily disciplinary to a more interdisciplinary focus in the past decades (Takemura et al., submitted). This is reflected in the topics of recent EGs and Sessions/Workshops at our Annual Meeting which are becoming more interdisciplinary to deliver fit-for-purpose science. In the current hierarchical structure, multiple committees with relevant disciplines must oversee the activities of those EGs, making the reporting process from EGs and guidance by Committees complicated and exhaustive. Given this challenge, SB agrees to revise the current committee structure and function to efficiently implement “Actionable Science.” However, careful consideration will be needed on how to restructure the committees from the current discipline-based structure to thematic basis* as recommended by the Report (**the recommended plan actually shows two thematic committees: climate and oceans, ecosystems with humans and two functional committees: Monitor and Data, Status and Predictions).*

First, as urgent socio-ecological topics change over time, themes for committees must be selected with a broad and long-term perspective. Second, the new committees should be established not merely by merging existing committees, and the balance of committee members’ expertise and roles should be clearly identified (As the members of the committees are nominated by member countries, it can be difficult to achieve a balance of expertise among the members of the committees). Admitting there has not been enough communication and coordination among current Committees, the proposed thematic committees may face the same risk of siloing without enhancing cross-committee coordination. Lastly, while agreeing that the new structure should highlight specific themes to address and functions to advance, SB considers the guidance from experts with deep knowledge of specific disciplines to still be highly valuable for PICES. To ensure the new committee structure accelerates actionable science, SB requests GC to facilitate sufficient communication with SB in its development process.

2.2 Alternative new Committee structures

Given the Review Panel clarifies that the suggested new Committee Structure is an example, SB suggests some alternative ideas for the new Committee Structure. ** Though this is not a consolidated SB suggestion, SB believes sharing alternative examples may still be useful for GC's early brainstorming.*

Themes aligning High-level International Ocean Science Directives

The goals and targets of high-level international ocean science directives such as SDG 14, UNDOS (and Vision 2030), are set to address ocean challenges that the global community is facing and contribute to the achievement of various international treaties, e.g. Paris Agreement, KM-GBF, BBNJ Agreement, Plastic treaty and various international fish stock agreement (so solution basis). PICES’s commitment to these global challenges will be more visible and streamlined by establishing thematic committees aligned with these goals/targets. Example themes: Climate variability and change (and ocean-based solutions), Sustainable fisheries (or food security), Ecosystem health (including pollution, and community resilience and adaptability), Observation and data, Innovative (basic) science, etc.

Enhance cross-committee communication

Some SB members suggest that the current discipline-based committee structure could still deliver actionable science if cross-committee communication and activity coordination are improved. However, maintaining this structure would require revising the current inefficient EG-Committee reporting protocol (see 2.1).

3. Integrative Scientific Programme

3.1 On the roles of ISP and SB

In the Recommendation, part of the role of the new Integrative Scientific Programme (ISP) seems to be redundant with the current SB role, e.g., coordinating and governing committees' activities and PICES science plan. SB feels it is not fully clear if this implies that SB is expected to act as the ISP Steering Committee and implement ISP (which FUTURE SSC currently does). Assuming that ISP will replace FUTURE to be the next PICES flagship science programme and that SB and ISP SC will remain separate bodies as they currently are (as SB believe they should be), their roles must be clarified to avoid redundancy.

3.2 On the topic of ISP

FUTURE has integrated EGs into its Socio-Environmental-Ecological-Systems (SEES) framework, which has enhanced collaborations between EGs and promoted an interdisciplinary approach to PICES science. While a new ISP can effectively be developed with the SEES approach as a conceptual framework, it needs to set achievable, tangible deliverables with a clear timeline based on priorities in the new PICES Science Plan. SB has not reached an agreement on whether ISP should be a decadal program or a series of shorter programs with more focused (short-term) goals to address urgent societal issues. If it is a decadal program, milestones with tractable deliverables should be set for every three or four years. Again, co-design and co-production practices involving science, governance, and administrative bodies of PICES should be implemented for the planning of ISP.

3.3. Other thoughts on new ISP development

** These are individual ideas from SB members, not consolidated SB suggestions. However, SB believes sharing these ideas may still be useful for GC's early brainstorming.*

Example of short-term ISP: evolved from WG49

One possibility is to expand the activities of WG 49 (Climate Extremes and Coastal Impacts in the Pacific). Recognising the increased risk of more frequent and more severe extreme events within the Pacific domain, WG 49 was established to provide a suite of potential solutions to these climate-driven changes through the integrated SEES approaches. Because it ranges from basic science to interdisciplinary science (consequences of climate extremes on fisheries, ecosystems, and coastal communities), a short-term ISP with a focus on climate extremes could evolve from WG 49.

Coordination of ISP and SmartNet

The Report does not specifically elaborate on the role of PICES in UNDOS or SmartNet in the new PICES structure and ISP. SmartNet is a UNDOS-endorsed programme representing ICES and PICES, and its implementation plan includes many elements recommended by the Panel for a new ISP: a focus on solution-based science; capacity development; diverse and equitable approaches to tackling issues facing the parties; expansion of geographic focus beyond the PICES convention area; establishment of new strategic partnerships; and various cross-cutting challenges. With no other current or suggested Committees leading cross-cutting challenges, such as ocean literacy, science communication, ECOP promotions, and wider community engagement, SmartNet should be given proper status in the new PICES Science Plan, at least by 2030. The roles of the new ISP and SmartNet should be carefully coordinated to minimize duplication of efforts and maximize synergy.

4. Capacity Development

PICES has emphasised Capacity Development frameworks, including the promotion of ECOPs with the Trust Fund scheme and technical training workshops. The scheme was particularly enhanced with the establishment of AP-ECOP and AP-SciCom since 2021/2, as seen in the various events they organised during Annual Meetings and intersessionally, e.g. mentor-mentee programme, science-policy training workshops, and introduction to PICES by AP-ECOP, and the Trilogy workshops on practical science communication skills by AP-SciCom (2022-2024). SmartNet (see previous section) plays a pivotal role in championing the engagement of ECOPs and experts from new partner organisations in PICES core activities, including their EG membership. Thus, the Recommendation items are already being put into practice.

5. Administration

While PICES EGs are proposing creative activities, e.g. the development of new data-sharing protocols (see 1.3), Science community events, ECOP promotions (see 4.), and summer schools, they often struggle with a lack of support/resources from PICES to implement those plans. SB strongly supports the Review Report recommendations that enhance PICES' ability to provide actionable science, such as *"Recommendation 4.3: allowing PICES Governing Council members to delegate nominations to their Science Board representatives to expedite the process and eliminate unnecessary delays*". Additionally, SB agrees on the importance of mobilizing human resources through partnerships with other organizations to strengthen PICES capacity.

On the new Committee structure, SB stresses that, whatever the new structure will be, consideration should be given to an operational level (e.g. on EG reporting protocol) to prevent administrative redundancy which could impede the smooth delivery of actionable science.

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Appendix 4

S-HAB Review Paper Manuscript

Controlling harmful algal blooms (HABs) in marine waters: current status and future prospects

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ABSTRACT

The societal, economic, geographic, and environmental impacts from marine Harmful Algal Blooms (HABs) have increased in many regions around the world. The growing array of impacts is large and varied, threatening human health, marine and freshwater wildlife, and ecosystems upon which many nations rely on for food, recreation, tourism, and a plethora of other goods and services. Although the HAB burden has grown substantially over the past few decades, marine and estuarine HAB control remains one of the least developed areas of HAB science. The disconnect between HAB control needs and solutions stems in part from public, stakeholder, and scientific uncertainties about the balance between benefits and potentially undesirable environmental consequences. Other more practical challenges can include substantial regulation of in situ testing, scaling up laboratory-proven technologies to attack widespread blooms that can move in three dimensions in open marine waters, and an immature commercial market. Here we describe the current status of control strategies targeting marine coastal and estuarine HABs, in particular those few approaches that have been tested on mesocosm to larger scale field applications. We identify the regulatory support, targeted science, investments, and public outreach that will be needed to accelerate the availability of applications for controlling HABs in marine waters worldwide.

1. INTRODUCTION

Harmful Algal Blooms (HABs) are a growing societal problem caused by the proliferation of algae that cause harm in diverse ways. Only a fraction of the many thousands of species of microscopic and macroscopic algae are considered HAB species, and the nature of their impacts vary widely. Many species, such as the dinoflagellate *Alexandrium catenella* and the diatom *Pseudo-nitzschia australis*, produce potent neurotoxins that can be concentrated in fish or shellfish (Anderson et al, 2021; Bates et al., 2018). Exposure to HAB toxins also can occur through inhalation when fragile cells, such as *Karenia brevis* or *Ostreopsis ovata*, release their toxins into marinewaters and sea spray, causing respiratory issues in people (Ciminiello et al., 2014; Lim et al, 2023). Certain species in the diatom genus *Chaetoceros* possess serrated spines that can lodge in fish gill tissues and lead to fish mortalities (Cembella et al., 2023). Other HAB species such as *Margalefidinium polykrikoides*, *Heterosigma akashiwo*, *Chattonella* spp. kill fish through mechanisms that remain unknown. Dense blooms of cyanobacteria and brown algae (e.g., *Aureococcus anophagefferens*) can shade submerged vegetation, impede the feeding of benthic organisms, impede recreational activities, and cause odor and oxygen-depletion problems (Gobler and Sunda, 2012). A variety of freshwater cyanobacteria genera also produce highly potent toxins that are a growing threat in marine waters (Burford et al. 2019).

Over the last 30 years, a rich body of international research yielding important discoveries have enabled advance warning of some HAB threats, and provided knowledge allowing optimized decision-making to help avoid or minimize some HAB impacts. During this period the international freshwater HAB research community has moved forward to generate a number of commercially available methods for controlling HABs (Kibuye et al. 2021; Tullos et al. 2025) and supported the development of a robust freshwater algae control industry. In contrast, there has been far less progress in HAB control solutions for estuarine and marine systems (Anderson, 2023). At the same time, many regions have experienced increasing societal, economic, geographic, and environmental impacts from marine HABs (Hallegraeff et al. 2021) while societies continue to rely on marine and estuarine ecosystem benefits to sustain tourism, protect coastal property, and meet expanding global food demand. Further, mounting HAB-related losses have made aquaculture industry insurers more reluctant to provide coverage (Trainer et al., 2020). As a result there is great pressure to accelerate the development of effective marine and estuarine HAB control.

Bloom control is controversial because of its invasive nature (Anderson 1997; 2023). HAB species are often a minor component of a highly diverse, beneficial planktonic community supporting estuarine and marine ecosystems, and the challenge is how to control or suppress only those problematic species. Achieving an acceptable balance between benefits and perceived negative environmental consequences of control methods is an understandable concern. Adding to this challenge are the logistical hurdles of targeting control treatments within the dynamic hydrographic marine environment of blooms that can span hundreds of kilometers.

Thirty years ago, many in the HAB science community believed that the challenges of control were too large and complex and that better understanding of these blooms and their impacts was needed, as were advances in HAB observing and forecasting capabilities (Anderson 1997). However, there has been a growing demand among many stakeholders for HAB science to produce acceptable, effective, and scalable HAB control approaches that can be transitioned to commercial partners. A staged, precautionary approach that advances only the most promising control strategies, through laboratory, mesocosm, and field studies, is showing that the benefits of control could outweigh potential undesirable ecosystem impacts (HAB RDDTT. 2008). This realization leads to the central questions of this paper:

1. What progress has been made over the last several decades in the field of marine and estuarine HAB control?,
2. What bloom control efforts have been implemented over large scales in natural waters, and how successful (and transferrable and scalable) were those efforts?
3. What can we learn from the countries and regions implementing HAB control that might help advance the field even further?

The focus of this paper is on control strategies targeting marine and estuarine (hereafter, marine) HABs, in particular those approaches that have been tested on larger scales, from mesocosm tanks to direct field applications in marine waters. A mini-review of the state of science for different control methods and case studies is presented to highlight successes and promising approaches. Also included is an overview of some regulatory requirements for HAB control in some regions, including those governing *in situ* testing and deployment, an evaluation of types of HAB events that are more amenable to control, considerations of relevant societal and scientific challenges, and identification of several government funding programs and a novel US public-private accelerator program that advances HAB control. We use this assessment to identify regulatory changes, targeted science, and investments needed to advance the availability of marine HAB bloom control worldwide.

2.0 PREVENTION, CONTROL, AND MITIGATION

Strategies to manage HABs typically fall under the headings of prevention, control, and mitigation (PCM), each having different goals and approaches (Boesch et al. 1997). Prevention strategies reflect a priori environmental management actions that reduce the incidence and extent of HABs. These schemes often are slow to have noticeable effects on bloom frequency and magnitude. For example, nutrient reduction is widely considered the most effective means of preventing some types of HABs, yet even when there is a solid link between anthropogenic nutrient loadings and specific HABs, effective remediation through improved watershed management or discharge policies can take years to decades. Moreover, the majority of marine HABs are not related to cultural eutrophication in many nations (e.g., Anderson et al. 2008). Alternate ecosystem restoration efforts such as re-establishing bivalves, fish, and benthic macrophytes also can have bloom prevention benefits (Park et a. 2013; Imai et al. 2021), as can methods limiting the dispersal of harmful species (e.g. ballast water treatment; Gregg and Hallegraeff 2007).

Mitigation strategies comprise approaches to limit or delay undesirable ecosystem, human health, or economic and social impacts associated with HABs. The most effective mitigation strategies reduce HAB risks through detection, monitoring, forecasting, and event response. An additional benefit of sustained monitoring of cells and toxins, along with oceanographic and ecological parameters, is that it provides data to help understand HAB ecology, how HABs are impacted by climate change and other drivers, and enables development and testing of new management strategies, including bloom control.

Control strategies on the other hand directly kill HAB cells or destroy their toxins, physically remove cells or toxins from aquatic systems, or limit cell growth and proliferation. These strategies are typically short-term with fast response times compared to bloom prevention and mitigation efforts. Control strategies must “thread the needle” to avoid triggering unacceptable collateral damage to other ecosystem elements. Although challenging, HAB control strategies are becoming increasingly important for protecting human and ecosystem health given a growing world population and forecasts that climate and global change may lead to greater prevalence of HABs in the coming years (Hallegraeff 2010; Wells et al. 2015).

3.0 Feasibility of Bloom Control

HAB species are as diverse as the many habitats in which they occur, and HAB events may have minor to severe impacts. Due in part to this complexity, not all HABs are suitable candidates for control. The development, testing and implementation of HAB control strategies depend on four considerations: 1) the value or importance of the impacted resource; 2), the characteristics of the species and its bloom; 3) the feasibility and cost of implementation; and 4), societal support or resistance to action (Figure 1).

The value of the impacted resource can vary dramatically, from small-scale artisanal fisheries to industrial-scale ocean aquaculture (e.g., salmon farms) and water-dependent infrastructure (e.g., power or desalination plants). Some impacts are more difficult to quantify, such the extent to which tourism or recreation industries are affected by blooms, or the extent to which threatened or endangered species or critical habitat are episodically impacted.

Important species and bloom characteristics to consider include hydrographic location and spatial extent, cell densities and vertical swimming behavior, and the nature of the harmful species (fragile, rigid, colonial, solitary) and its life cycle. Yet another consideration is the nature of the impact associated with that bloom (e.g., production of toxins versus large but non-toxic biomass).

The feasibility and costs of implementation depend on the geographic scale of the outbreak, the match between a specific control technology and the susceptibility of the HAB species being targeted, the potential adverse environmental impacts of the treatment, the expense and proximity of resources and infrastructure needed for full implementation, and the extent of regulatory compliance that is needed, which often can be the greatest feasibility challenge.

Societal priorities and public perception of these three factors is a critical aspect. That is, does the combined weight of these elements balance favorably against the perceived environmental consequences of treatment (Kidwell 2015). Public resistance to HAB control tends to stem from a fear of avoiding significant environmental harm, while supporters may prioritize managing the bloom to achieve a desired outcome (e.g. protecting fisheries, tourism, human health). This balance differs greatly among societies and often has determined where HAB control strategies have or have not been implemented. Where concerns over action are high, it is important that these (largely environmental) concerns be balanced against the environmental and socioeconomic costs of no action (hereafter termed the no-treatment alternative).

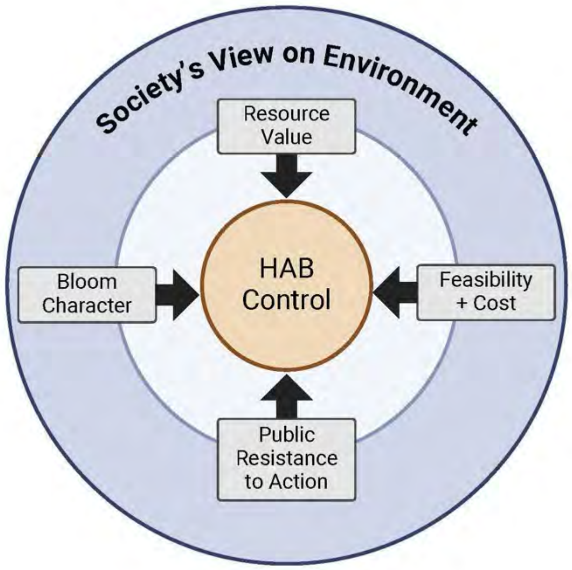

Figure 1. Factors considered when strategizing bloom control methods

4.0 Phases of bloom control research and implementation

There typically are four sequentially executed phases for developing a HAB control method: 1) evaluation of a preliminary product or proof of concept, 2) research and development on the product and application strategy, 3) demonstration and validation, and 4) full scale implementation for routine use (Table 1). These phases are sequential but also iterative. For example, products that have demonstrated efficacy and safety will undergo re-evaluation after technological modifications to enhance efficacy or to optimize deployment strategies. Preliminary products or concepts generally need to meet specific requirements to advance to subsequent phases. These often include cost, environmental impacts, and efficacy against target species, among other factors.

Table 1. Phases of HAB control technology development and implementation

	Phases of HAB Control Science			
	1) Evaluation of New Technology	2) Research and Development	3) Demonstration and Validation	4) Full-scale Implementation
Assessment Criteria	• Efficacy optimization • Specificity • Toxicology • Local biogeochemistry • Toxin release	• Matrix Effects • Efficacy • Environmental Impacts • Environment biogeochemistry • Storage stability • Application timing • Application duration & frequency	• Federal approvals/regulations • State/local permits • Large-scale confined evaluations • Scalability • Cost • Societal Engagement • Application licensing • Criteria for success • Standards of practice • Contingency plans • Commercialization potential	• Operational permit • Application license • Product registration • Local permitting • Formalize standards of practice and periodically update • Operational guidance • Commercialization • Law enactment • Quality control
Special Considerations	• Cost • Scalability • Resource availability (product) • Delivery mechanism • Environmental impacts • Permitting (in situ mesocosms) • Comparison technology	• Regulatory Requirements • Supply chain/resource availability (application strategy) • Direct and indirect impacts to public health • Application licensing • Societal perceptions/impacts	• Ease of use • Transport and storage of large volumes of product • Hazards/safety around obtaining & storing large amounts of product	• Long-term field monitoring of potential side effects • Near real-time HAB alert system to locate bloom area • Personnel and organization for field operation • Training for field operation

4.1 *Evaluation of New Technology*

New or improved technologies or products are tested at the lab scale in this phase (from test tubes to *ex situ* mesocosms), under controlled, isolated conditions so that response variables can be tested independently. Key considerations in this phase are product efficacy against target HAB species (based on variable application rates) and specificity (including species-specific considerations), contact-exposure time, impact on non-target organisms, potential release of intracellular toxins following treatment, the effects of natural water biogeochemistry (e.g., pH, salinity, temperature, dissolved organic carbon and other chemical compounds) on product performance, as well as how the product and process affects these parameters. Experiments are designed to support specific permitting data requirements for successive testing strategies.

4.2 *Research and Development*

Products or technologies showing promise in preliminary evaluations move to the next stage of testing, which occurs in mesocosms or at smaller (< 1 acre) limited duration, confined field scales (sometimes termed pilot studies). These larger scales enable evaluation of more complex matrix effects, weather impacts, community-level non-target impacts, application timing and methods, product storage stability/viability, geographic and habitat differences, and means to increase overall effectiveness. These are all major challenges, and thus large and well-financed team efforts are often required. Limited-use permits are usually necessary prior to these field trials and may include safety protocols to modify or discontinue a trial in the event of unforeseen negative environmental impacts. Limited-use permits are often site-specific and require coordination with local, tribal, provincial, and national authorities.

4.3 *Demonstration and Validation*

In this transition phase the product or technology is tested for longer durations in larger settings. Trial designs are informed by results from the Research and Development phase. Early societal engagement is critical in this phase to build trust with the community and foster an understanding of, need for, acceptance of, and willingness to see HAB control products tested locally. Regulatory evaluation and approval is a centerpiece of this phase, and may require product testing permits or permit exceptions, as well as registration, application permits, or licensing depending on site-specific, local, tribal, national, or international rules and regulations. There is significant variability in regulatory processes between nations and sub-national jurisdictions . The regulatory approval process is often lengthy and can have multiple criteria and timelines for implementation due to this variability. Engagement with all governing bodies is necessary to build support for large scale or longer duration trials.

Assessing scalability and cost effectiveness are particularly important considerations during this phase to best inform on the potential for large-scale applications and broad commercialization. For example, some highly effective strategies may be cost-prohibitive to treat large areas but may be appropriate to protect highly valued resources at smaller scales. Alternatively, cost-effective and highly efficacious strategies for larger blooms may face supply chain issues for raw materials that limit the possible scales for application. Additional considerations relate to the complexity and feasibility of product application, including availability of trained personnel, transport and deployment vehicles (aircraft, watercraft, trucks), protective equipment, spray drift, dispersal equipment, etc.. Logistical considerations include availability of the product(s), long-term storage, transportation to treatment sites, dispersal methodologies, disposal of excess or spent product, etc.. Managing the aerial or aquatic dispersal to maximize HAB exposure while limiting impacts to unaffected areas is a major consideration that may require engaging industry partners or professionals with relevant expertise such as with oil spill dispersant applications. Indeed, some product registrations that may be applicable to control methods require the use of licensed applicators to deploy the product. Lastly, the ease of access to the treatment sites needs to be considered, which may also require permits in restricted areas.

A feasibility study is typically conducted during the transition phase to establish the preliminary metrics for success. These include determining thresholds which include, but are not limited to, upper product limits for sensitive species or bloom phases, criteria to determine minimal effective concentrations, and benchmarks for termination or modification of a trial if adverse environmental impacts are observed. An open line of communication is typically established with the local community, resource managers, and health officials to share metrics of success and potential concerns and to detail what to expect during a trial. Assistance can also be requested from interested parties to help monitor for potential adverse effects.

4.4 *Implementation*

A product can only move to the implementation phase once it has been proven to be effective and has all necessary product registration, regulatory approvals, and operational permitting. At this point products can be transitioned into routine use by governments or the private sector. Here the metrics for success developed during the transition phase should be formalized into standards of practice. Resource managers and product applicators need to follow local and national regulations, standards of practice, and any related reporting requirements. Additional operational guidance may be needed, and should be periodically updated, to support appropriate and safe use of products to reflect technological advances.

5.0 APPROACHES TO BLOOM CONTROL

Bloom control approaches are diverse but can be broadly grouped into biological, chemical and physical methods (Boesch et al., 1997), although some bridge across these boundaries. No single approach is universally applicable and each has unique short-term impacts relative to longer-term benefits. The balance among these must be compared against the consequences of the no-treatment option before implementation recommendations are possible.

We present here a brief review of each category, along with a few unique case studies of successful and promising applications to control marine HABs in several nations. These case studies highlight several approaches but do not represent all current bloom control efforts.

5.1 Biological Bloom Control

Biological control uses organisms, pathogens, viruses, or their excreted products, to kill, inhibit, or remove HAB cells or toxins (see reviews: Anderson et al. 2017; Sellner and Rensel 2018; Anabtawi et al., 2024; Balaji-Prasath et al., 2022; Coyne et al., 2022; Imai et al., 2021; Pal et al., 2020). There can be overlap with some chemical control methods (e.g., use of algicidal compounds isolated from live organisms) but we group these approaches under biological control here.

Biological methods are increasingly recognized as environmentally sustainable options for controlling HABs (reviewed by Gallardo-Rodríguez et al., 2019). These methods can reduce biosafety concerns when native species (or their secreted or extracted compounds) are used. A benefit of biological approaches is that agents may target specific HAB groups or species, thereby reducing collateral effects on non-target organisms. An added advantage is that some bioagents may have the potential to both control HAB species and also degrade released toxins (Coyne et al., 2022). An example is the algicidal bacterium, *Rhizobium* strain AQ_MP, that lyses *Microcystis aeruginosa* and contains functional genes and metabolic pathways involved in the degradation of microcystin toxins in freshwater environments (Li et al., 2021). The benefits of such approaches are likely to increase public and natural resource managers' acceptance of biological control of HABs, which is crucial for the widespread application of these methods.

A common concern surrounding biological control is the potential that it may not target the problem organism but instead affect a broad range of planktonic species. Even if shown to be well focused in early field trials, there is concern that this specificity might shift after prolonged use, or when the background planktonic assemblages change, potentially leading to long-term and significant environmental consequences. Another concern is that environmental factors may affect the efficacy of bioagents. For example, Grasso et al. (2022) reviewed how temperature, nutrients, and irradiance can affect various facets of cyanophage ecology, including burst size, latent period, and infectivity, among others, which in turn impact the success of these viruses in HAB control. Similarly, Coyne et al. (2022) discuss how temperature, grazing pressure, and bacterial densities influence the efficacy of algicidal bacteria in open-water trials.

Yet other issues are scalability and deliverability, as there are significant challenges with producing sufficient organisms or their extracts to make applications economically and logistically feasible even over moderate spatial scales. Most HABs occur sporadically in time and space so applications using live bio-treatment organisms would require a means to maintain a sufficient quantity of healthy organisms to make usage on demand feasible. Extracts may be amenable to extended storage without significant loss of potency, but storage adds more testing steps and cost to the overall development process. Furthermore, most current research on biological control methods has primarily focused on their effects on algal species, with far fewer studies quantifying their impacts on higher trophic levels. It is fair to say that more studies on non-target organisms at multiple trophic levels are required to ensure the biosafety of bioagents for HAB control.

5.1.1 Viruses

Viruses have the potential to be effective agents for controlling HABs in both marine and freshwater systems (reviewed by Grasso et al., 2022; Ibrahim et al., 2022; Pal et al., 2020). Viral treatment relies on species-specific interactions leading to viral lytic or lysogenic life cycles (reviewed by Anabtawi et al., 2024; Grasso et al., 2022). Most studies on viral control of HABs have focused on cyanophages, which specifically target cyanobacteria (e.g., Grasso et al., 2022; e.g., Lin et al., 2020; Rong et al., 2022; Zhang et al., 2020a). Cyanophages display varying levels of host specificity, from infecting a single strain within a species to multiple genera. For example, cyanophage Ma-LMM01 specifically infects a toxic strain of *Microcystis aeruginosa* (Yoshida et al., 2006), while cyanophage A-CP1, isolated by Deng and Hayes (2008), can infect multiple species of *Microcystis*, *Anabaena*, and *Planktothrix*.

Fewer studies have explored the use of viruses to control marine eukaryotic HABs. Notable examples include the viruses HaV (Nagasaki and Yamaguchi, 1997) and HaNIV (Lawrence et al., 2001), which infect the raphidophyte *Heterosigma akashiwo*, and the virus HcRNAV, which lyses the dinoflagellate *Heterocapsa circularisquama* (Mizumoto et al., 2007; Nakayama and Hamaguchi, 2022; Nakayama et al., 2020) - see below. These marine eukaryotic HAB-infecting viruses are highly species-specific. For instance, the virus HaV, isolated from Japan's coastal waters, infects and lyses *H. akashiwo* without affecting other raphidophytes or phytoplankton in other classes tested (Nagasaki and Yamaguchi, 1997). Additionally, two types of HcRNAV (UA and CY) have been described based on their intra-species host specificity and the amino acid sequence of the major capsid protein, highlighting the complexity of the HAB host-virus system (Nakayama et al., 2013).

5.1.2 *Bacteria-Phytoplankton Interactions*

The interaction between phytoplankton and bacteria in aquatic ecosystems is diverse and complex (Fei et al. 2025, Amin et al., 2015; reviewed by Coyne et al., 2022; Durham et al., 2017; Seymour et al., 2017). While some bacteria generate beneficial effects for phytoplankton (e.g., Burgunter-Delamare et al., 2020; Cruz-López and Maske, 2016; Cruz-López et al., 2018; Yarimizu et al., 2018), many exhibit algicidal activity by inhibiting algal growth or lysing algal cells (e.g., Dungca-Santos et al., 2019; Hare et al., 2005; Shi et al., 2023; Zhang et al., 2020b). These algicidal activities occur through two primary modes: direct attachment and attack on algal cells (Coyne et al., 2022; e.g., Imai and Kimura, 2008; Roth et al., 2008; Shi et al., 2023) or, more commonly, the secretion of active compounds causing cell death (e.g., Chen et al., 2022; Pokrzywinski et al., 2012; Shi et al., 2022; Zhang et al., 2020b; Coyne et al., 2022;Wang, 2021). For instance, *Tenacibaculum* sp. GD3 exhibits strong algicidal activity against *Karenia mikimotoi* by direct contact, while utilizing algal metabolites for growth (Shi et al., 2023). Conversely, *Shewanella* sp. IRI-160 (Hare et al., 2005), Y1 (Chen et al., 2022), and Lzh-2 (Li et al., 2014a) secrete algicidal compounds, with IRI-160 and Y1 targeting dinoflagellates and Lzh-2 inhibiting cyanobacteria, highlighting the specificity and complexity of these interactions - see below. Recent research has focused on identifying bacteria that naturally co-occur with a target HAB species and developing strategies for algicidal bacterial application, which include direct dispersal of bacteria or their compounds, immobilized algicidal bacteria for targeted dispersal, multi-functional systems (e.g., co-immobilized algicidal bacteria and microalgae, co-immobilized bacteria with different functions, and bioengineered bacteria with multiple functions). The variability among habitats and the diversity of HAB species means no single approach is suitable for all cases.

5.1.3 *Seagrasses, Macroalgae, and their Bacterial Communities*

Substrates like seagrass beds attract natural algicidal bacteria that kill or inhibit the growth of various HAB species have been found to be abundant in seagrass and macroalgal beds (Imai et al., 2006, 2021; Inaba et al., 2017, 2018, 2020; Onishi et al., 2020; Mehrotra et al., 2021; Mayali and Azam 2004; Meyer et al. 2017). Types of seagrasses and macroalgae reported as sources range across multiple taxonomic groups, including two seagrass species (*Zostera marina* and *Z. japonica*), four green algae (*Ulva* sp., *U. lactuca*, *U. australis*, and *Cladophora ohkuboana*), five red algae (*Gelidium* sp., *Corallina pilulifera*, *G. elegans, Chondrus ocellatus,* and *Gloiopeltis furcata*), and three brown algae (*Saccharina japonica, Sargassum thunbergii,* and *S. dupulicatum*), with the detected bacterial densities ranging between 10^4 and 10^8 CFU (or MPN) g^{-1} wet weight (reviewed by Inaba, 2024). Bloom suppression can be substantial, with growth of *Chattonella antiqua* being terminated when filtered seawater from a *Z. marina* bed is added to surface seawater in laboratory experiments (Inaba et al., 2019).

The taxonomic groups of the antagonistic bacteria isolated from seagrass and macroalgal beds are mostly found to be among two phyla, “Bacteroidetes and Proteobacteria”. Although the specific algicidal mechanism is not known, both of these groups appear to be related to bacteria known for polysaccharide decomposition (Inaba, 2024); the cell surfaces of dinoflagellate and raphidophyte HAB species contain polysaccharides (Yokote and Honjo, 1985; Wang et al., 2020).

In addition to hosting antagonistic bacteria communities, macroalgae also are known to produce allelopathic substances to suppress the growth of HAB species (Tang and Gobler, 2011; Tang et al., 2014; Sylvers and Gobler, 2021). These findings suggest that protection and restoration of macrophyte beds may enhance nearshore coastal resilience against HABs.

5.1.4 *Parasites*

Studies also suggest that parasites can potentially control HABs. Current research primarily focuses on parasitic dinoflagellates, such as *Amoebophrya* spp. (Bai et al., 2007; Long et al., 2021; Velo-Suárez et al., 2013; Park et al., 2004) and *Parvilucifera* spp. (Alacid et al., 2020; Park et al., 2004), which infect other dinoflagellates and contribute to the termination of their blooms. These parasites are less specific than viruses, with some being capable of infecting over 50 species across various genera including the HAB species *Margalefidinium, Alexandrium, Dinophysis, Karlodinium*, and *Akashiwo* (Alacid et al., 2020; Bai et al., 2007; Long et al., 2021; Park et al., 2004; Velo-Suárez et al., 2013). Some dinoflagellates, such as *Alexandrium minutum* or *Scrippsiella donghaiensis*, can secrete defensive metabolites against these parasites, presumably reducing their potential effectiveness (Long et al., 2021).

Additional studies have focused on parasitic fungi as HAB control agents. Parasitic fungi, such as chytrids from the phylum Chytridiomycota, have been documented to infect both marine and freshwater HABs, including cyanobacteria, dinoflagellates, and diatoms (reviewed by Gleason et al., 2015). Chytrids have shown potential in controlling freshwater cyanobacterial blooms (e.g., Gerphagnon et al., 2013; McKindles et al., 2023) and also marine HAB species (Gleason et al., 2015) including *Pseudo-nitzschia* (Hanic et al, 2009). However, their effects on marine HAB species are less studied (Lepelletier et al., 2014). Non-parasitic fungi have been applied for HAB control in freshwater ecosystems. Anabtawi et al. (2024) provide a detailed review of this and other strategies in freshwater environments.

5.1.5 Case Studies of Biological Control of HABs

5.1.5.1 *Heterocapsa circularisquama* virus

Background: Lake Kamo is a saltwater lake on Sado Island, Niigata Prefecture, with a shore length of 17 km, an area of 5 km^2, and a maximum depth of 9.7 m. The Lake was originally a freshwater lake fed by four rivers. Approximately 120 years ago, a channel was excavated to connect it to the open sea to make it a saltwater lake. The channel is small, with a width of 28 m, a length of 200 m, and an average depth of 1.7 m, leading to poor seawater exchange. Operations of cultured oysters in Lake Kamo, Japan suffered the first serious bloom of the marine dinoflagellate *Heterocapsa circularisquama* (Hc) in the fall of 2009, resulting in economic losses estimated at over US $2 million. This dinoflagellate specifically kills bivalves, including cultured Pacific oysters and pearl oysters. To address this problem, a biological control method was developed using the algal virus HcRNAV.

Routine monitoring demonstrated that HcRNAV proliferates during the declining phase of *Hc* blooms, followed by virus accumulation in the sediment (Tomaru et al., 2007; Nakayama and Hamaguchi, 2016). The virus is generally host-specific and has high replication rates, and therefore has limited effects on co-occurring organisms, allowing high viral titers to be used. One significant benefit is that the method uses natural sediment containing HcRNAV, instead of HcRNAV alone, as adding natural sediment to surface waters is more publicly acceptable than the introduction of cultured viruses. Sediments are also abundant and can be easily collected whereas culture facilities to produce pure virus can be expensive and time-consuming.

Implementation: From 2019-2023, this method was implemented three times in Lake Kamo in collaboration with local officials and fishermen, but has not yet been used in other areas where *Hc* occurs. The safety and effectiveness of the sediment containing HcRNAV was first demonstrated under laboratory and field conditions, revealing the amount of sediment required to kill *Hc*, the environmental impact of sediment spraying, and the effects of the HcRNAV in the sediment on other aquatic organisms (Nakayama et al. 2020). These data were required for the approval and cooperation of fishermen and the city, local, and prefectural governments. From the start of this research in 2011, it took almost 8 years to receive permission for the practical use of sediment-containing virus as a HAB control method in 2019, as detailed below.

Application Evaluation: The long process began with a small-scale microcosm experiment (closed bottle test) conducted in 2011 to verify the effect of virus-containing sediment on a natural *Hc* population. When *Hc* increased to about 8,000 cells/ml in Lake Kamo, bottles were filled with bloom water. Then, virus-containing sediment (frozen in 2009, then thawed before use) was added to the treatment bottles and autoclaved sediment was added to the control bottles. The effect of the added sediment was assessed after 5 days of exposure. In order to incubate the bottles in as natural a state as possible, they were immersed in the lake at a depth 50 cm from the surface (Nakayama et al.2013).

Field demonstrations were essential to move this biological method to larger-scale use, but such experiments had never been conducted in Japan. The regulatory and social permissions for a mesocosm field trial took 5 years after the first successful bottle test (Table 2). Permission was needed from the Fisheries Agency (under the Ministry of Agriculture, Forestry and Fisheries of Japan), the Niigata Prefectural government, the Niigata city office, the fishing association, and fishermen. Among these, the Prefectural government permission was most critical. Long consultations with local fishermen led them to eventually request approval of the trials. As a result, the prefectural government recognized the potential effectiveness and environmental acceptability of this method and responded positively to their request. This decision, a first for Japan, led to the de facto approval by the Fisheries Agency and Sado City Hall, which enabled the 2016 field trials to begin in Lake Kamo (to be followed later by a larger-scale practical application in 2019).

Table 2. Timeline for approval of virus use as a method of HAB control

	Steps to implementation of virus for HAB control
2009	*H. circularisquama* bloom outbreak
	Various benefits of the virus control were studied in the lab.
2011	Closed bottle test in Lake Kamo
	Negotiate field test permits with the Niigata prefectural government and local authorities.
2014	Niigata prefectural government allowed the test to be conducted onsite.
2016	An open field trial was conducted in Lake Kamo
	Negotiate practical application permits with the prefectural government
2019	Practical application on site, the prefectural government gave the permit.
	The method was implemented in the field.

Two floating cage mesocosm experiments were used for the field trials. The mesocosms were fabricated with canvas sheets used for aquaculture and each was filled with 15,000 L of ambient Lake water containing ca. 3,800 cells/mL of Hc. Control and treatment sediments were added to the respective mesocosms as for the earlier bottle experiments. There was a 99% decrease in Hc cell density in the treatment relative to the control mesocosm (from ca. 3,000 to ca. 40 cells/mL) within five days (Nakayama et al. 2020).

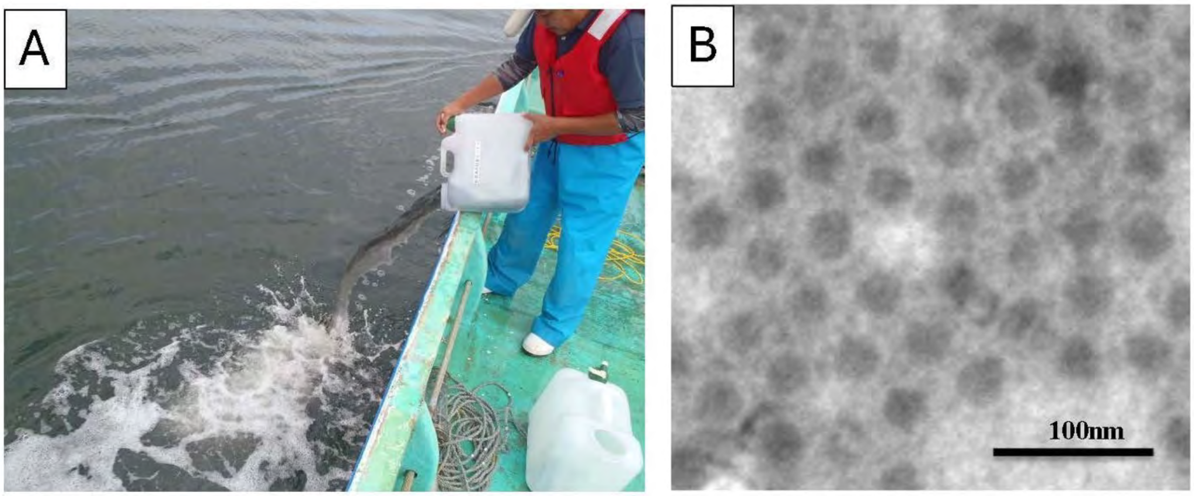

Figure 2. (a) Spreading sediment containing HcRNAV and (b) negative staining image of HcRNAV by transmission electron microscopy.

Large-scale treatment: The field treatment in Lake Kamo in 2019 was preceded by collection of sediment containing HcRNAV from the Lake in 2018, after the termination of a Hc bloom. In July 2019, a Hc bloom was detected in its early stages (760 cells/ml). The prefectural government immediately approved the application of sediment. First, in a small container, the bloom water and the sediment containing HcRNAV were mixed and incubated for 3-4 hours to increase HcRNAV before spraying. Because this approach effectively creates water that is highly enriched with HcRNAV, only a very small amount of sediment was needed to treat the entire lake. Specifically, ~ 5 kg of bottom sediment was used in this way, with the resulting enriched water used to treat 5 km2 (Fig. 2). The spraying was carried out every month from July to September in 2019, effectively limiting Hc cell proliferation to low densities. It was decided that additional treatments would be done if a Hc outbreaks returned, however, Hc blooms declined to low densities after the application in 2020, and treatment has not been necessary since 2021. In recent years, however, Hc blooms have also been occurring at other locations, so local governments are preparing to spread sediment containing HcRNAV in these areas. The success of the treatment at Lake Kamo has led to an acceptance of this method in Japan.

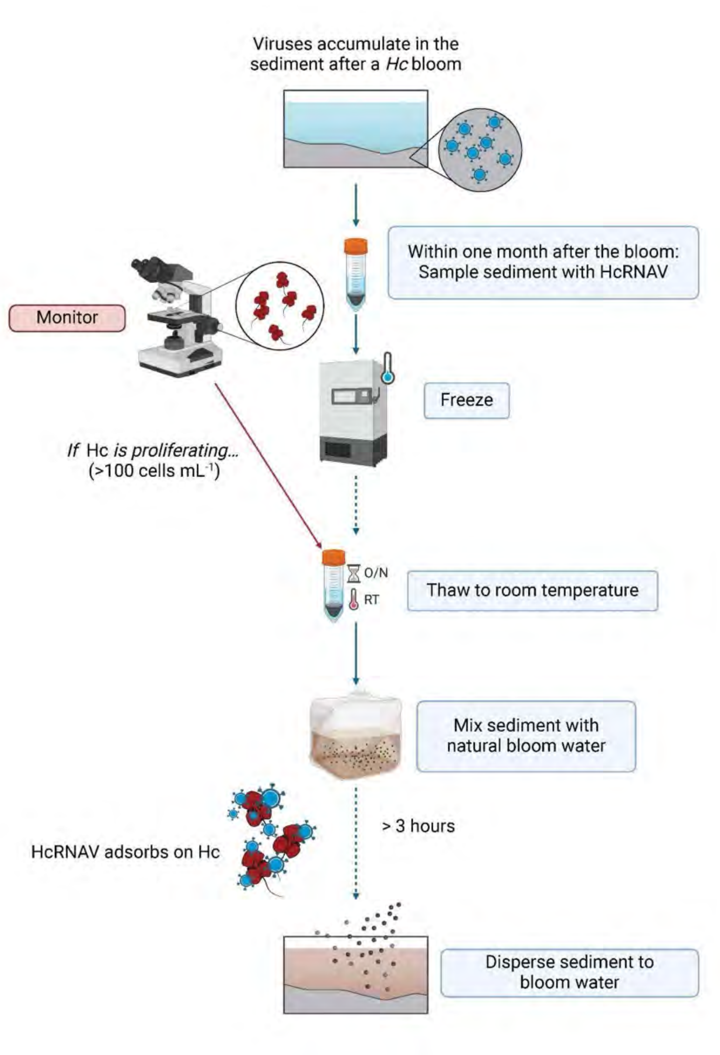

Figure 3. Method for concentrating H. circularisquama RNA virus (HcRNAV) from sediment and dispersing it into the natural environment to control blooms.

Environmental Impacts: Two steps were taken to minimize the potential environmental impacts of spreading sediments containing HcRNAV on marine life such as shellfish and plankton. The first was to minimize the impact of sediment dispersal on added nutrients and turbidity by using a two-stage process. Small amounts of sediment containing HcRNAV were incubated with seawater containing Hc in a ~50 L tank to increase viral abundance, after which the solution was sprayed onsite (Nakayama et al. 2020). This method reduced the amount of sediment to be spread while enriching the abundance of HcRNAV in the application. A 2016 field demonstration revealed the effectiveness of this two-stage application (Nakayama et al. 2020). Second, the sediment was frozen to ensure that the cysts of harmful or toxic species were non-viable, which was confirmed by testing (unpublished data). Furthermore, the sediment was tested against bivalves and the findings show that sediment dispersal did not affect their survival (N Nakayama, unpubl. data). The combination of these steps confirmed that the spreading of sediments containing HcRNAV would have negligible effects on the environment and other aquatic organisms.

Successes and challenges: The public generally views the word “virus” as a synonym for a pathogen, so it is difficult to obtain social approval for the practice of spraying viruses in the natural environment. Of benefit here was the planned use of natural materials from the local sediments (i.e., not introduced from other regions). Regular project outreach was conducted at a variety of biannual meetings with local officials, including workshops that explained efforts to improve the local marine environment in addition to the control for Hc blooms. In parallel, outreach was conducted at biannual local community meetings to explain this method and to present research results. The current challenge is to replicate the treatment success demonstrated in Lake Kamo at other coastal locations in Japan that are impacted by Hc blooms.

Regulatory issues: The Japanese government had no official regulations concerning the spreading of organisms in the environment but was nevertheless reluctant to permit these unprecedented activities. In Niigata Prefecture, where Lake Kamo is located, fishermen and the local community gradually came to understand this method and sought approval from the local government, which eventually led to prefectural approval. The local prefectural government granted a permit to conduct a mesocosm test four years after communications began, and a total of nine years was needed to receive a permit for application of the virus-containing sediment in the Lake.

Social Issues: Researchers were proactive in explaining to fishermen and local communities how HABs were contributing to poor oyster growth in Lake Kamo. This active effort helped to develop a relationship of trust between the researchers and local communities. In Japan, even if the vast majority of the people agree, no major change will occur unless a local leader or government official approves. For example, permits were requested from another prefectural government for a different region but approval has yet to be granted due to the negative social perceptions about spreading viruses. If a Hc bloom occurs in a different area, it will be easier to obtain permission from the local government if sediment (containing HcRNAV) from that specific area is used for bloom treatment. Therefore, promotional activities will be conducted in each area where treatment is needed, and the manual describing the detailed technique will be shared.

Scalability and breadth of applicability: Given the small amount of sediment (5 kg) needed to treat a 5 km2 lake, this bloom control method is well suited for treatment of large areas when necessary. Treatment of a 100 km2 area might only require 100 kg of sediment, which would be quite easy and inexpensive to disperse. In terms of the applicability of the method to other HAB species, viruses coinciding with blooms of Karenia mikimotoi and Heterosigma akashiwo have been isolated but have not yet shown effectiveness in controlling them. The characteristics of these viruses and their relationships to their hosts are currently being investigated.

Application issues: Viruses accumulate at the sediment surface so manpower, special equipment, and a vessel are needed to collect sediments prior to freezing and HAB treatment. A manual is currently being prepared, describing the series of operations, including collection of sediment containing HcRNAV, sediment preservation, and sediment spreading. This will be published on the Japan Fisheries Research and Education Agency website and local officials will be trained to implement this method using the manual as a guide.

5.1.5.2 Shewanella

Background: Shewanella sp. IRI-160 is an algicidal bacterium isolated from the Delaware Inland Bays, USA with algicidal activity that has high specificity for dinoflagellates (Hare et al., 2005). This bacterium secretes water-soluble bioactive compounds (referred to as IRI-160AA) and does not require direct attachment for effect (Pokrzywinski et al. 2012). Toxicological studies demonstrated there were no negative effects of this algicide on non-target organisms, including non-dinoflagellate phytoplankton, zooplankton, invertebrates, or juvenile finfish tested at levels required for dinoflagellate control (Pokrzywinski et al., 2012; Simons et al., 2021; Tilney et al., 2014a). Over two decades of study has been conducted to understand the mode of action of this product on model dinoflagellate species. The algicide directly impacts photobiology by damaging chloroplasts and causing their displacement within the cells, (Tilney et al., 2014b; Pokrzywinski et al., 2017a; Grasso 2018), destabilizes/unravels chromosomes and damages/translocates nuclei resulting in cell cycle arrest (Pokrzywinski et al., 2017a; Pokrzywinski et al., 2017b), and stress responses and related programmed pathways resulting in cell death (Pokrzywinski et al., 2017b). Confirmation of these processes at the molecular level has been obtained through transcriptomic (Wang, 2021; Wang and Coyne, 2023) and metabolomic studies (Wang, 2021; Wang and Coyne, 2022). Recent work has focused on elucidating the active compounds in IRI-160AA, which include ammonium and amines (e.g. putrescine), that work synergistically against dinoflagellates resulting in reduced growth or mortality (Johnson, 2023; Ternon et al., 2018; Wang, 2021; Wang and Coyne, 2024).

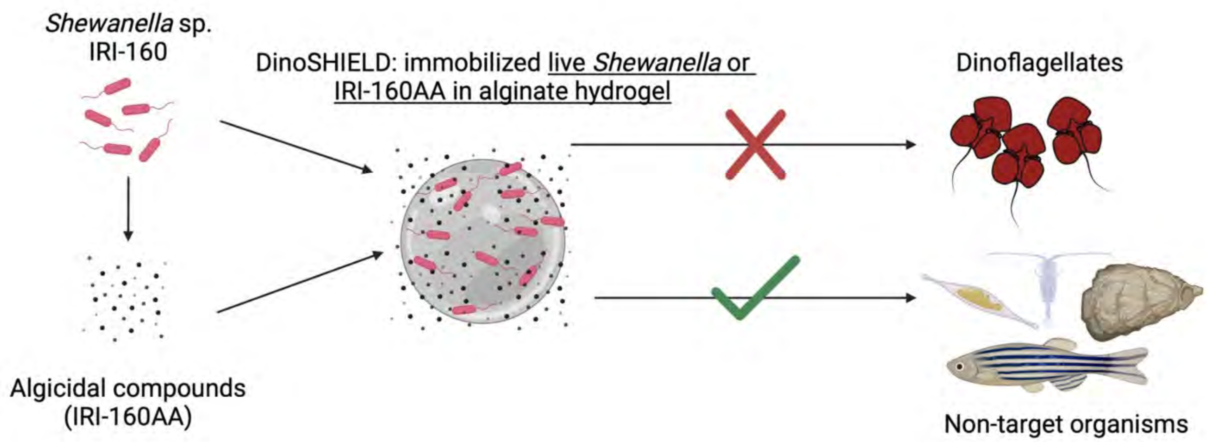

Figure 4. DinoSHIELD is a biocontrol technology that embeds either the algicidal bacterium Shewanella sp. IRI-160 or its secreted algicidal compounds (collectively referred to as IRI-160AA) in alginate hydrogel. This formulation specifically targets dinoflagellates (red X) without causing negative effects on non-target organisms in the water column (green check mark).

Implementation: Field trials of Shewanella sp. IRI-160 are in the preliminary stages at this time and are awaiting the necessary regulatory approval.

Application Evaluation: While effective, the direct dispersal of large quantities of bacteria or their algicidal compounds may cause biosafety concerns (Coyne et al., 2022). To address this issue, alternative approaches were explored to limit the need for high-dose and frequent re-applications by concentrating and immobilizing algicidal bacteria or their algicides for controlled release. Algicidal bacteria have been demonstrated to be effective at controlling algal growth after immobilization in porous matrices (Coyne et al., 2022). Therefore, current work on Shewanella application is investigating novel deployment methods (including using alginate hydrogels), for both the Shewanella bacteria and their algicidal compounds in field applications. Several demonstrated high retention of Shewanella sp. IRI-160, including alginate hydrogel (Wang and Coyne 2020). Alginate is a natural polymer produced by bacteria and brown algae, and is non-toxic, highly biodegradable, and low-cost (reviewed by Lapointe and Barbeau, 2020), characteristics that make it a good carrier matrix for applications of Shewanella sp. IRI-160 or its algicidal compounds (Wang and Coyne 2020; Wang et al. in prep). Collectively, alginate beads prepared with Shewanella or IRI-160AA are termed DinoSHIELD (Fig. 3). The advantages of using DinoSHIELD are two-fold. First, immobilized algicidal bacteria or their active compounds provide continuous and slow-release in situ control of dinoflagellates without the need for frequent, high-dose reapplication. Second, DinoSHIELDs may be strategically deployed in areas that are experiencing, or at risk for, HABs, and then removed when no longer needed.

Large-scale treatment: DinoSHIELD is currently in the Demonstration and Validation phase phase (see Section 4.3) where researchers are working to optimize DinoSHIELD efficacy, stability, and scalability in preparation for larger-scale field demonstrations. The goal of this work is to demonstrate that DinoSHIELD can be used to control blooms caused by the toxic dinoflagellate Karenia brevis along the U.S. Gulf coast. Before moving into field trials, to ensure the safety of DinoSHIELDs in natural environments, a study was conducted at the Mouth of the Broadkill River, Lewes, DE, USA, treating over 2900 L of site water (Wang et al. in review) (Fig. 5). This study assessed DinoSHIELDs embedded with live Shewanella under non-bloom conditions, showing negligible effects on non-target microbial communities. A series of field demonstrations are now planned along the U.S. Gulf coast of Florida that will use both turbidity and bubble curtains to confine the trial in the native environment. The goal of the field studies is to optimize the delivery of the algicide from DinoSHIELDs containing either the immobilized Shewanella sp. IRI-160 or cell-free algicidal product and demonstrate the utility of this technology for continuous red-tide management in Florida and other states that experience blooms of Karenia brevis.

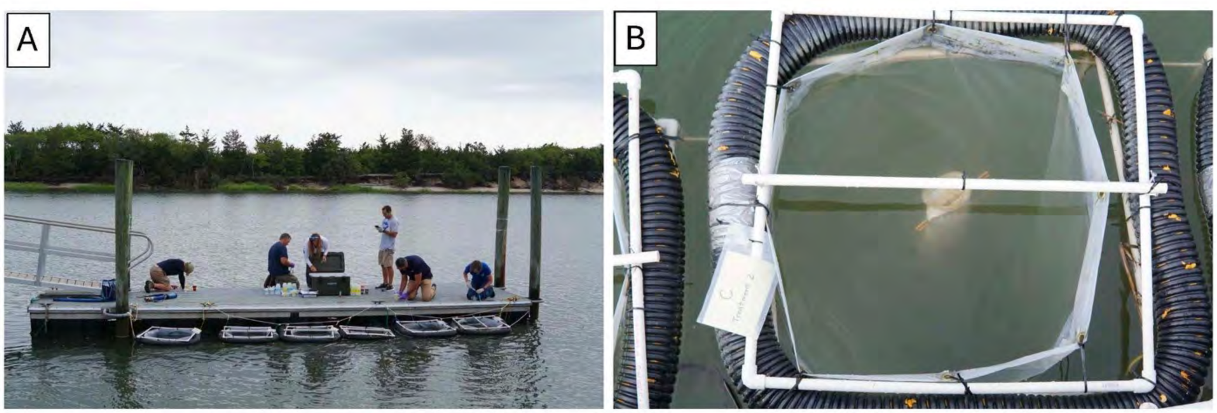

Figure 5. Dinoshield in action in the field. A. In situ mesocosm study in Delaware, USA showing deployed DinoSHIELDs in B. suspended bags conducted under non-blooming conditions to assess potential impacts to non-target species in the microbial community (see Wang et al. in review).

Successes and Challenges: The in-situ mesocosm findings (Wang et al. in prep) indicated that DinoSHIELD minimally affected water quality parameters such as pH, salinity, and dissolved oxygen at levels effective against Karenia brevis in lab settings. Shewanella release from DinoSHIELDs was limited, and the overall bacterial density did not increase in the treated mesocosms. DinoSHIELDs did not affect the overall photosynthetic productivity of the algal community but did increase community species richness. These findings support the potential of DinoSHIELDs as an environmentally neutral method for managing dinoflagellate blooms.

There remain two primary challenges for implementation of DinoSHIELD products for HAB control. The first are the complex regulatory issues for obtaining permits for full field testing, for which societal acceptance is vital. The second relates to scalability issues for both producing sufficient product on relevant time scales and application of these products at temporal and spatial scales that enable effective bloom control.

Regulatory issues: The permitting process for DinoSHIELD, including the initial field tests, has been particularly challenging because it involves federal, state and county regulations which vary considerably. Two examples highlight the diversity of permitting needs. In Delaware, where the initial mesocosm trials were conducted, the regulatory process is relatively straightforward. A single permit from the Delaware Department of Natural Resources and Environmental Control (DNREC) (https://dnrec.delaware.gov/) is sufficient for applying DinoSHIELD in all natural waters of Delaware for several years. This permit, categorized under the aquatic pesticide section of the National Pollutant Discharge Elimination System (NPDES), allows the discharge of biological and chemical pesticides for algae control. However, although it permits the use of live Shewanella IRI-160 in DinoSHIELD because the organism is native to Delaware waters, it does not allow use of dissolved agents isolated from Shewanella (IRI-160AA).

In contrast, Florida's regulatory requirements for DinoSHIELD application vary based on site location, often requiring state and county-level permitting. Here, there is also a need to consider permits for potential navigational hazards because DinoSHIELD is deployed in mesh bags throughout the water column. The team is currently collaborating with local partners in Florida to navigate the diverse regulatory landscape to expedite the permit acquisition process for forthcoming field demonstrations along the southwest Florida coast.

Social issues: A notable challenge with any biological control method is managing public perception and societal acceptance. A major component of the DinoSHIELD development process is to inform and engage representative stakeholders on the use of DinoSHIELD, as well as assess the risks and benefits of this technology. Several strategies are being used to communicate research findings and garner support and feedback early and often. These include technical bulletins, informational videos, surveys, and technical workshops involving critical stakeholders, including state, regional, and local water resource managers, representatives from the aquaculture community, technical experts, and the general public. This also provides an opportunity for the community to give feedback on the technology and request further information or to voice lingering concerns that they may have before implementation.

After years of engaging with stakeholders to explain DinoSHIELD, there has been a growing acceptance of biological control methods. This shift is particularly evident when stakeholders are informed about the native characteristics of the bacterium and their safety to non-target organisms. Garnering this stakeholder and public support will be critical components to successfully transitioning this control strategy to implantation and routine use.

Scalability and breadth of applicability: Scalability poses a significant challenge for DinoSHIELD. Expanding field applications of DinoSHIELD will require an effective supply chain for the substantial amounts of reagents necessary for both hydrogel fabrication and bacterial culturing. This scale-up also demands a considerable workforce and extended time frames for production. To improve the scalability of DinoSHIELD products, the research team is optimizing bacterial growth and algicide production, aiming to identify cost-effective production protocols. The team also is working to maximize algicide delivery rates by testing different concentrations of bacteria or extracted algicide to reduce the hydrogel quantities needed to achieve effective application rates. Additionally, the team is determining the stability of DinoSHIELD under various storage and transportation conditions to establish thresholds for production lead times and product shelf life.

Several related challenges have been identified including efficient management of funds for sufficient reagent purchase (especially challenging for the US Federal Government), creating reliable supply chains, and maintaining large quantities of bacteria or algicide while ensuring matrix stability of the DinoSHIELD products. Current thinking is that this control method is most applicable to HABs in relatively small systems like canals or embayments. Large-scale treatments in the more dynamic open marine environment would currently be challenging for this methodology.

5.2 Chemical Bloom Control

Chemical bloom control refers to methods that rely on the release of dissolved organic or inorganic algicides that kill, inhibit, or remove algal species or their toxins. In many cases the distinction from other control methods is clear—a direct impact of a substance on cell metabolism—while in other instances, the relationship is more complex. For example, dissolved chemical materials that induce cell flocculation (e.g., clays, polymers) still rely on physical processes for flocs of cells to develop and sink. Similarly, ozone nanobubble treatments, like hydrogen peroxide, can cause stress to cells through direct oxidative effects, but there is also evidence that ozone nanobubble treatments can alter organic matter characteristics and nutrient form which may result in changes to phytoplankton community composition. Generally speaking, chemical control strategies tend to have rapid response times, less specificity for target organisms, and a range of environmental impacts that are unique to each approach.

Few chemical control methods have progressed to implementation and evaluation stages in recent times. Perhaps the best example of chemical control for HABs is the use of copper sulfate and other algicides to regulate phytoplankton blooms in reservoirs and other freshwaters, but there are few examples in marine waters. Freshwater applications began in the early 1900's and remains a common treatment option today where permitted. While it is shown to be highly effective at eliminating HABs (and other phytoplankton), copper can sometimes generate other environmental issues; e.g., community shifts and decreased biodiversity, increased nutrient stress, deoxygenation, and impacts at higher trophic levels (Watson, 2024). Far fewer data are available on the application of copper-containing algicides to treat marine HABs, in large part because of greater attention to environmental constraints than for many freshwater systems.

On a more general level, in the USA, new chemical algicides have strict review, manufacturing, and labeling requirements under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) that set maximum application rates and identify use restrictions. The review process is long and costly for manufacturers and has limited the availability of new products, but has protected the environment from unintended negative effects from new and untested chemicals. A new "pesticide" (the term in the US that describes any chemicals used to control HABs) cannot be used or marketed for algae control on waters of the US without being registered (licensed) by the US Environmental Protection Agency (EPA). Before EPA can register a pesticide under FIFRA, the applicant must show it will not cause unreasonable adverse effects on the environment. This means there cannot be: 1) any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of its use; or 2) a human dietary risk from residues that result from a use of a pesticide in or on any food.

The US Federal Food, Drug and Cosmetic Act (FFDCA) authorizes EPA to set tolerances, or maximum residue limits, for pesticide residues on foods. In setting tolerances, EPA must make a finding that the tolerance is "safe," defined as meaning that there is a "reasonable certainty that no harm will result from aggregate exposure to the pesticide residue." To make the safety finding, EPA considers: 1) the toxicity of the pesticide and its break-down products; and 2) aggregate exposure to the pesticide in foods and from other sources of exposure. Since HAB control treatments will be tested or eventually implemented in marine waters that contain fish, shellfish, and other animals that are considered food, FFDCA represents another set of regulatory constraints or hurdles to developing a chemical HAB control strategy. Not only must developers demonstrate that their product does not negatively impact benthic animals, for example, but they must also show that there are no dangerous residuals from their product in fish or other potential human foods living at the treatment site.

In practical terms, the foregoing means that those developing HAB control methods for US marine systems that are based on chemicals, or chemically modified substrates (see below) need to carefully consider the regulatory pathway for testing approval and eventual product registration under FIFRA and FFDCA. A result is that some choose chemical constituents from the "exempted" minimum risk pesticide lists rather than trying to isolate and evaluate novel and potentially more effective compounds.

The European Union also regulates the application of chemicals in natural waters, and approval must follow the procedure outlined in the Biocidal Products Regulation (EU) No 528/2012 (Regulation E.U. (2012)). In this regulation, algicides are classified as biocidal products, specifically under Product-type 2 (PT2). To gain approval, the active substance must first be evaluated and approved at the EU level by the European Chemicals Agency (ECHA), based on evidence of efficacy and safety for human health and the environment. Once the active substance is approved, the algicide product itself must be authorized—either through a national authorization in a single member state or a Union authorization for EU-wide use. Products intended for use in aquatic environments must undergo a detailed environmental risk assessment, particularly to evaluate impacts on water quality and non-target organisms.

5.2.1 Case Study - Chemical Control using Hydrogen Peroxide

Background: Hydrogen peroxide (H2O2) is a naturally occurring reactive oxygen species (ROS) known to induce oxidative stress in cells, leading to physical damage and a reduction in photosynthetic yield (Mittler, 2002). A key advantage of H2O2 over many other chemicals is its rapid breakdown into water and oxygen within hours to days, depending on aquatic conditions, form and formulation of the product.

Cyanobacteria exhibit higher sensitivity to H2O2 compared to most other organisms (Weenink et al. 2021; Matthijs et al. 2012), making them a primary focus of past research on this mitigation strategy. Laboratory studies have demonstrated the efficacy of low concentrations of H2O2 against cyanobacteria (Barroin and Feuillade, 1986; Drábková et al., 2007a,b; Barrington and Ghadouani, 2008). Initially tested in laboratories and mesocosms, H2O2 was later applied to entire (small) lakes with cyanobacterial blooms (Matthijs et al., 2012; Barrington et al., 2013; Huang and Zimba, 2020; Weenink et al., 2021; Lusty and Gobler, 2023; Piel et al., 2021, 2024). The selective toxicity of H2O2 at low concentrations (approximately 2 mg/L) makes it an effective method for targeting cyanobacteria while sparing most other organisms (Weenink et al., 2022). Different formulations of granular and liquid H2O2-based algaecides are commonly used in the USA to control cyanoHABs in freshwater systems (e.g., Kinley-Baird et al. 2021, Pokrzywinski et al. 2022; Lefler et al. 2022,2024), with recent studies looking at their effectiveness in marine species (e.g., Hu et al. 2022) and/or modifications in H2O2 based algaecide labels.

Controlling the activity of harmful eukaryotic algae such as dinoflagellates requires higher concentrations of H_2O_2 due to both instability of peroxides in marine waters (Hu et al. 2022) and lower sensitivity of eukaryotic algae. Effective concentrations thus have the potential to harm other algae and zooplankton. Despite this drawback, H_2O_2 can be an optimal choice for treating isolated HABs in confined areas. H2O2 has been investigated for treating dinoflagellates in the ballast water of ships (Ichikawa et al., 1992; Bolch and Hallegraeff, 1993; Gregg et al., 2009). Its effectiveness has also been tested on the brown tide HAB species Aureococcus anophagefferens (Randhawa et al., 2012) and red tide HAB species Karenia brevis (Hu et al. 2022). The effective dosage of H_2O_2 varies significantly among different species. For example, A. anophagefferens is highly sensitive to H_2O_2, and a bloom of this species could be eradicated by a final concentration of 1-2 mg/L of H2O2 (Randhawa et al., 2012). Hu et al. (2022) found that concentrations between 4.89-7.08 mg/L of H2O2 killed Karenia brevis in 24 h. In contrast, Ichikawa et al. (1992) found that concentrations up to 30 mg/L were needed to render the cysts of Alexandrium catenella non-viable. Cysts of Gymnodinium catenatum from ballast water were highly insensitive and required concentrations up to 5000 mg/L to eliminate them (Bolch and Hallegraeff, 1993).

Implementation: A notable example of using H2O2 to mitigate harmful dinoflagellates in the field is the treatment of an Alexandrium bloom in the Netherlands (Burson et al., 2014). A very dense bloom of Alexandrium ostenfeldii, exceeding 1 million cells/L, occurred in the brackish Ouwerkerkse Kreek in The Netherlands. The bloom produced both saxitoxins and spirolides, and was implicated in the death of a dog with high saxitoxin stomach content. Since the Ouwerkerkse Kreek regularly discharges its water into the nearby Oosterschelde estuary, prompt action was necessary to avoid contaminating extensive shellfish beds there. Treating the water with a concentration of 50 mg/L of H2O2 effectively eradicated the bloom, marking the first successful field application of H2O2 to eliminate a dinoflagellate bloom.

Application Evaluation: The treatment to eradicate Alexandrium in the Ouwerkerkse Kreek followed a three-step approach. First, the required H2O2 dosage was determined through laboratory experiments with A. ostenfeldii. A concentration of 50 mg/L H2O2 was needed to effectively kill the dinoflagellates. Second, the method was then tested in a small, isolated canal adjacent to the Ouwerkerkse Kreek to evaluate its effectiveness in a controlled, natural environment. Finally, after being successful in the canal, the treatment was scaled up to the entire creek system with a surface area of 0.12 km2, an average depth of 5 m, and a maximum depth of 8 m. The creek was partitioned into a southern section of 317,000 m3 and a northern section of 107,000 m3 through construction of a temporary sand-filled dam along the bridge which crosses the creek. Another temporary sand-filled dam isolated the creek from the agricultural canals and ditches at the northern end. A 15,000 L tank with a 50% (v/v) H2O2 concentration was placed on a raft in the water. The H2O2 was prediluted with water from the creek in an intermediary tank to arrive at a 1% (v/v) H2O2 concentration which was injected in the water using a specially designed injection system called a ‘‘water harrow’’ (Matthijs et al., 2012). The target concentration of 50 mg/L H2O2 was achieved after 8 hours of injection in the entire creek. Following this, the H2O2 injection was halted, and the concentration gradually declined to natural background levels within 50 hours.

The photosynthetic yield of the Alexandrium ostenfeldii population in the creek decreased to less than 5% of its initial value within 8 hours after the H2O2 treatment (Burson et al. 2014). This decline was similar to the response in the laboratory and canal tests. The number of A. ostenfeldii cells and cysts declined from about 1.1 million cells L-1 before the treatment to less than 2000 cells L-1 (> 99.8% removal) after 48 h, while green algae and euglenophytes became dominant. Concentrations of 13-desmethyl spirolide C and saxitoxin were reduced below local regulatory levels of 15 mg L-1 after 96 h. The numbers of zooplankton decreased from over 40,000 individuals L-1 at the start to less than 15 individuals L-1 after 50 h. The zooplankton community consisted mainly of rotifers and copepod nauplii.

Large Scale Treatment: There have been no steps to date to expand hydrogen peroxide treatments to larger scales for bloom control.

Successes and Challenges: The results indicate that H2O2 treatment is an effective emergency management option for mitigating toxic Alexandrium blooms, particularly when immediate action is necessary. To date, there has been no reported follow-up or adoption of this method in other countries for Alexandrium, though some H2O2-based algaecides are now labeled for use in marine waters in the US. In the Netherlands, while it remains a viable option for future use, high-density blooms requiring such intervention have not reoccurred since 2012.

While H_2O_2 can effectively control toxic dinoflagellate species, its broader ecological effects raise concerns about unintended lethality towards non-toxic dinoflagellates (Mardones et al., 2023). One major risk is the potential for oxidative stress-induced lipid peroxidation in microalgal blooms, which can trigger the formation of aldehydes that may further exacerbate toxicity, such as in mortalities of farmed fish (Dorantes-Aranda et al., 2015). The ecological implications of reactive oxygen species (ROS)-mediated toxicity remain insufficiently understood, highlighting the need for further research to elucidate the underlying mechanisms. Given these uncertainties, the application of H_2O_2 for HAB control should be approached with caution near farmed fish. To mitigate potential risks, environmental impact assessments (i.e., real-time in situ cytotoxicity assays) should be conducted before large-scale application, considering species-specific responses and possible secondary toxic effects.

Regulatory issues. In the Netherlands, adding H2O2 to natural systems requires a license of the Dutch Board for the Authorisation of Plant Protection Products and Biocides (Ctgb). The urgency for treatment was high due to a threat to human health at a nearby campsite, the death of a dog, and the risk of contaminating mussel beds in the Oosterschelde estuary if the brackish water containing toxic dinoflagellates was discharged from Ouwerkerkse Kreek. Due to this emergency situation, the license for H2O2 application was expedited.

Social Issues: The public was informed about the background findings and plans for treatment with H2O2 through local community meetings, and the community was supportive of the planned bloom control under the extreme circumstances caused by this bloom.

5.2.2 Case Study - Chemical Control using Copper

Background. Blooms of the red tide organism Karenia brevis can readily cause massive kills of fish and other marine organisms as well as producing aerosols in the surf environment that impact humans (Landsberg et al, 2009; Pierce and Henry, 2008). Based largely on HAB control successes using copper compounds in freshwater systems, early work in the 1950’s and 1960’s examined the use of copper and other chemical algicides for use in marine systems. Two lab studies were conducted in the early 1960’s to find chemicals that could kill or inhibit Karenia brevis with low-level doses. More than 4306 compounds were screened (Marvin and Proctor, 1964a) with the goal to achieve 100% lethality after 24 h at doses between 0.01 and 1.0 ppm. Marvin and Proctor (1964b) found only 5 compounds that could achieve these goals, and of these copper sulfate was determined to be the most promising, similar to the experience in freshwater systems.

Application Evaluation: More recently, the efficacy of three copper-based, US EPA-registered algicides were tested for potential use as emergency HAB treatments for Karenia brevis control: copper citrate and copper gluconate, copper ethanolamine complex, and copper sulfate pentahydrate (Hu et al., 2022). The authors found that their lowest tested concentration, ~0.3 mg Cu/L, killed K. brevis within 24 h but did not test its effects on non-target species. More work is needed on the broader ecological treatment effects, the longer-term fate and persistence of the copper substrates, and the effects of site characteristics (particularly water chemistry) on the efficacy of copper-based HAB control.

Large Scale Treatment: There have been no recent studies using large scale treatments of copper-based algicides in marine waters. However, two large-scale field trials conducted in the 1950's tested the efficacy of copper sulfate for HAB bloom control, the first along the west Florida coast (Rounsefell and Evans, 1958) and the second in a man-made lagoon near Galveston, TX USA (Marvin et al. 1961). The first field trial in 1957 used $CuSO_4$ pentahydrate ($5H_2O$) to mitigate an outbreak of K. brevis on the west coast of Florida in open waters 4.5 km offshore and ~50 km alongshore near St. Petersburg (Rounsefell and Evans, 1958). The treated area covered ~40 km2. The initial bloom density was ~10 million cells L1 at the start of treatment. Using an estimated copper concentration of 0.18 mg/L, a total of 95 metric tons of $CuSO_4$ was dispersed in the bloom by dragging burlap sacks containing $CuSO_4$ behind ships, and over broader areas, using crop-dusting aircraft. Karenia brevis concentrations became undetectable in most areas immediately following the treatments and reports of respiratory irritations decreased, signifying the rapid success of the treatment. In contrast, a similar copper treatment did not kill K. brevis the Galveston Bay, TX study, despite adding copper twice (Marvin et al. 1961). The difference in response was likely attributable to the large amount of suspended matter and organic chelators (e.g., humic matter) in the shallow bay water, which would have reduced concentrations of copper in its freely available state (Sengco 2009). Therefore, the use of copper was not recommended as a viable control mechanism for K. brevis blooms in enclosed bays (Sengco 2009).

Successes and Challenges: Bloom concentrations In the western Florida trial increased again after less than 2 weeks in two of the five monitoring areas. It is not clear if this re-appearance was due to currents advecting new bloom-containing waters into these areas, or if it was attributable to resurgent growth of cells that remained after copper treatment. Cost estimates for the treatment (in the 1960s) was about $620 per km2 which was considered too costly for routine applications, particularly given that it provided only temporary relief from the bloom and aerosols. The collateral damage to the ecosystem likely was significant due to the broad toxicity of copper sulfate, although reports of impacts on aquatic organisms were limited and the application rate is considered low based on recommended dosages found in current copper-based algicide labels..

Regulatory and social issues: The mixed results of the early field trials led to the method never being recommended for widespread use in marine systems. Some believe that this failure stifled progress in chemical HAB control in the US for many years (Sengco 2009). Social issues were generally a small consideration at the time, beyond the simple assessment of treatment effectiveness and costs. The increasing awareness of environmental issues in the following decades was an additional impediment. Only recently have there been efforts to re-examine the potential use of copper-based compounds as a "backup" for marine HAB control. It is noteworthy that similar environmental concerns are much less prevalent for copper-based HAB control in many freshwater systems used for drinking water or recreational activities.

5.2.3 Case Study - plant-based algicides

5.3 Physical Bloom Control

Physical control methods for blooms span methods that physically harvest, settle and bury algal cells, as well as methods that limit or block the spatial extent or impact area using booms or other barriers. Mechanical means of managing algal blooms include dredging of sediments, sonication, aeration, oxygenation and harvesting.

Sediment manipulations. Physical removal of sediment through dredging can effectively eliminate HAB resting stages, including akinetes, diatom resting cells, and cyst beds. Sediment disturbance or deposition of sand or other material can bury these cells below the oxygenated surface layer, inhibiting germination (Kidwell et al., 2015; Anderson 2017; Brown et al., 2019; Sellner and Rensel, 2018). Sediment resuspension associated with dredging can also be beneficial by covering cysts with additional sediment, reducing their likelihood of germination due to a lack of oxygen. This effect can also be accomplished through capping bottom sediments by adding sand or previously dredged materials that are free of cysts (e.g., offshore sediments; Brown et al. 2019).

An alternative to dredging (i.e., sediment removal) is tillage or plowing of bottom sediments that can help control HABs by resuspending non-harmful algae species (e.g. diatoms), and nutrients, resulting in rapidly forming blooms of non-harmful diatoms that competitively outnumber HAB species (Imai et al., 2021; Ohara et al., 2023; McClimans et al., 2010). However, it is crucial to understand the distribution of cysts of HAB species and determine whether the sediment in the target area contains a dense population. If so, localized removal of cyst beds are advised to be conducted prior to considering tillage or plowing of bottom sediments (Imai et al. 2021).

Ultrasound. Ultrasonic technologies may be an attractive, chemical-free management option for HABs, though this approach has been investigated primarily to treat cyanobacterial blooms and not yet for marine HAB control. The underlying mechanism is that high and low-pressure effects from the longitudinal ultrasonic wave in a solution forms cavitation bubbles that can potentially lyse or inactivate cells when they collapse (Suslick and Flannigan, 2008; Wu and Nyborg, 2008). However, there are conflicting results when using the low power ultrasound needed for HAB control (Li et al., 2014b; Park et al., 2017; Lürling and Tolman 2014a,b; Lürling et al., 2014; Klemenčič and Klemenčič 2021; Bohrerova et al. 2023; Purcell et al. 2013). Thus, science-based data of the effectiveness of low power ultrasound on cyanobacteria and marine HAB species is lacking. Moreover, the lethal effects likely are not restricted to HAB species, although there are few data on which to make this assessment. However, if shown to be effective, these devices may not require as rigorous regulatory approval or environmental impact permits as other HAB control mechanisms.

Bubble Curtains. Bubble curtains (or direct aeration) has been used in fish farms to limit HAB associated impacts on fish survival (Gallerado-Rodrieguez et al. 2019). Bubble curtains are created by porous tubing arrayed around the bottom perimeter of fish net cages. When a bloom occurs, pumping commences and results in significantly better survival than in non-treated cages (Sellner and Rensel 2018). The underlying mechanism may relate to the lysis of fragile HAB cells due to the shear imposed when bubbles burst. It is also likely that the bubbles increase oxygen concentrations, helping stressed fish to survive. While this method may be considered mitigation rather than bloom control, it may be possible to improve this technology by creating nanobubbles or incorporating ozone into nanobubbles to facilitate direct impacts on HAB cells.

Deep-water upwelling. Deep-water upwelling or airlift aeration is one of the most widely used and efficient methods to protect fish aquaculture net cages from HABs (Sellner and Rensel 2018), though here again, this method might be best characterized as a mitigation strategy, not one for bloom control or suppression. The goal of airlift upwelling is to replace surface water occupied by high concentrations of HAB cells with deep water where few cells would be present. The bottom water functions as a dilution mechanism and can create lateral flow at the surface that can transport HAB cells away from the fish cage. Results are improved by the use of perimeter skirts. Fish-killing HABs act by damaging fish gills through either exposure to toxins or damaging compounds, or to mechanical damage from diatom spines. This effect can be partially mitigated by reduced feeding (less respiratory demand) and by increasing dissolved oxygen concentrations in the cages. As with bubble curtains, deep-water upwelling can increase dissolved oxygen saturation, particularly when the airflow is combined with oxygen. Although this method is commonly used with good results in British Columbia fish farms (Sellner and Rensel 2018; see case study below), it was not effective against a bloom of the raphidophyte, Pseudochattonella, in Chilean salmon farms during a major outbreak in 2016 (Clement et al.

2016). This may be because fish farms were too shallow, such that the upwelling brought HAB cells to the surface, rather than the desired cell-free water.

Clay Flocculation: Clays are surface active substrates that rapidly absorb dissolved organic phases in seawater, including the mucopolysaccharides on the surfaces of phytoplankton. Spraying a slurry of clay minerals onto surface waters leads to the formation of clay/cell flocs that sink rapidly to the bottom sediments (reviewed in Yu et al., 2017). In recent years the method has been optimized through the use of the more reactive clays, and through additions of polymers, oxidants, or other materials to the clay that can : 1) alter the surface charge of the clay particles to improve their electrostatic reactivity with HAB cells; 2) create long polymer chains to bridge among flocs, thereby trapping cells through net or sweep capture as the aggregates settle through the water column; and 3) sequester or destroy HAB toxins in the water column that are released by cells captured and ruptured during flocculation.

A particular benefit of clay flocculation is that the flocs continue to collect cells as they sink, so the clay treatments added to surface waters can be effective through the mixed layer of the water column, an advantage over most other HAB control technologies. There is also considerable experience with the successful use of this approach at large scales (>100 km2) in marine waters of Korea and China for over 30 years (see below). An attractive feature of this method is that it uses inexpensive and environmentally benign minerals that often are a common constituent of marine sediments. Another benefit is that the extent of removal of different species from the phytoplankton assemblage varies with cell size, cell concentrations, and cell wall constituents and morphology (Qiu et al., 2017; Siclari, 2019). So while it has been shown to be effective for many HAB species, its application still leaves a significant “seed” community for ecosystem recovery.

One concern with the method is that although the clay mineral matrix is chemically inert, any toxic materials sorbed to clay surfaces may be ultimately released in the water column or pore waters (e.g., metals, toxins). However, studies have shown no negative effects on benthos from multiple clay applications in Korea (Park et al. 2013) or in China (Song et al.2021), though the field treatments for these studies have involved algal species that do not produce true neurotoxins. Another concern is that continued application of clays may negatively affect benthic environments, though this is not an issue in relatively well-flushed marine waters (Park et al. 2013). For other areas, the quantity of clay needed for HAB removal can be remarkably low (4-10 g/m2 or 4-10 tons/km2; Yu et al. 2017), so negative impacts are unlikely (Song et al. 2021).

5.3.1 Case Study - Deep-water Upwelling at Canadian Fish farms

Background: Fish farms in British Columbia, Canada, are large, typically producing 2,500-5,000 tons of salmon and are sites where HABs can have major economic impacts (Trainer et al., 2020). The primary HAB threat in British Columbia is Heterosigma akashiwo, a raphidophyte, though a number of other HAB species also are of concern (e.g., species of the genera Chaetoceros and Pseudo-nitzschia). Early warning of impending bloom development, or more often bloom advection into the vicinity of fish cages, is critical to enable control methods to be implemented in time.

Implementation: Deep-water upwelling systems currently are utilized across all aquaculture farms in British Columbia, with growing interest and adoption by other countries as they face increasing occurrences of annual plankton blooms and associated fish mortalities. The decision process for activating upwelling relies on high quality phytoplankton monitoring of the surrounding waters, with a focus on problematic species. Companies rely primarily on manual microscopy techniques, and some have adopted automated microscopy (e.g., the FlowCam or the Imaging FlowCyobot), or both (D. Trethewey, pers. comm.), with qualitative and quantitative sampling being done during each tidal cycle during the elevated risk months. Characterizing both the spatial and vertical distributions of HAB species with discrete sampling and net tows (for more low density HABs) is important as it informs whether the depth of water drawn for upwelling will decrease or exacerbate the HAB impacts. It is also critical that the farmers capture and enumerate all harmful species, as each have different thresholds for triggering the bloom control protocol.

For implementation, a compressed air hose is lowered below and in the middle of the fish cages to allow the drawing of deep water upwards into the cages. In British Columbia, many fish farm sites are in areas with strong current velocities, and the net cages are large enough to receive the upwelled water without excessive lateral dispersion. If the cages are placed in a side-by-side configuration parallel to the current (Fig. 6), adjacent cages can share the upwelled water, reducing the need for additional pumping systems.

Application Evaluation: The use of deep-water upwelling has been optimized by fish-farm personnel through a long trial and error (D. Trethewey, pers. comm.). What follows is the best practice approach that has evolved at Greig Seafoods in British Columbia.

Figure 6. Deep water upwelling system used during a Heterosigma akashiwo bloom at a British Columbia, Canada, fish farm on the west side of Vancouver Island. Photo credit: CPI Equipment, Inc.

Dispersing compressed air at depth with a surface pumping system requires substantial energy. Finding the right balance between air pressure and volume of transport is a constant challenge to farmers, with the effectiveness of these systems being constrained by their capacity. For instance, a system generating 90 PSI can push air down to a maximum depth of 14 m, which may not be deep enough to entrain HAB-free water. Modern systems often feature multiple compressors—up to six, providing a total of 72 cubic meters per minute—and can reach depths of ~25 m. These systems use a network of aeration disks, combined with precise control over the direction of airflow, to target areas with high plankton concentrations within the cages. Integration of oxygen into the aeration system also helps farms maximize dissolved oxygen concentrations, a particularly important feature to reduce the stress on cultured fish when upwelled deep waters have low oxygen concentrations.

Large Scale Treatments: Farms typically use a combination of leased compressors and purchased (capitalized) assets. The financial investment for a comprehensive aeration system on such farms generally falls within the range of $200,000 to $400,000. This cost variance primarily depends on the number of fish pens that need coverage and the complexity of the distribution channels required to ensure effective air or oxygen delivery throughout the system. At maximum operational capacity, each compressor consumes approximately 400 L of fuel per day. It's common for farms to operate between two to five compressors simultaneously, depending on the scale of the operation and the immediate environmental challenges faced, such as the intensity of the HAB. If air compressors or suitable air blowers are already available, capital costs for airlift aeration will be restricted to air lines and diffusers. In regions where HAB are typically seasonal events (spring to early fall), fish farmers may utilize rental compressors to further reduce capital costs (Fig. 6).

Site selection and the use of proper equipment are critical concerns. Depending on water clarity, some shallower sites may contain algal populations throughout the water column, rendering the method ineffective (see above). If bottom waters or sediments are rich in H_2S, mixing of this gas into surface waters could cause mortalities of the densely packed fish. Another concern is high nutrient (N, P, Si) concentrations in the upwelled waters will promote algal production, potentially exacerbating HAB conditions.

Successes and challenges. Currently, deep-water upwelling systems are utilized with successful results across all aquaculture farms in British Columbia, and there is growing interest and adoption by other countries as they face increasing occurrences of HABs and associated fish mortalities. One of the challenges has been getting timely data on phytoplankton species composition. In the past, salmon farmers had to submit water samples for phytoplankton/HAB analysis, which took several days. This has been overcome by employing their own algae experts who have built libraries of local species of algae. These in turn have facilitated the use of automation and machine learning in surveillance. In 2019, Greig Seafoods had fewer mortalities from HABs than they would have experienced without the combined deep-water upwelling and automated monitoring. They also avoided starving the fish unnecessarily when algae were not toxic. The number of hunger days in 2018 were reduced by 41% on their facilities in the Esperanza area, where harmful algae can be a challenge.

Farms that experience HABs infrequently often report higher mortality rates. This paradoxical outcome can largely be attributed to a lack of experience among staff members, who may be less prepared to effectively respond to HAB events. Conversely, sites that conduct daily monitoring of HABs are typically more aware of potential threats and are quicker to implement bloom control strategies. The insurance industry, recognizing the economic benefits of such proactive approaches, is increasingly advocating for the implementation of deep-water upwelling systems as a means to manage these risks more effectively.

Regulatory issues. There are no regulatory issues with deep-water upwelling in Canada, mainly because aquaculture falls outside of the equipment/construction government agency oversight. In BC, aquaculture companies often follow local laws in regards to electrical and construction standards. For the plankton mitigation systems this is mainly affected under the boilers regulation which pertains to the compressed air requirements. A certified welder must put the manifold together, and any vessel holding more than 15 PSI of air storage must undergo annual inspections.

5.3.2.1 Case study - use of clay to control HABs in South Korea

Background: The marine aquaculture industry in South Korea has a market value of 2.7 billion USD (Statistics Korea : kostat.go.kr/anse/). These fish and shellfish farms are distributed widely along the 2,000 km-long southern coast of Korea, primarily located at about 15-30 m depths, 200 to 500 meters offshore. The use of clay flocculation for HAB control is considered to be one of the most advanced strategies based on the number of algal species and habitats that have been studied, the number of studies on ecosystem and environmental impacts, and the multiple uses of this technology over relatively large areas (≥100 km2; Park et al. 2013). The bulk of this work has been done in Korea and China, both actively using clay flocculation, but with significant differences in the types of clay used and the manner in which the clay is deployed. While other HAB mitigation methods have been examined in Korea [marine bacteria (Kim et al., 2008), microscreen filtration and ozone (Kang et al., 2001), ultraviolet radiation (Jung, 2000), parasitic dinoflagellates (Park et al., 2004, 2013), and microzooplankton predators of bloom species (e.g., Jeong et al., 2003, 2008)], only clay control methods have been used extensively in Korean waters (Na et al., 1996; Choi et al., 1998; Kim, 2000; Sun et al., 2004).

Implementation: Historically, the first massive Margalefidinium polykrikoides blooms (maximum 30,000 cells mL-1) occurred in 1995, resulting in USD $60 million loss of farmed fish (about 10% loss of all cultured fish products that year). This massive economic loss to the aquaculture industry and the resulting public pressure resulted in the decision by the Korean government to apply clay to control M. polykrikoides blooms and to protect aquafarms in 1996. This decision was based on studies in the late 1980s in which a field trial using natural clay was conducted to control M. polykrikoides blooms near fish farms in Japan (Shirota 1989). In Korea, this natural clay was a yellow loess that was readily available locally from nearby rivers.

Since its first application in 1996, natural clay dispersal has become the prime control technique of Korea’s HAB management scheme for fish farms (notification no. 2016-43 of Ministry of Ocean and Fisheries; Park et al. 2013). Since that implementation, M. polykrikoides blooms have occurred almost annually (1,000 to 50,000 cells mL-1), but with considerably lower fish-kill losses of USD $1-20 million each year (Fig. 7).

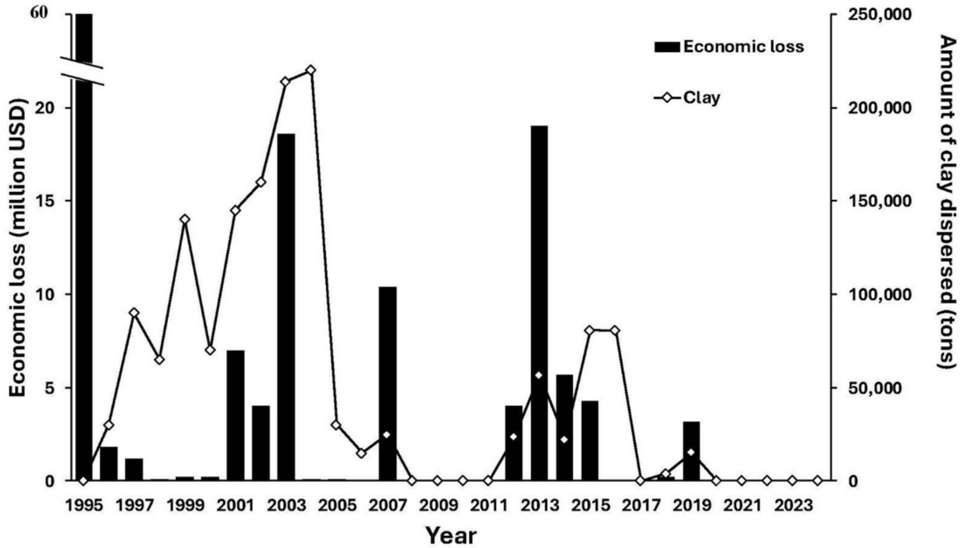

Figure 7. Fish kill loss by M. polykrikoides blooms and amounts of natural clay dispersed in Korean marine waters for HAB mitigation.

Application Evaluation: Rigorous lab testing of the potential effects of natural clay on shellfish and fish started after its emergency use in the field in 1996. High concentrations of natural clay and with continuous resuspension had initial negative effects on shellfish health, but health returned to normal within 2 days after the clay treatment (Seo et al. 2008, NIFS HAB report in 2013). No negative effects were found on fish at 10g/L of clay (NIFS HAB report in 2013), concentrations generally well below that of clay dispersed in the sea (≤ 10 g L-1 = ~ 100-400 g m-2 clay dispersed).

The yellow loess used in all these lab studies and field applications is a natural material that is only moderately effective in removing HAB cells. Studies showed that using electrolysis to alter clay surface charges greatly improved HAB cell removal (Park et al. 2013), and further study examined the use of chemical modifiers to enhance HAB removal efficiencies. Four clay types now have received approval for use in South Korean marine waters...

1. Unprocessed clay: Seawater is pumped and mixed with natural clay in a chamber to produce a slurry of clay aggregates that is sprayed over the sea using a first generation (1G) clay (slurry) dispenser. This method is simple to apply and can be used by small fishing boats or fish farm rafts.

2. Fine clay: Breaking the natural clay into finer aggregates before dispersal improves the efficiency of HAB removal by ~10-%, though application costs increase 60-fold. A second generation (2G) clay dispenser was developed that uses three blades rotating at high speed in a mixing chamber, which crumbles the clay and mixes it with seawater before spraying the slurry directly into the sea from boats. This method generates a larger portion of clay aggregates < 50 µm, roughly equivalent to the ~40 µm size of M. polykrikoides, which increases cell-clay aggregation rates and HAB removal efficiencies by 10% to 60%.
3. Electrolyzed clay: The short-term dispersal of large amounts of clay has the potential to negatively impact benthic organisms (e.g., clams) by disturbing feeding patterns, suffocation, or burial (Shumway et al., 2003; Archambault et al., 2004). A third generation (3G) clay dispenser (electrolytic clay dispenser, ECD) was therefore developed that minimizes the quantity of clay used and enhances the HAB removal efficiency. With ECD, the seawater is hydrolyzed via an electrical current to produce sodium hypochloride (NaOCl) and then clay is added to the hydrolyzed seawater to produce a seawater/clay slurry. NaOCl is widely used as a cost-effective way to inhibit seawater biofouling of ship and electric power plant cooling systems (e.g., Christian et al., 1995). The concentration of NaOCl is controlled by adjusting the electrical input, and NaOCl is converted back to NaCl under sunlight (Jeong et al., 2002). The potential harmful effect of electrolyzed clay was tested against various marine organisms. Electrolyzed clay can kill red tide dinoflagellates at 300-500 ppb of NaOCl on the clay, but other organisms including finfish, diatoms, brine shrimp, and macroalgae (LD50 at 1,200-12,000 ppb) were much more tolerant to NaOCl (Jeong et al., 2002).
4. Modified clay: To identify better control substances to use with clay, 160 commercially available materials used for other purposes (e.g., water or soil treatments) were investigated by the Korean Ministry of Oceans and Fisheries. Of these, four were found to be safe and effective, and are approved and applied in Korean waters; a) clay powder with palm oil; b) clay plus shells of shellfish; c) mudstone; d) clay with sophorolipid (glycolipid liquid from the yeast, Candida bonbicola). The timeframe for approval of modified clay was 3 to 10 years from their initial evaluation, primarily due to the funding needs at each step of the process.

Ecosystem impacts due to clay dispersion, particularly the benthos, have been assessed since 1998. The National Institute of Fisheries Science has monitored environmental changes in areas where yellow clay has been frequently dispersed during M. polykrikoides blooms, with an emphasis on the benthos. No significant impact on the biomass or species composition of the benthos, such as annelida, mollusca, decapoda, or anthropoda have been observed in the areas of clay dispersion and control (Park et al. 2013). Due to the effectiveness and practicality of clay, clay dispersal has become a central element of Korea's management scheme. In fact, many fish and benthic organisms in the treatment area seem to thrive on the clay substrate (Park et al., 2013). For the last 15 years, effects of clay dispersal on the benthos have been monitored in clay dispersal areas. Before and after clay dispersal, no significant changes were found in the number and diversity of benthic organisms. No fish or shellfish kills were observed following treatments with high concentration (10 g per liter) of natural clay in laboratory and mesocosm experiments (NIFS HAB report in 2013).

Large Scale Treatment: Modified clays currently are used for HAB control primarily at commercially valuable shellfish farms (e.g. abalone) because the costs are up to 10 times higher than for natural clay. Far less modified clay is needed for similar levels of HAB removal, which is a benefit because it minimizes potential negative impacts on the quality of shellfish products. For example, dispersal of 200 tons of natural clay/km-2 yields ~ 70% HAB removal, while only 100 tons of modified clay/ km-2 is needed for a similar level of removal. Local governments can choose control methods from 1, 2, or 3G clay dispensers (described above) or modified clay, which depends on budget, commercial value of the aquafarm, farmed fish or shellfish, geographical location, and HAB density (Fig. 8). Electrolyzed clay is used when blooms are large (>100 km2) and significant fish kills are expected.

Figure 8. Various methods of clay dispersion for HAB removal in Korea. (A) 2G clay dispenser; (B) 3G clay dispenser; (C) Spraying modified clay

The decision to initiate clay dispersal is guided by the Ministry of Ocean and Fisheries online alert system, which reports local government data on the concentrations of M. polykrikoides near fish farms. Clay dispersal is initiated when concentrations exceed 100,000 cells L-1 over a wide area. The clay already has been moved from storage (usually in June) before the typical bloom season onto a barge centrally located offshore for easy distribution to the participating boats. Several hundred boats owned by local fishermen and local governments are directed by the Ministry of Ocean and Fisheries to the locations where they should spray the clay. Clay is sprayed while facing away from the farms, targeting the areas where the M. polykrikoides bloom is occuring. In the case of large-scale blooms, clay dispersion may continue for up to four months. Spraying is repeated daily until M. polykrikoides cell abundance is below the threshold levels established by the Ministry of Ocean and Fisheries. These data are collected by: 1) marine police using helicopters to give real-time locations; 2) Local government monitoring of coastal water; and 3) research vessel monitoring. Data are entered into a central database using cell phones by all groups to allow real-time decision-making by the government. Each local government makes the decision to continue or stop spraying, then reports this decision to Ministry headquarters. Every year in June, a practice event is held so that all participants in the actual spraying event are prepared. A detailed 300-page manual has been written describing the step by step operations to guide the practice sessions and the entire spraying process, including the decision-making by various government entities.

Regulatory Issues: The evaluation process for new control materials in Korea follows the standard four-step protocol for approval of any water treatment chemical: 1) assess and document the potential natural toxicity; 2) evaluate the control method in laboratory; 3) evaluate the method at sea; and 4) undergo committee review for approval. The first step is a document review that includes affordability, usability, eco-friendliness, and accessibility. An important aspect of the first step is that the material does not include toxic components by environmental water quality standards. The second step is laboratory tests, including efficiency of M. polykrikoides removal and survival rate of phytoplankton, zooplankton, shellfish, and fish in bioassays. The third step involves a mesocosm experiment in the sea including evaluation of water quality, survival rate, and removal efficiency. This step is a primary roadblock for moving forward, primarily due to cost. Candidate methods must have a high likelihood of success to reach the mesocosm stage. The last step of the evaluation is field deployments along the southern coastline of Korea. Separate funding is required for each of these steps, so the process takes several years before approval is granted.

Once the evaluation studies are completed, the findings are reviewed for approval by a 15-member committee comprising experts from universities as well as local and main government. Following approval, the local and main governments pay all the preparations needed for implementation in the field (Table 3). There is no cost for government employees needed for clay dispersal (up to 120 people per day).

Societal Issues: There is strong government and society support for the use of clay dispersion as a HAB control method along the south coast of Korea. Moreover, there is active societal participation in its implementation. This enthusiasm likely stems primarily from the demonstration of limited environmental impacts from clay dispersion after many years of use, along with the broad economic consequences that untreated HABs generate in this society.

Scalability and Breadth of Applicability: The clay products tested and implemented already have a demonstrated broad scalability in marine waters. The use of clays for HAB organisms other than M. polykrikoides needs testing, as its effectiveness will be influenced by algal surface to clay interactions, and relative particle sizes, with aggregation potential increasing as particle sizes become more equal.

Table 3. Cost of clay dispersal for HAB control in Korea (USD $). Modified from Park et al (2013).

Details	Price of clay	Clay stored (104 tons of clay)	Cost of clay transport (1 dump truck, 1 excavator)[1]	Cost of 1 clay dispenser and 1 ship	Cleaning costs of ship etc. (1 sprinkler truck)[2]
Cost	$ 20 per ton	$ 820 per year	$ 1,250 per day	$ 1,900 per day	$ 1,500 per day
To control 200 km2 of HAB area	20 tons per day	$ 820 per year	4−5 vehicles per day	20−40 ships per day	5−10 trucks per day
Total cost per day (200 km2 of HAB area)	$ 400	$ 820 per year	$ 5,000−$ 6,300	$ 38,000−$ 76,000	$ 7,500−$ 15,000

[1]Clay is transported by dump truck from storage facilities near the coast to bloom-affected areas. Then excavators are used to transfer the clay onto vessels, including ships and barges, used for HAB control.
[2]After the dispersion process is completed, sprinkler trucks are used to clean the control vessels.

5.3.2.2 Case study - use of clay to control HABs in China

Background: China has been working with clays to control HABs for more than three decades. The clay used most frequently in China is a purified clay that has been combined with the inorganic polymer polyaluminum chloride (PAC). This step reverses the inherent net negative surface charge of clays to positive, thereby increasing the electrostatic attraction of the clays to net negatively charged HAB cell surfaces (Yu et al. 1994a). The result is that HAB cell:clay aggregation rates increase, due both to improved particle:particle attraction (coalescence) efficiency as well the formation of larger, more diffuse aggregate networks (flocculation) linked together with the long PAC chains. The resultant higher single cell capture rates and higher particle sinking rates creates more effective bloom control with this modified clay (MC) relative to non-modified clays (Fig. 9). In addition, a residual effect of MC sorption of HAB cells is the inhibition of cell division, further restricting HAB development (Zhu et al., 2018).

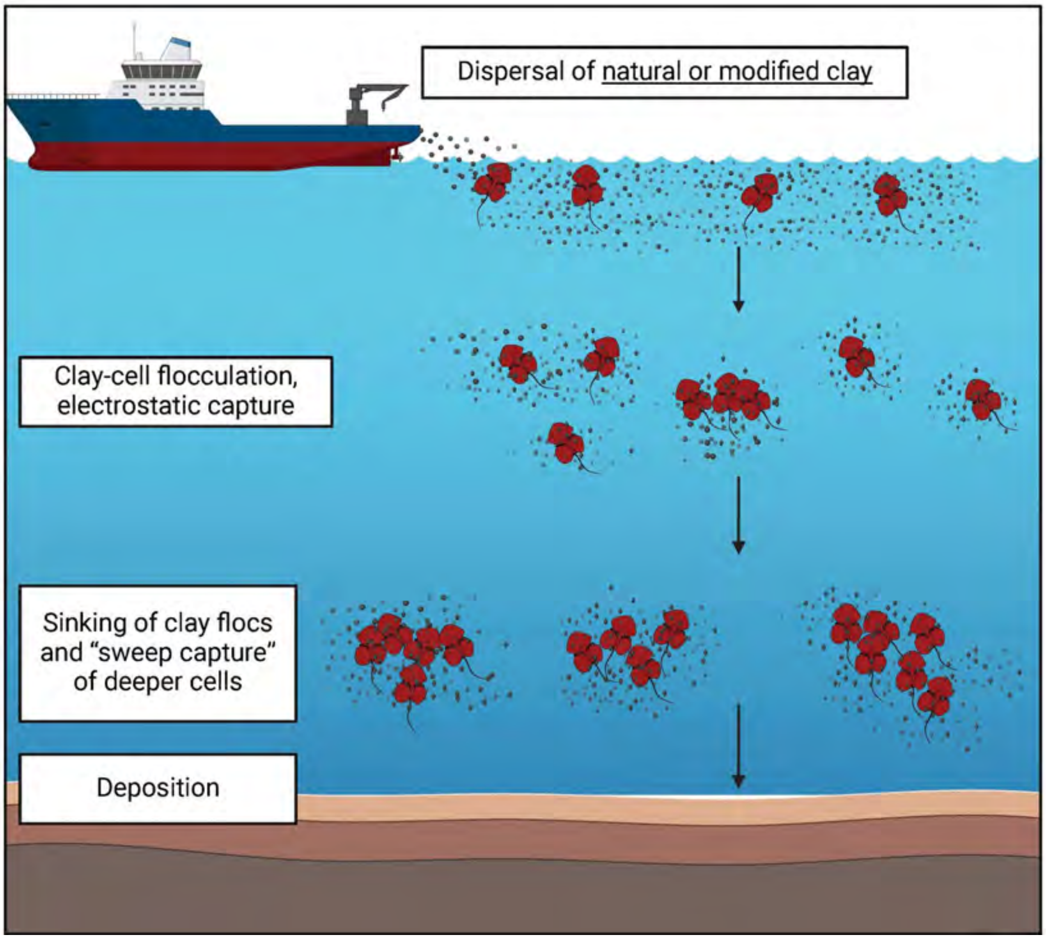

Figure 9. Method for dispersal of natural or modified clay.

Implementation: Studies of the efficacy of MC as a HAB control approach have been conducted in both large mesocosm tanks and in open waters. The first field studies using MC were conducted in 2005 to suppress cyanobacterial blooms in a 4 km2 freshwater lake in Nanjing. The Nanjing Environmental agency monitored the bloom and environmental changes during MC treatment and concluded that MC was effective in controlling the cyanoHAB while being environmentally benign (Mei et al. 2010). Following that successful application, MC was gradually accepted by the Chinese government, the public, and marine stakeholders, which enabled its large-scale use for marine HAB suppression on multiple occasions in Chinese coastal waters from 2005 to 2011 (Yu et al., 2017; Qiu et al., 2017; Jiang et al., 2023; Zhu et al., 2024).

Application Evaluation: The efficacy of MC for HAB control has been tested in the laboratory with many HAB species, including Heterosigma akashiwo, Procentrum mininum, Procentrum donghaiense, Nizschia closterium, Alexandium tamarense, Skeletonema costatum, Chattonella marina, Phaeocystis globosa, Aureococcus anophagefferens, Scrippsiella trochoidea, Chlorella vulgais, Isochrysis galbana, Karenia mikimotoi, Karenia brevis, Chlorella vulgaris, Litopenaeus vannameri, Nannochloropsis sp., Alexandrium catenella, Amphidinium carterae, and microscopic propagules of Ulva prolifera (Yu et al., 1994b,c; 1995; 1999; Song et al., 2003; Cao, 2004; Cao et al., 2004; Cao and Yu, 2003; Wang, 2010, 2014; Liu, 2016; Liu et al., 2016a, 2016b; Zhang, 2013; Zhang et al., 2016; Jiang et al., 2018, 2021; Qiu et al., 2019, 2020; Li et al., 2020; Liu et al., 2021, 2023; Wu et al., 2021; Jiang et al., 2021, 2023; Dong et al., 2021; Liu et al., 2022; Wang et al., 2023a,b; Yu et al., 2023; Li et al., 2023; Zang et al., 2024). Removal efficiencies during these lab tests typically can reach ≥ 80 - 90% at doses ranging from 0.1 to 0.5g/L).

The effects of MC also have been tested on a wide range of non-target planktonic, pelagic, and benthic organisms.. These studies include fish species (turbot embryos; Zhang et al., 2019a; Atlantic Salmon (Zhang et al., 2019b); marine medaka (Oryzias melastigma) (Zhang et al., 2022), a number of shrimp species (the opossum shrimp Neomysis awatschensis, Wu and Yu, 2007; juvenile kuruma shrimp Penaeus japonicas, Song et al., 2003; Cao et al., 2004; Wu et al., 2006; the white leg shrimp Litopenaeus vanamei, Song et al., 2021), bivalve species (the Pacific Oyster Crassotrea gigas, Gao et al., 2007a; the yesso scallops Patinopecten yessoensis and Mizuhopecten yessoensis, Wang et al., 2014a, Meng et al., 2022; and the hard clam Mercenaria mercenaria, Wang et al., 2019), abalone (Haliotis discus hannai juveniles, Zhang et al., 2020c, 2023), and sea cucumber (Apostichopus japnoicus, Wang et al., 2014b). In all cases, no significant negative impacts have been observed at MC loadings used for effective HAB removal in laboratory cultures and tanks (typically 0.1 – 0.3 g/L; reviewed in Song et al. 2021). The low environmental risk from MC is expected given that the modifying agent PAC is used as a flocculant in water purification treatments for drinking water and wastewater treatment.

An attractive feature of MC is that the surface modification can be optimized for different HAB species. A new formulation of MC was developed to regulate excessive proliferation of picoplankton (e.g., Nannochloropsis sp.) that can negatively influence shrimp culture in Chinese aquaculture ponds. Rather than PAC, clays were modified with other organic polymers, e.g. PDA (polydimethyldiallyammonium chloride), a polymer of longer chain length than PAC, to enhance the capture efficiency of the smaller cells. In addition to successful removal of excessive picoplankton, this version of MC also removed organic matter and pathogenic microorganisms, such as ciliates, bacteria, and viruses (Chi et al., 2022, Chi et al., 2024; Ding et al., 2022; Ding et al., 2021; Zhu et al., 2023)). Over 300 acres of culture ponds have benefitted from this MC usage since 2020.

MC has the added potential benefit of influencing water quality in ways that can reduce the intensity of HABs. PAC and alum (a closely related aluminum compound) are used in lake restoration to immobilize dissolved nutrients and transport them to bottom sediments (e.g., Araujo et al. 2016; Kasprzak et al. 2018). MC is particularly effective for removing dissolved phosphate (up to 98% at high MC loading; Deng and Shi, 2015) and dissolved silicate (40 – 60%) in diatom cultures (Lu et al. 2015). In contrast, there is minimal absorption of nitrate or ammonia (Song et al. 2021). MC also has been shown to slow the release of nutrients from sinking cell:MC aggregates, thereby reducing the influence of legacy nutrients (Lu et al., 2014, 2017). Reductions in chemical oxygen demand have also been reported with the use of MC (Gao et al.2007b; Yu et al., 2017).

Large Scale Treatment: During early-stage applications, specially modified fishing boats were used to disperse MC by pumping from tanks containing a clay/seawater slurry. Later, multiple platforms and equipment were developed for different types of applications and scales. A dedicated clay dispersal craft was designed for applications in shallow-waters. For nearshore, localized treatments such as around aquaculture ponds, a series of portable, self-feeding sprayers were developed and are available through manufacturers affiliated with the Institute of Oceanology, Chinese Academy of Sciences (IOCAS). Larger-scale applications, such as an ongoing program for nuclear power plant treatment, necessitated the development of a ship-mounted sprayer module capable of holding six tons of MC that can be automatically mixed with seawater and applied with a 55 m wide spray. At loading rates of 4-10 g MC/m2 (= 4-10 tons/km2), this bloom control strategy is relatively inexpensive for use over large areas, as is currently the case in China.

One highly publicized effort was to clear a Chattonella bloom at the sailing venue of the 2008 Olympics in Qingdao (Yu et al. 2017). Thirty fishing boats were used to spray 360 tons of MC over an area of 86 km2 (4 tons/km2) in 30 hours, successfully clearing the water for the event (Fig. 10). Another major field treatment occurred in 2015 when a massive Phaeocystis globosa bloom threatened to clog intakes for the critical cooling water of a nuclear power plant in Fangchenggang city, southern China (Yu et al. 2017). The MC product and sprayers were mobilized to the site, an implementation plan was developed, staff were trained, and a three-month campaign implemented from Dec. 2015 to Feb. 2016. Repeated treatments were applied to the 2 km2 cooling water intake channel and pond, as well as a 6 km2 buffer area adjacent to the inlet channel (Fig. 11). These efforts were successful at keeping bloom concentrations low which enabled the nuclear plant to continue uninterrupted operations.

Figure 10. Large scale HAB suppression using MC in open (oceanic) waters in China

Successes and Challenges: Modified clay dispersal is now widely accepted for HAB control in China. Over 20 large-scale MC treatments have been conducted nationwide to date, the largest covering 86 km2 in 2008. To meet the many different HAB and water quality challenges nationwide, more than 10 formulations of MC have been developed and manufactured, some focused on the control of HAB species, and others on environmental improvement, water quality, and aquaculture.

The surface modifications of clay offer an avenue for control not just of HAB species but also the toxins they release on lysis or death. Many of these lipophilic toxins still cause harm to higher trophic levels (e.g., fish kills). While some clays have been shown to remove up to 58% of dissolved brevetoxin (Pierce et al. 2011), the current versions of MC are much less effective for brevetoxin (~0 - 30%; D. M. Anderson et al., unpub. data). MC also showed no significant effects on dissolved paralytic shellfish toxins (PSTs; Song et al. 2021). Efforts are underway to develop MC with immobilized oxidants that can target toxins. For example, MC modified with potassium peroxymonosulfate (PMPS-MC) effectively removed Alexandrium pacificum cells and rapidly reduced intracellular and extracellular PSTs toxicity at a concentration of 0.1g MC/L (Song et al., 2023).

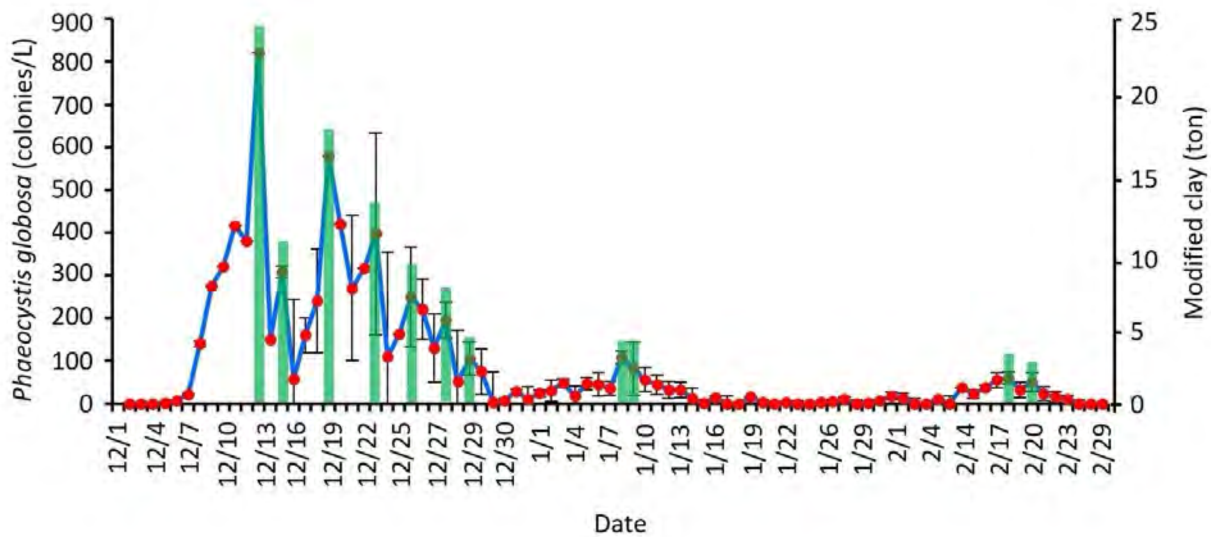

Fig 11. HAB control in the cooling water pond of Fang'Cheng'Gang Nuclear Plant from 2015 to 2016. Red circles denote the concentration of Phaecystis globosa colonies; green bars show the MC amount released into the pond. Modified from Yu et al. 2017.

Regulatory Issues: The approval of MC for HAB control proceeded from lab tests to field applications, during which the general public and local authorities provided step by step comments and approvals. Initially, there was no precedent for field control of large-scale blooms in China, making it challenging for local authorities to approve potential technologies for field application. However, successes of field applications using clay flocculation to suppress HABs in Korea help to guide the approvals. As there were no laws guiding the evaluation of the effects of HAB control and potential impacts during the application, local authorities asked the organization that developed the technology to provide relevant literature and a third-party evaluation to prove the effects and ecological safety. Independent experts were asked to evaluate the potential approaches for field tests, and a third party entity monitored the field tests and provided those data to the experts for final judgement. Further, an additional independent evaluation of the findings was conducted to ensure their validity. The repeated applications and findings then were summarized in the National Standard of Red Tide Control and Emergency Plans of Red Tide Control documents, which provide a baseline guide for the authorities and the public to use for future applications.

Societal Issues: MC now is accepted by multiple stakeholders, including local and national government authorities, infrastructures (e.g., power plants), aquaculture companies, and the public. MC has been listed in the National Standards issued by the Ministry of Nature Resources (Technical guidelines for treatment with red tide disaster, GB/T 40743-2014) as well as being incorporated into the emergency plans for red tide control in many coastal provinces/cities of China. A Standard Operating Protocol for applying MC in the field has been developed (Technical specification for red tide control with modified clay, DB37/T 4753-2024). This success has led to MC being commercialized in China. Stakeholders can obtain the products in the market and independently to use according to the instructions, and third party, site-specific evaluations are recommended before and after field application.

Scalability and Breadth of Applicability: As with clay dispersal in South Korea, the scalability and breadth of applicability has already been well demonstrated. Success of the method is leading to its expanded use in Chinese coastal waters.

5.3.2.3 Case study - use of clay to control HABs in the United States

Clay flocculation to control HABs has been explored experimentally for over two decades in the US, but this control strategy remains less advanced compared to China and Korea, largely due to more stringent regulatory requirements. After considerable early work on a range of clay types (e.g., Sengco et al. 2001; Sengco and Anderson 2004; Lewis et al. 2003), US researchers moved away from this line of research due to strong opposition from some segments of the public. A major problem was that the most effective clay used by US researchers at the time (termed phosphatic clay; Sengco and Anderson 2004) was a byproduct of phosphate mining in Florida, and this material (and phosphate mining in general) was associated with many deeply held environmental concerns relating to organic contaminants and radioactivity in the clay. The public was deeply concerned about the potential use of this material in natural waters, despite its extraordinary efficiency in removing Karenia brevis cells (Sengo and Anderson. 2004).

Work on clay flocculation essentially restarted in 2018 following a major Florida red tide of Karenia brevis that lasted more than a year (Weisberg et al. 2019), prompting many in the state to push for effective bloom control strategies. The decision was made to work with new clays, including the Chinese MC described above. Since K. brevis was not a species that Chinese colleagues had studied to that point, and since it produces potent neurotoxins that had also not yet been studied by the Chinese, the work began with small flask and tank studies, with and without benthic animals (Devillier et al. 2023). Experiments then shifted to mesocosm tanks (80- and 1,400L) containing clams, urchins, and crabs (Devillier et al. 2024), again with MC as the main clay to be evaluated, but with other clay formulations tested as well.

Application Evaluation: Although considerable work had already been completed on the use of MC for HAB control (reviewed by Yu et al. 2017) a major knowledge gap was the effects of potential release of lipophilic neurotoxins when treating K. brevis. In this case, the treated water as well as flocculated cells and clay debris could negatively impact planktonic and benthic communities. In that instance, special constituents added to the clay might destroy or sequester toxins (e.g., oxidants, activated charcoal) greatly limiting these impacts.

Recent studies (Devillier et al. 2023, 2024) used MC in aquarium tanks containing K.brevis as well as blue crab (Callinectes sapidus), and 1,400 L mesocosms containing K.brevis, blue crab, urchins (Lytechinus variegatus), and hard clams (Mercenaria campechiensis). The MC treatments effectively controlled K. brevis cells, with >95 % cell removal in several hours at clay loadings as low as 0.1 – 0.2 g/L compared to no impacts in controls containing K. brevis or clay alone. Similarly, in earlier experiments with K.brevis and a different clay, Lewis et al. (2003) found that a PAC-modified phosphatic clay was non-toxic to infaunal amphipods (Leptocheirus plumulosus and Ampelisca abdita), grass shrimp embryos (Palaemonetes pugio) and larval sheepshead minnows (Cyprinodon variegatus). Moreover, animal mortality in the clay treatment of cultured K.brevis was not significantly different compared to untreated K. brevis, meeting the "no greater harm" criterion often used to evaluate the negative impacts of HAB control treatments.

In all of the recent MC studies with Karenia brevis, a common finding was that during the flocculation and sedimentation process, some brevetoxin was released into the medium and was not adsorbed by the clay (eg., Devillier et al. (2024). This was evidenced by a decrease in parent brevetoxin and an increase in derivative toxins over time, a pattern that can be explained by toxin release after cell death and subsequent conversion of parent toxins to other forms (Pierce et al., 2011; Abraham et al., 2015). Furthermore, despite removal of 95% or more of the cells, the total toxin load in the tanks decreased only 66%, with the difference being toxin in the sedimented clay/cell floc plus released, dissolved toxin. Although this release of toxin during flocculation and sedimentation was a concern, the experiments are still considered successful since the vast majority of the cells were killed or destroyed. In a treatment of a natural bloom, an equivalent result would suppress the bloom population and reduce future K.brevis development over the succeeding weeks or months, so a short-term release of toxin might be an acceptable outcome, particularly since the no-treatment option would include future animal mortalities and other impacts due to the HAB itself.

More recent studies have turned to further modifications of the clay through the addition of algicides, oxidants, or other bioactive compounds (e.g., curcumin; Hall et al. 2024), and these either release less toxin during flocculation and cell death, or chemically destroy or sequester the dissolved or particulate toxin. At this writing, clay formulations are being tested that remove >95% of the K. brevis cells in 2 or 3 hours, with 75-80% toxin removal in 24 hours (D. M. Anderson, unpub. data).

Large Scale Treatments: There have been no field-scale or large-scale treatments of clay dispersion for HAB control in the US at this time.

Regulatory Issues: Studies with MC and other clays in the US have predominantly been conducted in small tubes, flasks, and mesocosm tanks. The next step in this development process will be pilot-scale (~2,000 - 4000 m2) studies of natural K. brevis blooms in canal (physically constrained) sites to enable better controlled experiments. This step requires applications to the Florida Department of Environmental Protection (DEP) for de minimus permit exceptions (i.e., impacts are expected to be small, so no permit is required). Approval is also required from several US federal agencies with mandates relevant to the planned studies in marine waters, including the US Army Corps of Engineers (navigation and changes in water depth) and the US Fish and Wildlife Service (endangered species) and the National Marine Fisheries Service (critical fish habitat). It also is necessary to gain pre-approval for multiple possible treatment sites (typically canals or small embayments), given the unpredictability of K. brevis blooms. Also needed are agreements from every abutter owning property adjacent to each pilot-study site. Even with all local and state approvals in hand for six west Florida sites at this writing, final clearance for clay dispersal pilot studies is currently awaiting determinations from the US Environmental Protection Agency (USEPA).

Some of the constituents in modified clays (e.g., most clay minerals like kaolinite) are "minimum risk" under FIFRA (see above), and thus do not require an experimental use permit for pilot-scale studies less than one acre (4,047 m^2). Other constituents (e.g., some oxidants, PAC), require authorization however, and that can require the submission of data from ecotoxicology impact studies such as those using standard USEPA test organisms, typically conducted by an independent, third-party contractor. As described above, for non-exempt compounds, FFDCA approval requires "tolerance thresholds" to be established for each constituent. Even though some of these compounds are approved for use in freshwater, a separate approval and registration process is required for their use in marine waters.

Note also that beyond the initial problem of getting USEPA approval of test sites for these reasons, further challenges lie ahead, as large-scale, operational implementation for HAB control will require products to be registered with the USEPA under FIFRA, and that can require considerable experimental and legal expense. Once registered, a clay treatment can only be conducted by licensed applicators, as is the case with algaecides in freshwater.

Societal Issues: As noted above, long-standing opposition to clay dispersal for HAB control has relaxed somewhat since the massive bloom of K. brevis in 2018, enough to not impede the extended regulatory approval process for small-scale testing at a restricted field site. There the bottleneck has been with federal regulations.

Scalability and Breadth of Applicability: US application of modified clays for marine HAB control are still in a testing or experimental stage. This is in part because more studies are needed on efficacy and impacts, but also because planned pilot-scale studies are currently stalled due to US regulatory requirements.

6.0 Final perspectives

The societal, economic, geographic, and environmental impacts from HABs in marine waters have increased in many regions over the last 30 years (Hallegraeff et al. 2021), as has the demand for acceptable, effective, and scalable methods for controlling HABs in these systems. This review has provided a summary of the current status of marine HAB control technologies and applications with a focus on those that have been attempted on relatively large scales, such as in mesocosm tanks or open marine waters. This represents but a small subset of many technologies that are being evaluated globally, but the relatively small number of case studies described here highlights the continuing challenges inherent in trying to control unpredictable outbreaks of a single marine algal species within a complex planktonic assemblage distributed throughout a water column that is mixing and advecting with tides and currents, and spanning spatial scales sometimes for hundreds of square kilometers. As daunting as these challenges are, there are grounds for optimism. The status of our capabilities and understanding is better than it was nearly 30 years ago (Anderson, 1997) and prospects for continued advancement are good. But progress on bloom control technologies must accelerate to match the mounting global scale of the HAB phenomena and its many impacts.

This compilation reveals some of the challenges that are commonly encountered. One view that emerges is that it is significantly easier to implement HAB control strategies on natural blooms in some jurisdictions than in others. In part, this difference reflects the extraordinary social, cultural or economic value of some HAB-threatened resources and the need to protect them, as is the case with South Korea's US$ 1.5 billion fish farming industry. But this difference also reflects varying national approaches to environmental protection, regulatory tolerances and requirements. One example is in Europe, where other than the treatment of an Alexandrium ostenfeldii bloom in the Netherlands (see above), there have been no significant bloom control efforts or studies, despite a long history of HAB research in the region. In our view, this reflects the effectiveness of shellfish monitoring programs and harvesting closures, which, though destructive, are short-lived with impacts that can be managed. Another reason may be a deep societal distrust of control technologies.

Another example is the modified clay (MC) that has been used effectively on more than 20 occasions over large areas along the coast of China (Yu et al. 2017), but which has yet to receive regulatory approval for field testing in the US, despite significant effort. This discrepancy is notable because there have been many published environmental impact studies with MC (reviewed in Song et al. 2021) all reaching the conclusion that this technology has minimal negative impacts compared to those expected under the no-treatment option. Thus the constraint in countries that focus on environmental protections is not necessarily with demonstrated dangers from the methodology, but rather the regulatory requirements that require the submission of multiple types of data, including ecotoxicological studies and residue analyses that are often far beyond the capabilities and resources of the scientists and engineers developing control strategies. In effect, substantial early investments are required by developers to generate and submit data to obtain the clearances for small-scale, in situ pilot studies that may well demonstrate their method will fail to control blooms.

Thus, it is clear that well intentioned regulations designed to protect marine environments have impeded innovation and progress in the emerging field of marine HAB control. In many cases these regulations were not established for controlling HABs in marine systems or to safeguard industries or communities reliant on beneficial uses of these ecosystems. Broad environmental protections initially enacted to protect marine habitats or specific species (e.g. Pacific salmon) now govern the development of HAB control technologies intended to sustain these resources. In other cases, rules enacted to regulate treatments to control harmful pests like insects or rodents are being applied to marine HABs.

One consequence, as in the US, is that investigators and end users may forgo investing in the development of new ideas and turn instead to lists of “minimum risk” or exempt pesticides (or inferior chemical solutions) in an attempt to control HABs, as these have little or no regulatory concerns compared to novel and potentially more effective compounds (see section 5.2.3). Regulations have been established for good reason, but might be seen as too restrictive, particularly on research needed to advance HAB control methods. Regulatory approaches to controlling other extreme natural phenomena that can quickly become an urgent threat to life, property and economy may offer useful lessons on how to balance societal benefits and environmental risks of effective methods of control. For example, emergency responses to forest fires include large airborne dispersals of flame retardants - chemical tools that are routinely deployed but can pose environmental and health risks to plants and aquatic life (Gimenez et al. 2004).

One explanation for the more rapid progress on control of freshwater versus marine HABs might be that the commercial market is much larger and the HAB problems more uniform and widespread (i.e., cyanoHAB toxins impacting drinking water supplies). Companies or researchers developing a product therefore can better justify the investment for toxicological research and application filings. In contrast, the market for marine HAB control technology is harder to define because the problems are more diverse in terms of causative species, toxins, and impacts. A control technology developed for use against dense blooms of Karenia brevis (a neurotoxin producer) may not be appropriate for blooms of Aureococcus anophagefferns, the harmful, but non-toxic brown tide organism. Not only are these species markedly different in size and habitat, but the resources impacted (and their value) differ dramatically as well. The diversity in marine HABs and their impacts may contribute to a poorly defined and fragmented market for control methods, greatly restricting technology development and implementation.

In countries where marine HAB control methods have been deployed to protect highly valued aquaculture fisheries, such as South Korea, China, and Japan, one common feature is the coordination and investment in developing control methodology by government entities. Much of Japan's HAB research, including the development of monitoring and control technology, is supported by the Fisheries Agency. To date, the HcRNAV virus dispersal method (Case Study 5.1.5.1) is the only technology that has been put to practical use in Japan, but the Japanese government continues to support the development of other control technologies. In South Korea, a “HAB Control Technology Development” program was supported by the National Institute of Fisheries Science under the Ministry of Ocean and Fisheries from 1997 to 2016. This led to the development of control methods such as clay dispersion devices and deep-water upwelling. Another program, the “HAB Removal System Development”, was led by the South Korea Ministry of Science and Information and Communication Technology (MSIT) from 2013 to 2018. Algicidal membranes, aquafarm filtering systems, and other related technologies were developed through this program. Korea also supported a public contest (“HAB Control Substance Development”) organized in 2014 by the National Institute of Fisheries Science, which identified four types of modified clay (Case Study 5.3.2.1) that ultimately were approved for use.

In contrast, US, European and many other countries’ investments in HAB control greatly lagged compared to investments from other countries like Korea and China. In 2009, the US federal government established the HAB Prevention, Control and Mitigation (PCMHAB) program within the National Oceanic and Atmospheric Administration (NOAA) . PCMHAB funds research on controlling HABs, through development, demonstration, and application. A second US program, US Harmful Algal Bloom Control Technology Incubator (HAB-CTI), streamlines the vetting process of novel HAB control ideas to support scientific innovation that focuses on strategies that could be scalable and effective at controlling blooms. This HAB-CTI program is advised by other government agencies, academia, non-governmental institutions, and industry partners, and provides critical “seed money” for short-term (one-year) proof of concept projects to generate data that support full, multi-year research and development proposals. The HAB-CTI also helps developers and end-users navigate permitting and licensing requirements.

A separate US program funding HAB control technology development is the Florida Red Tide Mitigation and Technology Development Initiative (RTMTDI). This independent and coordinated regional funding program is specifically focused on developing prevention, control and mitigation technologies targeting Florida red tides (Karenia brevis). An important part of the RTMTDI was the construction of a mesocosm/raceway facility with a capability to produce large volumes of K. brevis culture for research—to safely test techniques, compounds, and technologies in a controlled setting. Annual project meetings among grantees promote sharing of approaches and identification of challenges, particularly regulatory needs.

In China, multiple authorities support HAB control research, including the Ministry of Science and Technology (MoST) and the National Science Foundation of China (NSFC). Prevention, Control, and Mitigation of HABs (PCMHAB), sponsored solely by MoST, has been in place since 2017. The PCMHAB program of China has focused mainly on the development, demonstration, commercialization of applicable technologies in monitoring, early warning, forecasting and emergency control of HABs. These include HABs causing extreme losses to the marine economy, such as the ichthyotoxic Karenia mikimotoi, and Phaeocystis globosa. In recent years, similar programs were proposed by other Ministries of China, including the Natural Resource Ministry of China, and the Ministry of Ecology and Environment of China. These programs may focus on much broader aspects of marine environmental protection, with HABs as a major concern.

7. Recommendations

Around the world, complex and expanding HABs threaten communities, businesses, and governments who are increasingly reliant on marine and marine ecosystem services. Although there has been progress in HAB control research, there are few practical solutions to help in managing the majority of marine and estuarine HABs. Now is the time to accelerate research, testing, and implementation of HAB control methods if we are to help alleviate the mounting societal pressures on global marine systems. This paper summarizes the state of HAB control science to document viable options and highlights several methods that have been deployed in situ to control blooms of marine HAB species. Despite over three decades of research, only one effective bloom control option is in regular use, and then only in two countries (modified clay dispersal in China and South Korea). Some demonstrated and proven options are not in routine use (e.g. applications of naturally occurring algal virus HcRNAV in Japan and hydrogen peroxide in the Netherlands). Other options show promise but have not been adequately evaluated for scalability, cost effectiveness, or environmental impacts (e.g., alginate beads prepared with Shewanella or IRI-160AA and modified clay in the USA). Still other promising approaches are stalled by societal concerns, regulatory hurdles or both. But the HAB research community is beginning to rise to these challenges to tackle the demand for marine and estuarine HAB control technologies, bolstered in some cases by increased investments by government agencies. However, current efforts are still far outshadowed by the breadth of the global HAB problem.

Accelerating progress towards developing a suite of control methods fitted to the most problematic HABs requires a reset of research perspectives, a re-organization of research funding, formal involvement of industry and commercial partners, and perhaps most importantly, a recognition that some major HABs are similar to other actionable extreme events (e.g., hurricanes, fires, etc.). Focusing research community efforts on one or a small subset of HABs in reliably problematic "test bed" field sites, with societal, regulatory and logistical support for short-term experiments, would fast-track research advances and commercialization opportunities; a "moon-shot" approach that has demonstrated effectiveness. Here we present a list of recommendations under three broad categories to help shape this and other strategies to hasten the development of effective HAB control.

Looking forward, efforts are still needed to innovate, sustain, and accelerate progress on HAB control. These efforts should also include public and manager outreach strategies to avoid having unfounded fears override decisions to deploy HAB control methods that have been proven safe and effective. Further, some nations with strict environmental regulations may need to revisit the balance between permitting and the need to advance promising control methods with in situ testing. Here we offer a bold moonshot idea and additional recommendations to help advance progress in this area.
Add a paragraph on focusing efforts in one or a few "probem" areas/HABs.. Moonshot to generate rapid progress, with the effort helping to identify approaches that will work in other regions. (issues - quality of life.. problem scale,.. readiness to push forward. … example is Florida)

Applying the four factors described in section 2.0. to be considered when strategizing control methods to actual marine or estuarine blooms which occur around the world and considering that certain societies may be more amenable to use of bloom control strategies, one realizes there are likely few recurring HABs, in locations where they cause costly blooms impacting societies that are receptive to use of HAB control.

Identifying a few such locations could allow for investment in a "moonshot" type approach to more quickly advance promising control methods to operations. We envision investment in a few well funded, coordinated and intensive programs designed to advance a promising control method targeting an identified priority location in concert with regulatory reforms that promote research and innovative In situ testing, potential private sector partnerships and a strategy of engagement with stakeholders and the public to evaluate risks versus the benefits of utilizing solutions to control blooms in marine waters. HABs\locations which may be most amenable to such an intensive approach include West Coast Florida \Karenia brevis blooms;

A) Identify which HAB phenomena are the most amenable to control.

1) Identify HABs for which control efforts make sense both economically and practically. For example, in an area with routine monitoring for shellfish toxins, bloom control efforts might not be needed since the resource and its related industry are already protected to some degree by monitoring and harvesting restrictions. This might be the case for areas subject to PSP outbreaks in the US, Europe, and many other areas of the world where blooms are frequent and widespread, but where shellfish industries remain viable and productive as a result of short-duration closures or quarantine efforts. On the other hand, high-value resources such as fish farms, power or desalination plants, or even tourist areas might easily justify the cost and challenge of control efforts. In those cases, an additional consideration is the distribution and scale of the HAB. It may not be feasible to consider control of a marine HAB spanning hundreds of km along a coast, but it might well be possible to treat portions of those blooms that have entered small embayments or canals, or to attack the large marine bloom at hydrographic passes and other entryways into inland waterways to keep the species from spreading to new areas. The key is to keep expectations reasonable in light of the characteristics of the impacted resource, the nature of the impacted region (hydrography, configuration), and the susceptibility of the HAB species to control efforts With the exception of treatment of large scale blooms in Korea and China, the most effective current control options can only treat blooms in small embayments or canals. The lessons learned from such applications will help improve our ability to expand to control solutions to more expansive blooms under more challenging circumstances.

2) Assess the socioeconomic footprint of HAB events to gauge the relative costs of bloom control against the value of the protected resource. The desire for HAB control is driven largely by the economic loss of resources (Trainer et al., 2020), so the greater the disruptions and cost the greater the societal (and thus regulatory) willingness to explore control options. There are challenges associated with social and economic assessments (Suddleson and Hoagland, 2021), but a growing body of literature details methodologies to improve these assessments and to identify and quantify community or industry vulnerability and resilience to HABs (Adams et al., 2018, Jin et al., 2020, Suddleson and Hoagland, 2021). In a similar way, studies are needed that estimate the total cost of HAB control treatments at both small and large scales. This has been done in Korea (e.g., Park et al. 2013), accounting for all relevant expenses, from the cost of clay to the labor and ship time for dispersal. This is not an easy task, but if enforced for all treatment technologies under sonsideration, will help to determine if a specific control approach is justified by the socioeconomic benefit. Better efforts to assess the socioeconomic impacts of HABs and the costs of control methods will be key to driving investment in HAB control strategies.

3) Define early on the economic market for marine HAB Control. There is no point in advancing research on a HAB control methodology or product if it is not likely to be viable in an economically sustainable operation. The likely candidates who may be responsible for implementation costs include one or a mixture of:

a. Federal governments
b. State or provincial, tribal, or city governments
c. Businesses (e.g., marinas) or industries (aquacultured salmon)
d. Individuals or communities (e.g. homeowners associations)
e. Infrastructure stakeholders (e.g., desalination plants, nuclear power facilities)

Evaluating the likelihood of economic sustainability of a bloom control approach is in many ways more important than the likelihood that it is effective in bloom control.

B) Development and testing of promising HAB control methodologies

1) Promote international collaborations on new control approaches and extend existing approaches to new organisms and habitats. Utilize the direct experience with HAB control in some nations to link with innovations in others to optimize the development of new strategies. International collaborations should be encouraged via the Intergovernmental Panel on Harmful Algae Blooms (IPHAB), its co-sponsors the UNESCO Intergovernmental Oceanographic Commission (IOC), and the Food and Agriculture Organization of the United Nations (FAO), as well as through muti-national regional ocean science bodies (e.g. the North Pacific Marine Science Organization [PICES]), and international conferences (e.g. the International Conference on Harmful Algae [ICHA]). Harness the full capacity of scientific discovery by increasing the exchange of ideas, advances, and experiences (technical, logistical, and societal) to accelerate the use of marine control technologies.

2) Link scientists and engineers to work on control methodologies. Accelerating development of effective and logistically manageable approaches to HAB control hinges on synergy between science and engineering, which currently is rare in this field. New steps are needed to organize j oint symposia and workshops to foster these interactions. Feedback on new designs will be essential, especially from application experiences in different habitats, so combining these workshops with training and reporting efforts from industry and resource managers would be invaluable.

3) Increase investments in HAB control research at national and sub-national levels. Current levels of funding for HAB control research in many cases are far below the economic impact of recurrent HAB events. Attracting private sector investments in HAB control requires promotion of promising findings from small-scale field testing and a more robust pipeline of new ideas.

4) Promote partnerships with the private sector, including the insurance industry. Translating promising control methods from laboratory to in-situ scales, and other engineering solutions such as product licensing, storage, transport to affected areas, and application of control solution to the bloom requires levels of investment that exceed those of normal science-

funding agencies. Decisions by industries to make these investments center on the potential commercial viability of the product or methodology (highlighting the recommendation A3). Involving companies that insure against HAB-related losses at early stages can help guide decision-making on the practical benefits of potential HAB control strategies.

5) Explore combinations of existing and new technologies. While the effectiveness of the single-strategy HAB control approaches can vary widely, there has been little effort on the potential benefits of combining methods that use different mechanisms for control (e.g. remove cells vs. destroy toxins). Taking this approach may lead to better outcomes faster than undertaking prolonged efforts to maximize the effectiveness of any one method.

6) Create “incubators” where HAB control technologies can be tested and validated for larger-scale field evaluations. A major roadblock to developing HAB control methods in many nations is the circular problem that methods cannot be field-tested until they are shown to have no, or manageable harmful effects, but obtaining this evidence requires that they be field-tested. A network of international sites should be designated for small-scale field testing of bloom control technologies in a controlled setting. These facilities should engage a research management process that follows a structured path, with decision thresholds to discontinue testing of technologies that fail one or more of accepted field-feasibility criteria.

7) Streamline the regulatory processes governing in situ testing of HAB control approaches. Regulatory approvals for in situ testing are often unwieldy, requiring extensive submissions to multiple agencies. The approval process should be simplified at national and regional levels, not by weakening oversight but by using existing regulatory approval criteria for similar treatments used in other conditions (freshwaters, wastewater treatment, oil/gas/mining remediation, pesticides). This reorganization would allow the use of existing research data on products, greatly reducing the cost and complexity of developing HAB control in marine waters.

8) Harness advances made in freshwater HAB control. HAB control in freshwater systems is far advanced compared to that in marine systems. Interactions between the two communities could help identify and develop methodologies for cell removal or suppression, in addition to practical and economical methods for dispersing algicides over large areas.

9. Severe HABs should be treated like other extreme events or natural disasters. As shown by (Alvarez et al., 2024), some severe HABs have impacts that may exceed those of other extreme events, for example, hurricanes in Florida. For the purposes of emergency response, severe HABs should be treated like other extreme events. This is only a small subset of all HABs, so criteria should be developed to determine which are classified as extreme events.

C. Gaining societal support for the research on, and implementation of HAB control.

1) Support social and behavioral science research on responsible development and implementation of control strategies. No bloom control approach is sustainable without social acceptance. Developing effective communications strategies to gain public awareness and trust hinges upon understanding the levels of public knowledge, attitudes and perceptions. This understanding, in turn, can guide the types of education, changes in laws, or economic incentives needed to gain acceptance of HAB control. All this is facilitated by strong coordination among researchers, stakeholders, community leaders, and decision-makers.

2. Develop and encourage public and stakeholder co-development, outreach and support. The successes of HAB control should be shared widely with the public and stakeholders to gain support for these activities. The successes of public engagement in identifying new solutions for HAB control have been shown in Korea, where funding competitions are open to the public to share and test their ideas.

Synopsis

The growing array of global HABs and their impacts is large and varied, threatening human health and the health of marine and freshwater wildlife and ecosystems upon which many nations rely on for food, recreation, tourism and a plethora of other goods and services. Bloom control strategies have moved from a little studied area of HAB science to a major priority in several countries and regions, but practices to control HABs in marine systems remain absent in most nations. Not all HABs can be or should be controlled. In many cases alternate strategies of managing impacts through mitigation strategies (e.g., harvest closures) are more appropriate. Even when control is desirable, decisions for its implementation must be weighed against the ecological and human impacts that will occur without treatment. Nevertheless, we lack a suitable range of tools for effective bloom control for cases where HABs are causing extreme impacts on coastal tourism, ecosystem services, human health, or aquaculture facilities. The need for acceptable and effective HAB bloom control methods will only grow in the coming decades as societies increasingly rely on marine waters for food security and other critical resources. Stimulus is needed if we are to accelerate research and development of bloom control strategies to meet this need.

8. Acknowledgements

This work is a result of two recent workshops, the first being held in Seattle, WA, from 21-22 October 2023 in association with the North Pacific Marine Science Organization (PICES) Annual Meeting and was titled (W3): GlobalHAB International Workshop on Solutions to Control HABs in Marine and Estuarine Waters. This workshop was held with support from the Global Harmful Algal Blooms (GlobalHAB) Programme and PICES. The second workshop was a 3.5-day HAB Control Writing Workshop, from February 27-March 1, 2024, held in Forks, WA, at the Olympic Natural Resources Center, a field facility of the University of Washington, and supported by the NOAA National Centers for Coastal Ocean Science and PICES. We thank these organizations for their support of this work. We acknowledge Dr. Zhiming YU, Dr. Xiuxian SONG and Dr. Xihua

CAO for their help with this manuscript. DMA was supported by the Florida Red Tide Mitigation and Technology Development Initiative, State of Florida, Florida Fish and Wildlife Conservation Commission grant to Mote Marine Laboratory (initiative agreement #19153) and by funds provided by the NOAA PCMHAB program through NOAA Grant NA21NOS4780156.

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Appendix 5

SG-GREEN Final Report & Recommendation

Study Group: Generating Recommendations to Encourage Environmentally-Responsible Networking (SG-GREEN}

Final report and recommendations

Authors: Vera L. Trainer (USA), Hiroya Sugisaki (Japan), co-chairs; Robin Brown (ex-officio representing PICES), Sung Yong Kim (Korea), Jae-Hyoung Park (Korea)

Executive Summary
With Decision 2022/S/4(ii), PICES approved the Study Group on Generating Recommendations to Encourage Environmentally- Responsible Networking (SG-GREEN). This group conducted a survey of PICES participants, consulted with other international science organizations and Regional Fisheries Management Organizations, reviewed published information and conducted a beach cleanup session at PICES-2024. A detailed analysis of the survey of PICES participants was published in PICES Press. This final report provides recommendations from the Study Group for each of the Terms of Reference and additional information that supports these recommendations.

Background:
The CoVID-19 pandemic has accelerated the need for and expansion of remote conferencing capability worldwide. While there may never be a complete replacement for the social events and serendipitous brainstorming provided by in-person meetings, the urgency of climate change impacts of global travel has highlighted the importance of a balanced approach to sharing scientific knowledge through a combination of remote conferencing and in-person meetings. Similarly, a targeted focus on the UN Decade of Ocean Science for Sustainable Development (UNDOS) has brought to light the importance of remote conferencing as a platform which can provide increased opportunities for under-represented people and countries to be heard, despite economic, travel, or other limitations. Also, some EU countries are now limiting scientist's travel in recognition of the urgent need to address the climate crisis. This discussion on greenhouse gas (GHG) impacts of travel also attracted some parallel discussion on other 'green' implications of international science activities.

PICES has the opportunity to play a leadership role in exploring the appropriate balance of; in-person and remote meetings, pursuing practices leading to the reduction of greenhouse gasses (GHGs), and exploring potential investments in climate-responsible industries, thus providing an example for the international community. This will create a lasting positive legacy for PICES well into the future, that helps improve environmental justice, equity, and diversity in planning its engagement with the worldwide scientific community.

Terms of Reference:
1. Identify a mechanism agreeable to all PICES member countries for sustained green meetings within the PICES scientific structure. In particular, to establish a mechanism that is inclusive to under-represented people and communities, early career ocean professionals, etc.
2. Create recommendations for PICES on best practices to reduce GHG emissions and waste relative to meetings

3. Establish organization-wide green initiatives, such as: eliminating single use plastics, reduced printing, reduced purchases of single use or limited use items at meetings, including meeting gifts.
4. Exploration of PICES investment in climate-responsible industries.
5. Provide recommendations for best practices in purchasing carbon offsets for members for face-to-face meetings, including suggestions for including offsets as part of the conference registration fees
6. Provide suggested actions to promote PICES green initiatives and climate change information.

Final Recommendations - Summary

In-Person Annual Meetings (TOR 1, 2, 5)

a. Meetings should be as compact as possible because countries are allowing only a certain number of days for travel. Potentially move to shorter talks with brief questions, then open for longer discussion after all speakers in that session.
b. Tools such as Whova (an event management application for in-person, hybrid and virtual events) are a fantastic way to save paper used for printed agendas and to connect with people at the conference.
c. Provide lunch for workshops – hold them during lunch or afternoon. This will allow the annual meetings to be more compressed by optimizing the hours available for PICES work within a restricted number of meeting days.
d. Compress the annual PICES meeting. Hold business meetings online in advance of the annual meeting to allow for no business meetings in person or at least shortened business meetings during the annual meeting.
e. Presentations are available online on PICES website, pending approval by authors. Please make it widely known once presentations are available!
f. Explore including carbon offsets in the PICES Annual Meeting registration fee as an optional add-on, as requested in the PICES survey results.

Virtual & Hybrid Meetings (TOR 1, 2)

g. Have 2 people leading online meetings – one who is chairing and the other making sure that everyone is seen and heard.
h. Use the raise hand function (mandatory) for online and in-person attendees. By having everyone logged into the meeting on their computers, all participants feel valued and included.
i. Continue to review technology for virtual meetings (e.g. Whova or Gathertown for poster sessions)
j. Hybrid format should be used for all business meetings when possible, with possible short business meetings (1-2 h). Or perhaps consider (when technology has improved) completely virtual Annual Meetings every 2nd year.
k. Online meetings are better for non-native English speakers. Using the raise hand function gives an opportunity for all to participate, however internet access can still be a problem in some countries.

Partnership with Other Organizations (TOR 1, 2, 3, 4, 5, 6)

l. It was proposed to have a new SG as a collaboration with other international organizations. How do we get to net zero? This would be a Study Group on Sharing Best Practices.

m. Partner with other organizations…OECD (Organization to Economic Cooperation and Development) and international groups such as ICES, Ocean Solutions, Professional Societies (ASLO, AGU, ISSHA), APN, ECOP, (ONCE part of ISO, International Standards Organization) and organize a joint workshop. Continue to share "greening" strategies with other international organizations.

Recycling (TOR 1, 2, 3)

n. Reuse plastic name tags and announce on Whova that they are reusable.
o. PICES coffee cup as a swag item (cleanable). The reusable utensil set was very popular.

Investments (TOR 4)

a. PICES Secretariat and Governing Council should continue to investigate potential investments in climate-responsible industries.

Community Engagement (TOR 6)

b. Continue holding beach cleanup events or other environmentally-focused community outreach events, such as the beach cleanup event held in collaboration with the Waikiki Aquarium in 2024 (see Appendix 1).

SG-GREEN Activities:

1. **On-line Survey**

An online survey of PICES members to help us understand how to make PICES meetings more sustainable was conducted from October 2023 to March 2024 in collaboration with S-HD. Chinese colleagues were contacted separately, as they are unable to use Google Forms (Pengbin Wang led this effort). The survey was also extended to PICES members who could not attend PICES 2023 annual meeting, and the deadline was extended accordingly.

The survey included demographic questions to understand the participants' backgrounds, as well as questions on preferences for attending the PICES annual meeting either online or offline, and on topics related to carbon offset and ocean preservation.

A total of 158 participants from 11 countries responded to the survey. A request for greater participation in the survey was published after the PICES Annual Meeting in PICES Press Vol. 32, No. 1 (https://meetings.pices.int/publications/pices-press/PICES-Press-2024-Vol32No1.pdf#page=60) and the overall results of the survey were published in PICES Press Vol. 32, No. 2 (Appendix 2 and https://meetings.pices.int/publications/pices-press/PICES-Press-2024-Vol32No2.pdf#page=57)

2. **Information from International organizations (TOR 1**

SG-GREEN and PICES Secretariat sent messages to a variety of international marine science organizations and Regional Fisheries Management Organizations (RFMOs) asking for advice and experience with 'greening" of scientific meetings and related activities. We shared the results from the PICES survey conducted at PICES-2023 and asked the following questions:

a. Is your organization conducting similar efforts on "green conferencing", carbon offsets and ocean preservation issues? If so, would you like to share your results and insights?

b. Are you aware of other scientific groups/organizations who are conducting such work?
c. How do your considerations of "greening" of operations impact the ability of your organization to interact with PICES and other international organizations?

In general, we received very few responses, perhaps suggesting an opportunity for PICES to lead the charge in greening of meetings. Again, this suggests that a Study Group on Sharing Best Practices could be very helpful to guide international groups on greening of their meetings. The responses are summarized in the following table:

Organization	**Response**
ICES	ongoing discussions between Secretariats. Some policies have been developed for joint ICES/PICES activities as outlined in Section 3 for the MSEAS Symposium. There is a review of ICES experience with hybrid meetings in Section 5 below.
NPFC	nil response
NPA FC	NPAFC is conducting internal discussions on the important issue and will respond after this consultation is complete
ISC	Nil response
SOLAS	Nil response
SCOR	Nil response
NOWPAP	"Yes, our organisation (both NOWPAP and UNEP) are fully compliant with the current policy of UN to reduce our carbon footprint in relation to travel (downgrading travelling class, choosing the most direct route, etc,) and meetings (in addition to the latter – also encouraging holding meetings online to reduce travelling required. UNEP collects and assesses all information in relation to the carbon footprint. There are also measures introduced to avoid using of plastics. And this is relevant not only to scientific meetings but to meetings and travelling in general" (https://www.unep.org/about-un-environment/sustainability/environmental-performance)

3. **Literature and informational websites on carbon offsets**

Carbon offsets for travel, tourism, and shipping may be one of the most misunderstood and controversial topics in sustainable travel. There are many sites that promise exact carbon offset metrics per dollar spent, and others that leave the subject very vague. Unfortunately, there is no standard for purchasing or investing in carbon offsets, and the truth is that they are complicated and don't always work like they should, or as they're advertised. For example, in one particular instance one of the largest carbon offset suppliers employing protections for large areas of rainforest, were recently reviewed by scientists that analyzed their methods and outcomes. Analyses of their carbon offsets found that the offsets overstated their impact on deforestation (West et al., 2020). Thus, we are left wondering if carbon offsets are a viable option for sustainable travel, and if so, what the best options are.

For PICES purposes, given that we do not have the expertise or means to fully research projects in which to invest, we could follow what other large organizations have employed. For example, Marine Socio-Ecological Systems (MSEAS) has initiated a "Plastic and Carbon Policy" at their 2024 meeting. The statement on their 2024 meeting website states the following.

> ***Plastics use policy***
>
> *The organizers of MSEAS-2024 are actively seeking to minimize the use of single-use plastics and other waste at the conference, and are working with the Local Organizing Committee to achieve this. We recommend that participants bring their own reusable beverage containers. More information will follow.*
>
> ***Carbon offset policy***
>
> *The Convenors of MSEAS 2024 ask that you carefully consider the carbon cost of attending this conference.*
>
> *There are many discussions of ways to limit carbon emissions. If you plan to attend the conference then purchasing offsets is one of the simplest options available, and a range of airlines that offer carbon offset options can be seen at: https://thepointsguy.com/guide/everything-you-need-to-know-carbon-offsetting-flights*

Based on the above statements, it seems that MSEAS has left it to their constituents to manage carbon offsets on their own. PICES could go a step further and use information and tips from the article above (among other resources) to form a guide for PICES members. In addition, PICES could play a direct role in carbon offset purchasing if finances allow and there is consensus on a path forward.

An overview of key points taken from the article linked above, follow.

CO_2 basics

Airplanes emit various particles and gasses, including carbon dioxide (CO_2), into the atmosphere. In this article, we focus on CO_2 because it makes up 65% of global greenhouse emissions.

CO_2 is one of several greenhouse gases that occur in the atmosphere. When functioning properly, greenhouse gasses regulate the earth's temperature.

Estimating your carbon footprint

The US Environmental Pprotection Service (EPA) website has a Carbon Footprint Calculator but doesn't include flights

There are many calculators that can be used to estimate the carbon emissions related to flights. Many are simplistic and give a rough estimate by considering your mileage flown (*then links to site to do a simple calculation for yourself*).

Some calculators go a step farther and consider your class of service, since larger seats take up more space and hence account for a greater amount of fuel used per passenger. *These are all just estimates and change based on cargo weight, headwinds, plane shape/type, etc.*

Critics of carbon offsetting say that spending to offset emissions merely allows polluters to feel better about their emissions and discourages working to reduce them.

While there may be some truth to that, if you're going to fly, offsetting your carbon emissions by supporting the right projects is better than doing nothing.

Certified carbon offset organizations

Many companies and organizations are willing to take your money. Unfortunately, not all of these provide high-quality carbon offsets.

Some companies have entire teams that evaluate carbon offsetting projects to ensure that they are high-quality. *However, as stated above, PICES does not have the resources, time or access to evaluate individual projects in detail.* **The next best option is to get suggestions from environmental organizations you trust or well-recognized organizations that list certified and verified carbon offsetting projects.**

Three organizations that provide such listings are Gold Standard, Green-e and Climate Action Reserve.

On each organization's website, the projects are sortable by location and offset type(s).

Gold Standard makes it easy to donate to a particular project on their website, while Green-e and Climate Action Reserve refer you to individual projects

The site then moves onto suggestions for reducing individual emissions and lists all of the airlines with carbon offset programs and how each generally works.

Reduce your emissions

The most effective way to reduce your CO2 emissions is to reduce your fossil fuel consumption. This could mean having a teleconference instead of traveling for a meeting. If you do travel, you can reduce your footprint by taking vacations closer to home, flying nonstop when possible, taking a bus, train or fuel-efficient vehicle instead of a short-haul flight, booking a flight on a more fuel-efficient aircraft, flying economy class instead of business class.

Airline Carbon Offset Programs

Most airlines have internal practices and plans to decrease their carbon footprint. But, as some passengers become increasingly concerned about the carbon emissions associated with their travel, some airlines have started offering customers the opportunity to get involved.

This section of the article describes some carbon offsetting programs offered to customers by airlines. For each of these programs, participation by customers is completely voluntary and independent from the flight booking process.

4. **PICES investment in climate friendly industries**

In a discussion of SG-GREEN with the PICES Secretariat, the possibility of PICES investment of climate-friendly industries was discussed. PICES has short term investments of funds held in accounts that currently do not offer an opportunity for investment in climate -responsible industries. PICES is one of seven organizations in the International Fisheries Commission Pension Society. The IFCPS manages and invests aggregated funds from the organizations (all headquartered in Canada or the USA) and contributions to meet the pension commitments of the partner organizations. The IFCPS investment plan does include ESG (Environmental, Social and Governance) considerations when selecting investments and in fact climate change and carbon emissions is of importance to the member Commissions given their areas of responsibility. The Statement of Investment Policy and Procedures has the following language: "The Pension Society expects the Manager of Managers to report regularly (at least annually) on ESG rankings of the investment managers, carbon intensity and other key indicators to help it assess progress in managing ESG risks and opportunities". At a review, in November 2023, members discussed the complexities of carbon emissions and other contributors to climate change as well as related government policies that may influence investment risks, which speaks to the fact that climate-responsible investing is already a routine consideration at each annual meeting of the Society.

5. **Hybrid meeting considerations**

The PICES Secretariat has participated in a few hybrid conferences in the past year, including PICES-2022, ECCWO5 and the ICES ASC. A summary of their impressions is here: to run a hybrid meeting requires resources – technology and personnel. This is best done by a professional company and that comes with a cost. For the three events above production companies were used for each but the costs were NOT passed onto the registrants - registration fees for remote participants were subsidized by the sponsoring organizations. There are also still technical challenges – despite professional companies running the online portions both ECCWO5 and the ICES-ASC had connectivity issues. For PICES annual meetings the costs of the venue are covered by the host country. Hybrid annual meetings would be more expensive than the current in-person only model. Countries would save on travel costs but those are distributed among agencies and institutes and from different budgets, so it is not so easy to calculate or demonstrate savings. We have also had members tell us that even for virtual participation, travel approval is still needed for them to be able to pay a registration fee. For PICES-run International Symposia the registration fees cover the venue costs for the most part, with some additional contributions from organizations. If events are to be hybrid, then the organizers would need to decide whether the additional costs are shared by all registrants, or online costs are covered by online registrants. It is likely that fees for online participation would be as high, or higher, than fees for in-person participation if this was put in place and it is not clear people would be willing (or able) to pay (even if they save on time and travel costs). Whichever way the costs are apportioned, costs for running the meeting would definitely increase and registration fees would have to, as well. Hybrid definitely allows more people to participate, and if the sessions are streamed then there are recordings available which could be used as a resource after the meeting has ended. This was done for ECCWO5 (207 videos of talks are available where the authors gave permission) but so far there are not many views of the presentations. ICES Secretariat were kind enough to send their initial review of this year's ASC and here are some points relating to the hybrid component:

- Collectively, attendees watched more than 1,000 hours of conference video content, either live streamed or as recordings of sessions. Around 75% of this was from remote attendees watching the live streamed sessions.
- The experience for online attendees and speakers, and for conveners to incorporate hybrid into their sessions was mixed. Feedback points at difficulties in several areas and a lack of engagement from the remote audience. To some, including the videos from remote speakers had a negative influence.
- ICES staff report - Wide consensus that hybrid with live streaming is not preferred compared to a fully in-person conference, and that it diminishes the quality of sessions while costing lots of resources.
- Hybrid option is great for accessibility. If continuing to keep ASC online, advertise it a lot to have more online users. Keep experimenting with the hybrid format, consider if hybrid could be in select sessions only, and the cost not absorbed by ICES.
- From a feedback survey: Participants top three reasons to join online are cost reasons, institute not covering travel and to save CO_2. Online participants rated their satisfaction with the online experience a 2.2 out of 5. This reflects the feeling of remote participants that they were not able to participate in the sessions, as 62.5 % gave this answer.
- From a feedback survey: The experience of conveners of running a hybrid session varied from stating that the interaction with remote participants ruined the flow of the session and proved to be challenging, to ignoring remote presenters and having a great experience thanks to the technical team.

Cost of ICES-ASC hybrid:
There were costs relating to the hybrid setup of the venue that their Local Organizing Committee (LOC) covered and so aren't included, but for the remainder (Production company, additional ICES staff, IT software, etc.) it amounted to 356 Euro (CAD$ 515) per remote attendee, or $63 per livestream view.

Although it is agreed that watching a recorded presentation from a remote presenter is less engaging for the live audience, from a logistics perspective it is too challenging to rely on a live remote presentation. There are connectivity challenges that can occur with no warning, for anyone, and sound quality issues that often occur too. It makes it much less stressful for organizers and convenors to know that all the presentations in the session are ready to go, either as a PowerPoint given by someone in the room, or a video to play. There is merit in PICES and ICES continuing to share information and recommendations on hybrid possibilities, whether informally like this or through a dedicated meeting.

Appendix 1.
Beach cleanup activity, PICES 2024.

Appendix 2. SG-GREEN survey report

Vol. 32, No. 2 | Summer 2024 PICES PRESS NORTH PACIFIC MARINE SCIENCE ORGANIZATION

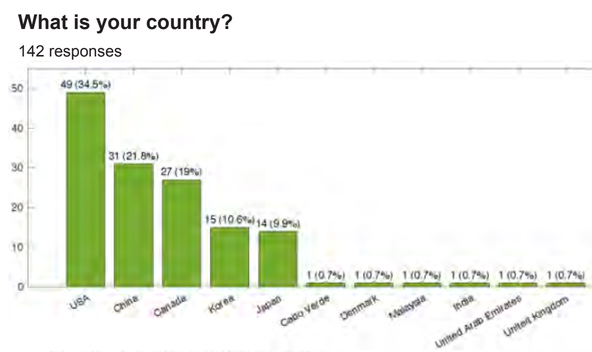
PICES by the Numbers: Survey on Reducing PICES Impacts on Climate Warming and Environment Restoration Activities (SG-GREEN)

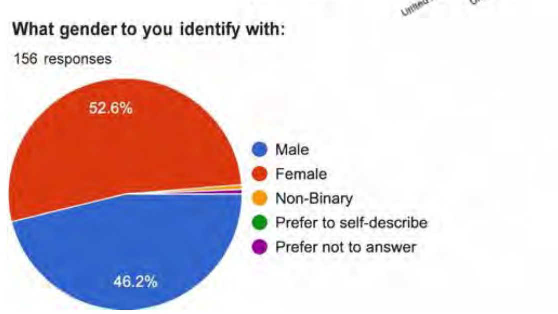
Vera Trainer, Hiroya Sugisaki, Robin Brown, Sung Yong Kim, and Jae-Hyoung Park

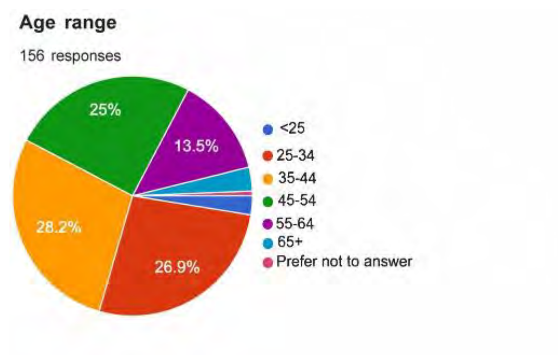
Climate scientists need to meet in a responsible manner. Our plan to reduce the impact of PICES on climate warming is part of the integrity of the organization. At PICES-2023 and over the months that followed, the SG-GREEN (Study Group on Generating Recommendations to Encourage Environmentally-Responsible Networking), with the help of the Human Dimensions Committee, conducted an online survey to query the PICES membership about their interest in changing how we meet, purchasing carbon credits to offset the cost of meeting in person, participating in beach clean-up, and other environmental activities. Given that many of us are climate scientists and care about the future of our planet, the responses to surveys show an overwhelming interest in changing the way that we do business. The survey was divided into questions about 1. Demographics, 2. Annual meetings, 3. Carbon offsets, and 4. Ocean preservation activities, and the results are summarized below.

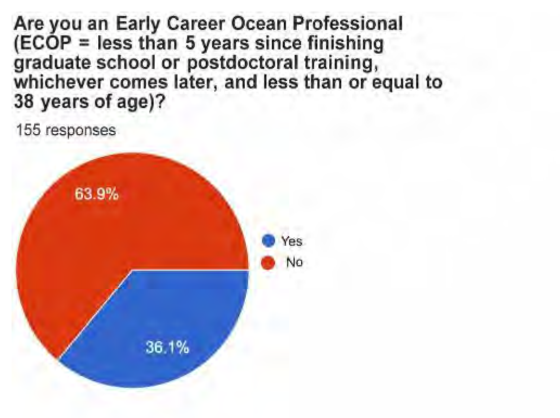
Demographics

Summarizing the demographic section, approximately 158 members completed the survey, with 53% identifying as female and 46% identifying as male. The age ranged from <25 to >65, with 36% identifying as Early Career Ocean Professionals (ECOPs). Most respondents were in the ecology, biology or fishery area of study (n=109) with others specializing in various areas of oceanography, including physical (12), chemical oceanography (8), general oceanography (8), polar oceanography or social science/ management (7).









What is your area of scientific study?
148 responses

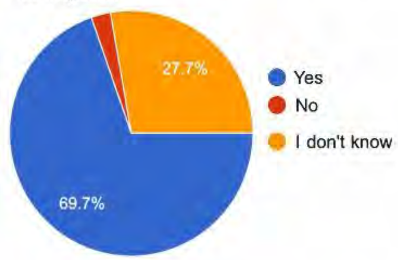
Ecology/Biology/Fishery: 109
Physical Oceanography: 12
Chemical Oceanograph: 8
Oceanography(broad): 8
Polar ocean: 2
Social science/management: 7

Annual Meetings

Most respondents felt that they would be allowed to attend the Annual Meeting in person (70%), even if there was a virtual option. However, for in person attendance, most people felt that their employer would require them to have a role, such as oral presenter, committee, or expert group chair. Approximately 60% of respondents stated that they would pay a registration fee to attend the PICES Annual Meeting virtually and would be willing to attend virtually (50%) if the meeting was outside their normal working hours.

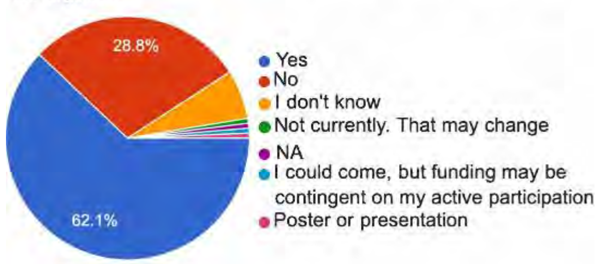
1. If there is a virtual option for a PICES Annual Meeting, will you be allowed to travel to attend the in-person meeting?

155 responses



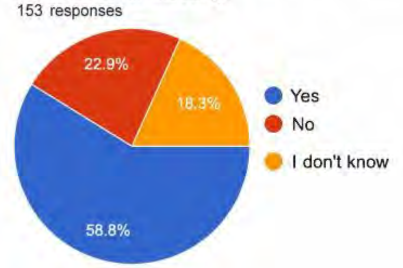
2. For in-person attendance, would your employer require you to have a role at the PICES annual meeting, such as oral presenter, chair of expert group, committee chair?

153 responses



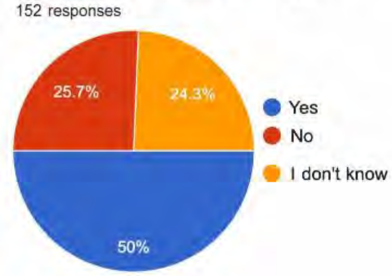
3. Will you pay a registration fee (less than the in-person registration fee) for virtual participation at a PICES Annual Meeting?

153 responses



5. Will you attend the Annual Meeting virtually if the meeting schedule is outside of your normal working hour, e.g. very early morning or at night?

152 responses



6. What approximate hours are you willing to attend the meeting?

Most participants prefer: 9:00-20:00 (local time)

4. What parts of the PICES Annual Meetings should be held in person?

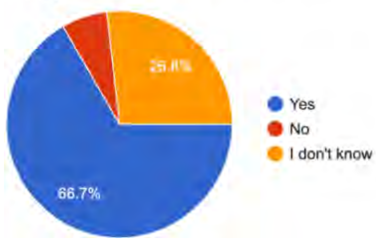
149 responses

Carbon Offset

There were strong feelings about carbon offsets, including 67% stating that PICES should provide recommendations on purchase of reliable carbon credits. Some respondents felt that a carbon offset fee should be included in the PICES registration fee (47%) while others felt that this fee should be paid by PICES as part of their annual operating costs (38%). Over 71% stated that they would like carbon offset recommendations to be a topic for a PICES expert group, which is why SG-GREEN members currently are writing a proposal for a new Study Group on this topic.

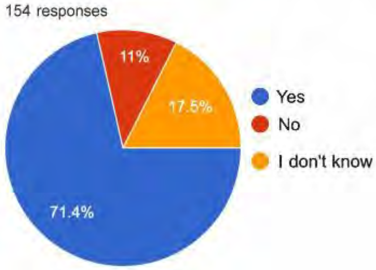
8. Should PICES provide recommendations on purchase of reliable carbon credits to offset the greenhouse gas emissions associated with PICES meetings? (carbon credit = a reduction, avoidance or capture of greenhouse gas emissions achieved by a certified project. One carbon credit represents the reduction or removal of one tonne of carbon dioxide or its equivalent in other greenhouse gasses)

153 responses



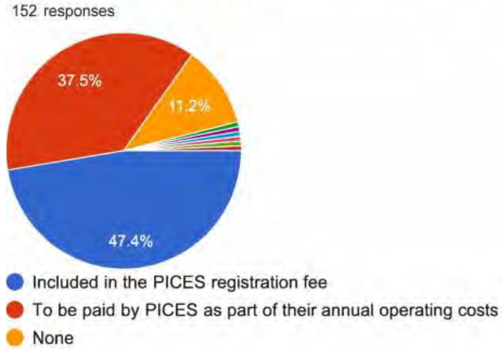
9. Would you like to see carbon offset recommendations (effectiveness, cost, etc.) a topic for a PICES Expert group to research?

154 responses



10. Would you be in favor of a carbon offset fee to be (select one option)

152 responses

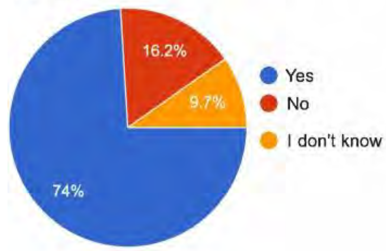


Ocean Preservation

A strong majority (74%) wanted to see a beach cleanup activity (and would participate in this activity) or other restoration activity as part of the PICES Annual Meeting, which is why SG-GREEN members currently are working with the PICES Secretariat to organize a beach clean-up activity in Honolulu during PICES-2024. 88% of the respondents are in favor of PICES eliminating plastic products (name tags, plastic bottles, cups etc.) at the annual meeting. Over 72% felt that PICES member nations should contribute an annual fee toward carbon offsets or another green project, such as habitat restoration.

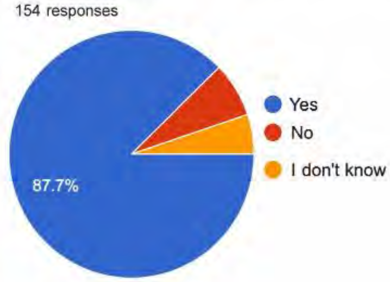
12. Would you participate in a PICES-sponsored beach cleanup or other restoration activity during the Annual Meeting?

154 responses



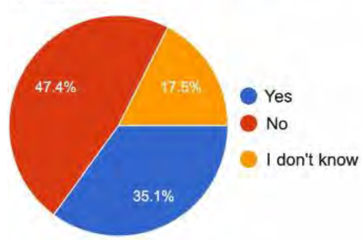
13. Are you in favor of PICES eliminating plastic products (name tags, plastic bottles, plastic coffee cups etc.) at its annual meetings?

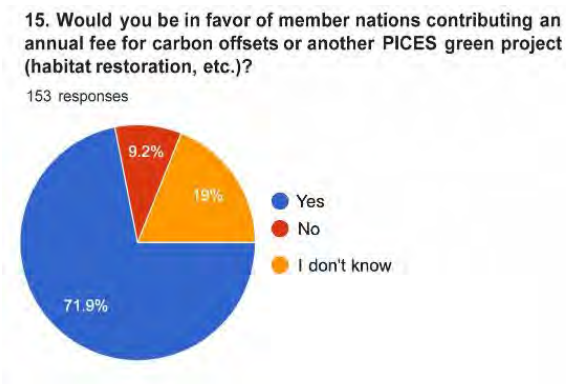
154 responses



14. Should PICES continue to provide meeting bags, stationery, and souvenirs, etc. at its annual meetings?

154 responses





In addition to the survey at PICES-2023, we have written to several of our partner organizations to ask how they are dealing with these questions. To date, we have heard:

- The Northwest Pacific Action Plan (NOWPAP) and the United Nations Environment Programme (UNEP) are compliant with the current UN carbon footprint reduction program relating to travel and plastic reduction. The travel policies include transitioning (where practical) to online/virtual meetings; travel by most direct routing, and other measures. UNEP collects and assesses all information in relation to the carbon footprint. UNEP purchases Certified Emission Reductions (CERs) from projects in Developing Countries as mandated by the United Nations Framework Convention on Climate Change (UNFCCC). UNEP has been climate neutral for the past 12 years. The UNEP greenhouse gas (GHG) management and reporting program can be found at https://www.unep.org/about-un-environment/sustainability/environmental-performance
- The Asia-Pacific Network for Global Change Research (APN) reports that they have moved to online/virtual meetings (where practical) and holding face-to-face meetings back-to-back to minimize the travel GHG footprint. APN has not yet introduced carbon offsets.

We are still awaiting responses from several other organizations (ICES, NPAFC, NPFC, ISC, SOLAS and SCOR).

Clearly, the PICES community has strong feelings about working toward climate mitigation activities as part of the PICES Annual Meetings. The SG-GREEN would like us all to continue the discussion to find ways to offset the cost of meeting in person to lead the way in collaboration with other international organizations.

Acknowledgments

Our thanks are extended to Mitsutaku Makino and the PICES Human Dimensions Committee for helping create the SG-GREEN survey.

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