2024 Report of Section on Ecology of Harmful Algal Blooms in the North Pacific (S-HAB)

For the past five years, S-HAB annual meetings have been held online prior to the PICES annual meeting in a shortened, two-hour format, greatly restricting interactions and progress. This year, we were pleased to resume the S-HAB annual meeting in person.

The 2024 S-HAB annual meeting was co-chaired by Drs. Pengbin Wang (China) and Mark L. Wells (USA) and attended by 12 members on site and 1 member online (see picture below). The meeting began with welcoming comments from both co-chairs and, as new members/participants were present, this was followed with short introductions from each participating member. The provisional agenda had been shared among participants ahead of the meeting and was adopted as proposed. The meeting was attended by members from five PICES member countries (*S-HAB Endnote 1*). The provisional agenda for the meeting (*S-HAB Endnote 2*) was reviewed and was approved by the Section.

On site, from L to R: Charles Trick, Yoichi Miyake, Setsuko Sakamoto, Yoshida Takafumi, Natsuko Nakayama, Ryoko Yano, Minji Lee, Mark L. Wells, Svetlana Esenkulova, William Cochlan, Misty Peacock, and Pengbin Wang. Online: Andrew RS Ross.

AGENDA ITEM 2
HAB Country Reports

Summaries of the HAB country reports are presented here (from East to West this year). In many cases, these data are for 2023 as the 2024 data were not available in time for the meeting. These presentations inform each PICES nation of occurrences across the Pacific region, with the intention of better understanding the broader driving mechanisms underlying these HAB events.

A. <u>USA</u>

Reported by: Misty Peacock (Northwest Indian College), William Cochlan, Mark Wells, and Vera Trainer

Overview – West Coast incidences of HAE produced mostly Domoic acid, and PSTs, though there were also reports of DSTs, shellfish killing toxins (yessotoxin), and evidence of freshwater cyanotoxins transferred to marine habitats (including Alaska). There were continued incidences of marine mammal strandings in 2023-2024, with a current HAB event in California that is causing many marine mammal strandings. There was an extreme PSP event from Northern California to Washington that closed shellfisheries, caused 20+ human illnesses, and recalled commercial shellfish. In California, Oregon, and the Washington outer coast, closures were due to domoic acid routinely (CA and WA outer coast) and this year, PSTs (CA, OR, WA and AK). Continued efforts for more offshore HAB sampling, modeling/forecasting of domoic acid, ocean acidification and multi-stressor events, satellite/remote sensing for HAB, identification of new/emerging HAB, and freshwater toxin transfer to the marine environment are areas of interest for academic, governmental, and tribal harmful algae researchers. Use of IFCB technology is a key technology and the US west coast network is expanding, with California's network being a stand-out highlight of monitoring changes in phytoplankton community changes over the course of a major *Pseudo-nitzschia* event. Several NOAA ECOHAB and MERHAB projects were funded in 2024 to address HAB on the west coast, including rapid response funding due to the PSP event.

California is monitored by HABMAP, Coastal Ocean Observing System, and multiple state, federal, academic, private, and tribal partners for harmful algae and toxins. There were punctuated *Pseudo-nitzschia* reportings in Southern-Central California, typically in spring, though it continued into fall 2024.There were marine mammal strandings during the early summer in California (many) and currently CA is in a large DA event, which is causing many mammal strandings. *Alexandrium* incidences were infrequent in southern California but were present above 10 000 cells/L in central and northern California. Northern California was closed due to PST toxins in shellfish in July of 2024, with concentrations between 600-800 ug STX eq/100 g shellfish. Closures due to *Dinophysis* and DSP events were not reported, and *Dinophysis* was infrequent in samples. There were multiple ASP commercial and recreational harvest closures throughout California. Southern and Central California experienced the longest closures while closures elsewhere were short-lived. California continues to produce a state-wide HAB newsletter (CA HAB Bulletin), weekly updates by email, and use of the C-HARM model for Domoic acid forecasting. Central and Southern California have also began including freshwater toxins found in the marine environment in weekly/monthly updates to the harmful algae community. There is a statewide Imaging FlowCytobot System for harmful algae which can be accessed at https://ifcb.caloos.org/dashboard which is now also available in the weekly HAB bulletin.

Oregon is monitored for HA by the ORHAB and SoundToxins monitoring programs, as well as the state of Oregon public health (shellfish). In 2023 from north to south, there were higher cell counts for *Pseudo-nitzschia* (both large and small) and greater concentrations of pDA, with toxic events happening in April–June, and September–November. Throughout 2023 both *Alexandrium* and *Dinophysis spp*. were present periodically at sampled sites. In November 2023, and periodically during May–August 2023, the southern Oregon coast was closed to shellfish harvesting due to domoic acid. There were minimal reported marine mammal strandings due to biotoxins. In May 2024, there was an unprecedented public health emergency for PSP over a 3-day holiday weekend, which closed commercial and recreational shellfish harvests, and had some PSP readings above 5000 ug STX eq/100 g shellfish. 21 people reported falling ill and commercial product was recalled from 8 states.

Washington is monitored for harmful algae by the ORHAB, SoundToxins, Washington Department of Health programs, and tribal nations. There were PSP events in multiple counties of Washington, along the entire coast of Washington State, including the inland Salish Sea. The State analyzed approximately 2500 shellfish samples for PSP, DSP, and/or ASP. There were multiple commercial and recreational closures. ASP events are confined to the coast (southern Washington) though *Pseudo-nitzschia* was seen throughout Washington state sampling locations, and into the South Salish Sea (Puget Sound), including in the North Salish Sea, in September. DSP events were mostly confined to inner Puget Sound and closures in southern Washington, including commercial closures. DSP events for recreational shellfish for DSP in northern Washington happened in August 2024. In Northwest Washington, there were more than 50 subsistence harvest closures for PSP and/or DSP events in 2023. Many beaches, including tribally-controlled beaches are currently closed due to PSP in northern Washington. Southern Washington was included in the PSP outbreak in May–July 2024, and the entire coast (to the northern border with Canada) was closed during the first weeks in June because of the PSP event. There were fewer shellfish die-offs compared to 2021. Monitoring efforts to identify other yessotoxin shellfish die-off events are currently ongoing, as is the implementation of an IFCB network. There is also work being done to monitor for DA offshore of the Washington coast using an ESP. DSP and PSP events did continue into the winter (January and February) in 2023. Several NOAA ECOHAB and MERHAB projects to monitor for HAB (using IFCBs, AUVs, ESPs, and more traditional methods) were funded for Washington state, as was support to expand data collection through citizen science, tribal, academic, and state partners.

Alaska is monitored by Alaska Harmful Algal Bloom network (AHAB), SoundToxins, Southeast Alaska Tribal Ocean Research (SEATOR), Kachemak Bay National Estuarine Research Reserve (KBNERR), Alaska Sea Grant, Aleutian Pribilof Island Association, NOAA, and other tribal, governmental, and academic groups. Elevated levels of PSTs found in shellfish continue to be found throughout the year at various SE Alaska beaches. In SE Alaska, approximately 1000 shellfish and 500 water samples were monitored for *Alexandrium* and PSTs, including cysts. A massive offshore *Alexandrium* bloom and PST was documented with a shipboard IFCB in 2022. Efforts to investigate the Arctic waters for *Alexandrium* are ongoing and there is an Alaska IFCB network in place. Near commercial and subsistence geoduck beds, an alarming number of *Alexandrium* cysts were present, but there has (of yet) been no correlation between cyst presence and winter geoduck toxicity. Alaska shellfish and fish samples continue to document some of the highest (ever) recorded concentrations of PSTs in seafood. The Aleutian and Pribilof Islands sampled weekly in 2023-24, and like Kodiak sampling, blue mussel samples were sometimes above the regulatory limit for PSTs. The Bering Sea had clams with elevated PSP levels, and both ASP and PSP were found in stranded or harvested marine mammals' stomachs. Similar to other US west coast states, Alaska has newly funded ECOHAB (NOAA) projects aimed at monitoring for PSTs and domoic acid by mapping cell densities and health assessments from marine mammals. Alaska has the most extensive network of citizen scientists monitoring for (mainly) PSTs, where 100% of coastal Alaskans subsistence harvest. The AHAB network and website presence has been updated substantially in the last year and facilitates gathering HAB data into one location.

B. Canada

Reported by: Svetlana Esenkulova (Pacific Salmon Foundation) and Andrew Ross (Fisheries & Oceans Canada)

1. Harmful Algal Blooms (HABs) on the Canadian West Coast

Based on PSF Citizen Science Oceanography Monitoring program, in 2023, harmful algal blooms (HABs) were widespread in the Strait of Georgia (Esenkulova et al., 2023). Both 2023 and 2022 were the only years from 2015–2023 where all five HABs taxa formed dense (>100 cells/mL) blooms (Table 1). *Pseudo-nitzschia* bloomed in Cowichan Bay in April, while vivid orange Noctiluca scintillans blooms (up to 2000 cells/mL) occurred from May to July in various areas (Figure 1), drawing public attention and news coverage. Heterosigma akashiwo caused dense blooms (>1000 cells/mL) in late May, and Dictyocha blooms appeared in July–August, with a new record of 2000 cells/mL at Nanaimo's site. Additionally, *Rhizosolenia setigera* bloomed in late August and September. Non-toxic *Chaetoceros* species, harmful to fish gills, were found in approximately 8% of spring and fall samples, the second-highest rate since 2015. Toxin-producing *Alexandrium* and *Dinophysis*, responsible for shellfish poisoning, were less abundant, with *Alexandrium* levels (~1/4 lower than average) and *Dinophysis* present in ~5% of samples.

HAB taxa (max cells per mL)	2015	2016	2017	2018	2019	2020	2021	2022	2023
*Noctiluca scintillans**	1	2	2	3000	800	1	3200	1000	2000
Heterosigma akashiwo	6	150	20	11000	25000	7000	10	15000	11000
Dictyocha spp.	5	700	400	10	10	50	150	140	800
Rhizosolenia setigera	250	800	1800	4000	500	5	500	400	180
Pseudo-nitzschia spp.**	N/A	N/A	N/A	4500	30	70	1800	2000	350

*Table 1. Maximum concentrations (cell per mL) observed in routine PSF Citizen Science monitoring program samples. Notes: *Noctiluca maximum cell counts are from opportunistic samples obtained directly from the bloom; **routine Pseudo-nitzschia enumeration started in 2018, in 2015–2017 it was enumerated only if it was a dominant taxa in a sample.*

Figure 1. Noctiluca bloom in Maple Bay, May 24, 2023. Photo by K. Shehan, PSF (left panel). Noctiluca bloom in Brentwood Bay, May 28, 2023. Photo by S. Hocker, DFO (central panel). Noctiluca cell under the microscope (right panel). Photo by S. Esenkulova, PSF.

To date, the analysis of 2024 samples from the PSF Citizen Science Oceanography Monitoring program is not yet complete. However, preliminary results show thick blooms of *Noctiluca scintillans* (Figure 2) in April, May, and July. *Rhizosolenia setigera* and *Heterosigma akashiwo* cells were also detected in some areas during the summer.

Figure 2. Noctiluca bloom in Sechelt Inlet, April, 2024. Photo by Nicole Frederickson, PSF (left panel). Noctiluca bloom in Wilson Inlet, July 27, 2024. Photo by Ginny Sherrow (right panel).

2. Marine Biotoxin Monitoring on Canada's West Coast

Since 2020, Fisheries and Oceans Canada (DFO) has been operating a Marine Biotoxin Monitoring Program in BC coastal waters, using LC-MS/MS to track biotoxins like ASP, PSP, and DSP (Ross and Mueller, 2024). Collaborating with PSF Citizen Science and the salmon aquaculture industry, the program aims to understand harmful algal blooms and their impact on salmon and marine mammals. It has revealed seasonal biotoxin patterns and links to water temperature.

3. Harmful Algal Biotoxins on the Canadian West Coast

Data from the Marine Biotoxin Program, DFO provides insight into harmful algal biotoxins, including those responsible for amnesic (ASP), paralytic (PSP), and diarrhetic shellfish

poisoning (DSP). These biotoxin concentrations show a clear seasonal pattern and appear to correlate with rising water temperatures and harmful algae presence (Ross et al., 2023).
In 2023, ASP toxin (domoic acid) peaked in April in the Strait of Georgia, while concentrations along the West Coast of Vancouver Island (WCVI) peaked later in the year, often reaching high levels on the continental shelf. PSP toxins generally peak in the summer, although 2023 saw lower levels compared to 2022, with notable exceptions in WCVI, Malaspina Strait, and during fall in the Strait of Georgia. DSP toxin levels were also generally lower in 2023, except in Cowichan Bay, and yessotoxin was notably reduced in the Strait of Georgia and absent from WCVI. Additionally, azaspiracid AZA2 was detected in Malaspina Strait in September and October 2023.
On the WCVI, farm sites showed significant domoic acid (DA) concentrations, with Farm A (Figure 3) recording a peak of 100 ng/L in June 2021. By 2023, levels had decreased and were more similar between Farms A and B, with a peak of 49 ng/L at Farm A. During the August 2023 La Perouse cruise, DA concentrations off Barkley Sound spiked at 223.2 ng/L, indicating the presence of *Pseudo-nitzschia*. PSP toxins, while lower in 2023 at both farms, reached a peak of 1027.7 ng/L during the La Perouse cruise.

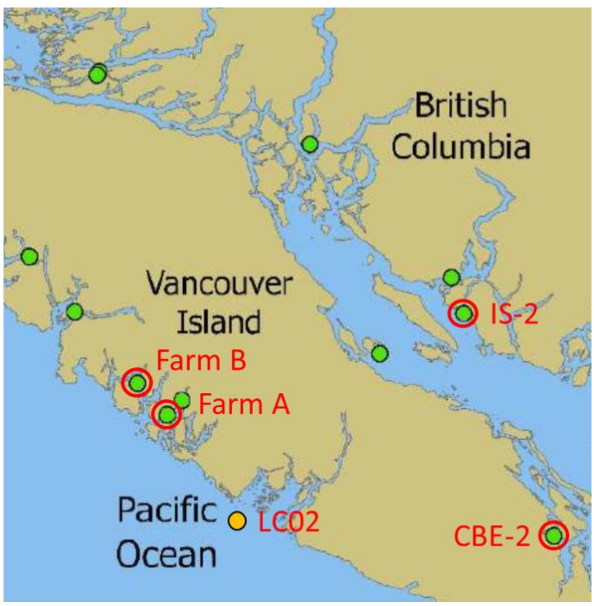

Figure 3. Long-term biotoxin monitoring locations near B.C. salmon farms (WCVI) and at PSF citizen science sites.

Seasonal monitoring in the Salish Sea further revealed that domoic acid and PSP toxin concentrations were lower in spring and summer 2023 compared to 2022, but higher levels were recorded in the fall. YTX and DSP toxins followed a similar trend, with 2023 showing reduced concentrations compared to the previous year (Ross et al., 2024).

Other notes

On the West Coast of Canada, several projects are focused on understanding harmful algal blooms (HABs) and the impacts. A new initiative is a collaborative project between the Pacific Salmon Foundation (PSF) and the Department of Fisheries and Oceans (DFO) that explores the potential impacts of harmful algal blooms (HABs) on juvenile fish under laboratory conditions.

Having received science merit approval, the project is now in its final planning stages. The experiment, scheduled for October, aims to assess the impact of the toxic *Alexandrium* on juvenile Chinook salmon. Using DFO's Salmon Fit-Chip technology, the project seeks to enhance this tool to better understand how HABs affect both wild and farmed salmon. By detecting HAB-related stress, this research offers a non-destructive method for monitoring the health of salmon populations in response to environmental challenges.

Another initiative, the We All Take Care of the Harvest (WATCH) program, was a pilot initiative led by the First Nations Health Authority (FNHA) aimed at addressing the impacts of climate change on seafood safety, security, and sovereignty for coastal First Nations in British Columbia. In 2023, the WATCH program hosted several meetings, including the "Safe Shellfish Solutions for Coastal First Nations" workshop, which focused on enhancing biotoxin testing and improving seafood safety for First Nations communities. These efforts are part of WATCH's commitment to addressing the challenges posed by harmful algal blooms and climate change, ensuring the safety and sustainability of seafood harvesting in coastal regions.

References

Ross, A.R.S., Mueller, M., Ip., B., Surridge, B., Hartmann, H., Haque, O., McKenzie, P., Frederickson, N., Esenkulova, S., Pearsall, I., Sastri, A., Hennekes, M., Shannon, H., Taves, R., Raftery, E., Perry, I. (2023). Marine biotoxin monitoring in BC coastal waters. In: Boldt, J.L., Joyce, E. Tucker, S., and Gauthier, S. (Eds.). 2023. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2022. Can. Tech. Rep. Fish. Aquat. Sci. 3542: vii + 312 p.

Ross, A.R.S., Mueller, M., Ip., B., Surridge, B., Hartmann, H., Nesbitt, B., McKenzie, P., Frederickson, N., Esenkulova, S., Pearsall, I., Sastri, A., Hennekes, M., Galbraith, M., Raftery, E., Kafrissen, S., Perry, R.I. (2024). Marine biotoxin monitoring in BC coastal waters. In: Boldt, J.L., Joyce, E. Tucker, S., Gauthier, S. and Dosser, H. (Eds.). 2024. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2023. Can. Tech. Rep. Fish. Aquat. Sci. 3598: vii + XXX p.

Esenkulova, S., Pawlowicz, R., Frederickson, N., Ross, A.R.S., Pearsall, I. (2023). Harmful algal blooms and oceanographic conditions in the Strait of Georgia 2022. In: Boldt, J.L., Joyce, E. Tucker, S., and Gauthier, S. (Eds.). 2023. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2022. Can. Tech. Rep. Fish. Aquat. Sci. 3542: vii + 312 p.

Ross, A.R.S., Mueller, M. (2024). Monitoring harmful algal biotoxins in British Columbia coastal waters. PICES Press 32 (2): 38-40. PICES-Press-2024-Vol32No2.pdf

C. Russia

Reported by: Tatiana Orlova & Tatiana Morozova (National Scientific Centre of Marine Biology FEB RAS, Vladivostok, Russia)

1. HAB events

In 2024 a monitoring survey focusing on potentially toxic species was conducted in Amursky Bay off Vladivostok City (Peter the Great Bay, Sea of Japan) (Figure 4).

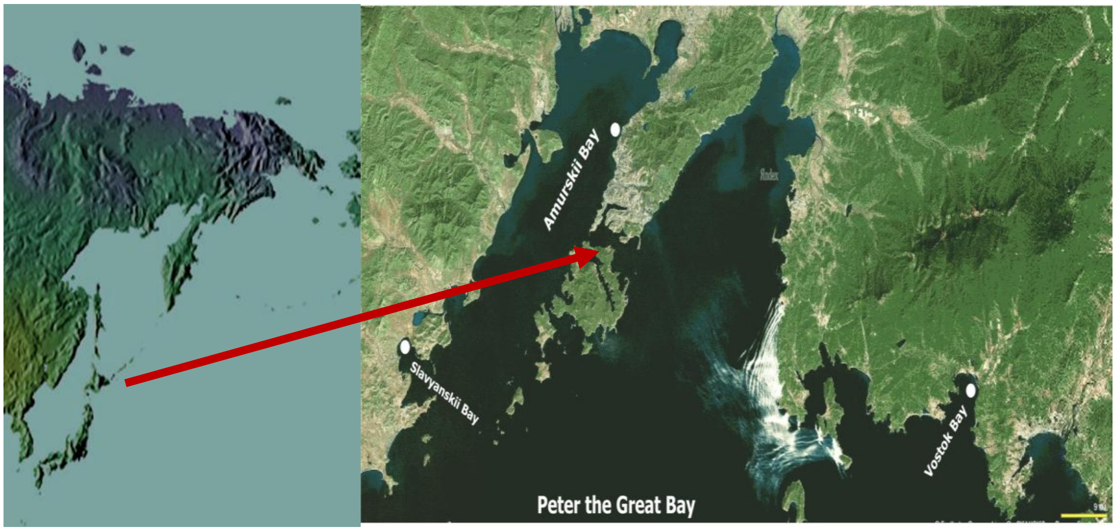

Figure 4. Amursky Bay off Vladivostok City (Peter the Great Bay, Sea of Japan)

The HAB events caused by microalgae belonging to five classes were observed (Table 2).

March	*Heterosigma* sp.	6.5 x10^6
June	*Pseudo-nitzschia pungens*	2.9 x10^6
July	*Alexandrium pseudogonyaulax*	1.1 x 10^6
July–August	*Skeletonema* sp.	12 – 24 x 10^6
July–August	*Prorocentrum cordatum*	1.7 – 2.6 x 10^6
August	*Lepocinclis steinii* (Euglenophyceae)	3.3 x 10^6
September	*Cylindrotheca closterium*	3.7 x 10^6
October	*Chrysochromulina quadrikonta*	8.1 x 10^6

Table 2. HABs species (maximal abundance, cells/L) recorded in Amursky Bay in 2024

On July 5–7, 2024, a large-scale bloom of dinoflagellates *Alexandrium pseudogonyaulax* was observed in coastal waters off Vladivostok and covered the surface of Amursky Bay over an area of about 1300 square kilometers. For its color and abundance of white foam, this event was called "Cappuccino" red tide (Figures 5 and 6). The abundance of *A. pseudogonyaulax* in the samples exceeded 1 million cells/l, but presumably, the concentration was much higher. The death of hydrobionts was not noted at this time.

Figure 5. Bloom caused by <u>Alexandrium pseudogonyaulax</u> in Amursky Bay (Peter the Great Bay, Sea of Japan), July 2024.

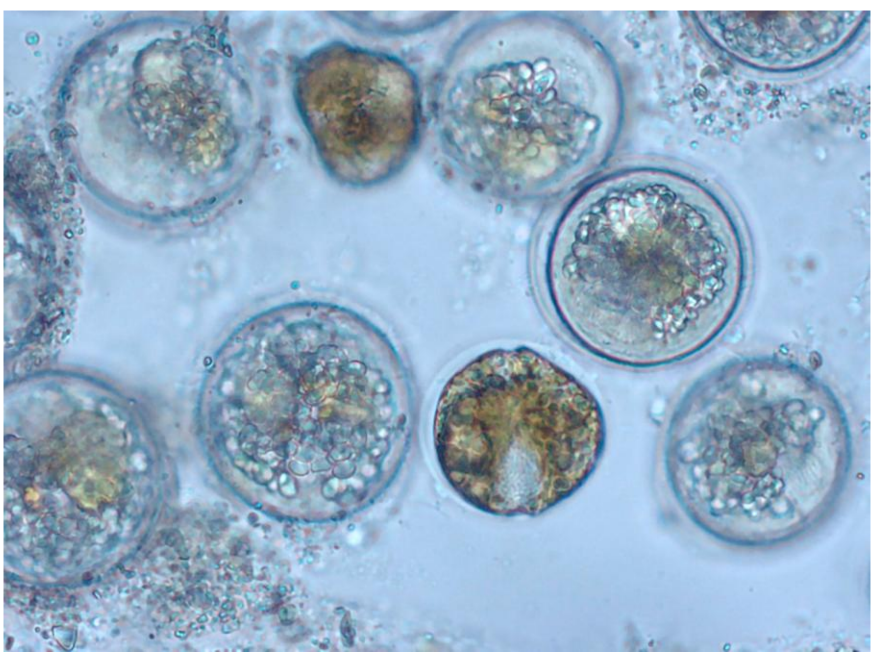

Figure 6. Cysts and vegetative cells of <u>Alexandrium pseudogonyaulax</u> in Amursky Bay (Peter the Great Bay, Sea of Japan), 5–7 July, 2024.

After the Cappuccino red tide bloom, a massive bloom of *Prorocentrum cordatum*, *P. triestinum*, *Skeletonema* spp., *Plagioselmis* sp., *Lepocinclis steinii* was registered in Amursky Bay in July and August. In September, a high abundance of diatoms *Cylindrotheca closterium* was revealed for the first time in Amursky Bay. From the end of September to the writing of this report, there was a bloom of haptophyta *Chrysochromulina quadrikonta* (up to 8.1 x 10^6 cells/L) observed in Amursky Bay for the first time (Figure 7). The hydrological parameters measured over the course of the bloom are shown in Figure 8.

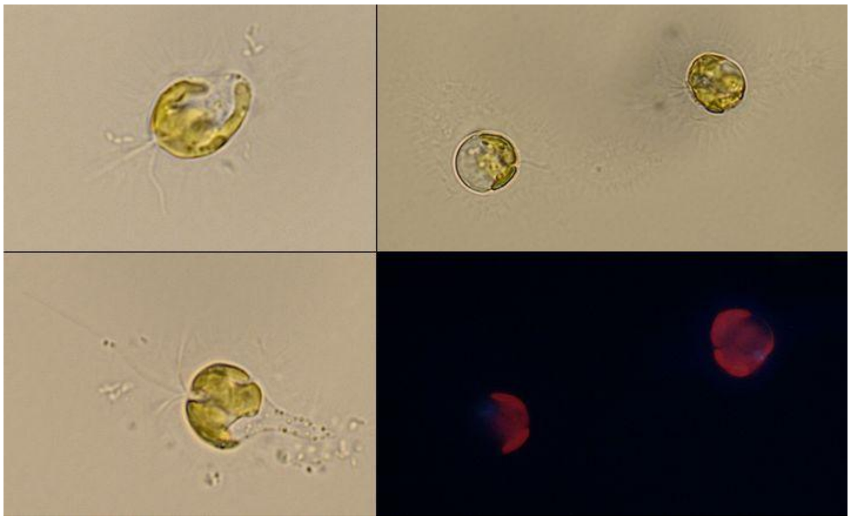

Figure 7. Vegetative cells of Chrysochromulina quadrikonta in Amursky Bay (Peter the Great Bay, Sea of Japan), 18 September–26 October, 2024.

Amursky Bay provides an “open-air laboratory” for the study of climate change in Russian coastal waters, including its impact on the blooms of several toxic microalgal species, which, in recent years, have undergone increases in their geographical range as well as their virulence and recurrence (the species *Karenia mikimotoi*, *Alexandrium pseudogonyaulax*, *Pseudochattonella verruculosa*, *Heterosigma akashiwo*, and *Chattonella marina*, and others of the genera *Ostreopsis*, *Crysochromulina, Dinophysis, Prorocentrum*, and *Pseudo-nitzschia* (Figure 9). The evolution of HABs in Amursky Bay can show the connections between key features of HABs (i.e., expansion, recurrence, and persistence) and their interaction with current and predicted global climate-change-related factors. These factors include large-scale climatic anomalies such as the lack of rain and heat waves, direction and strength of wind, and currents and can promote the massive proliferation of these species by creating ideal conditions for their growth and persistence as they affect water-column stratification, nutrient inputs, and reproductive rates.

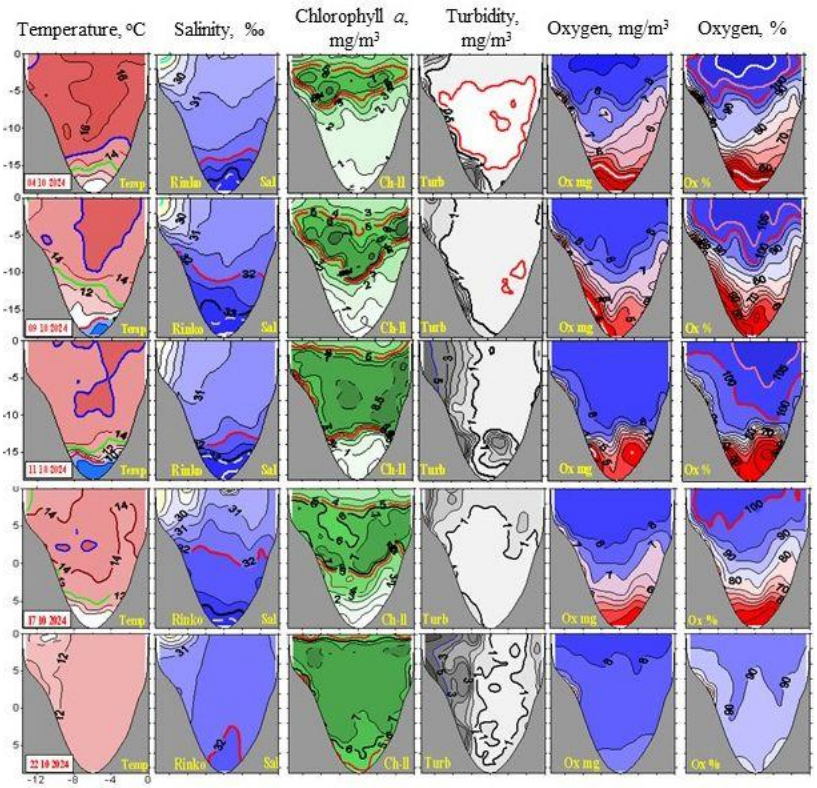

Figure 8. Hydrological parameters measured by the CTD probe ASTD102-Rinko (JFE, Japan) at the monitoring station in Amursky Bay during Chrysochromulina quadrikonta bloom.

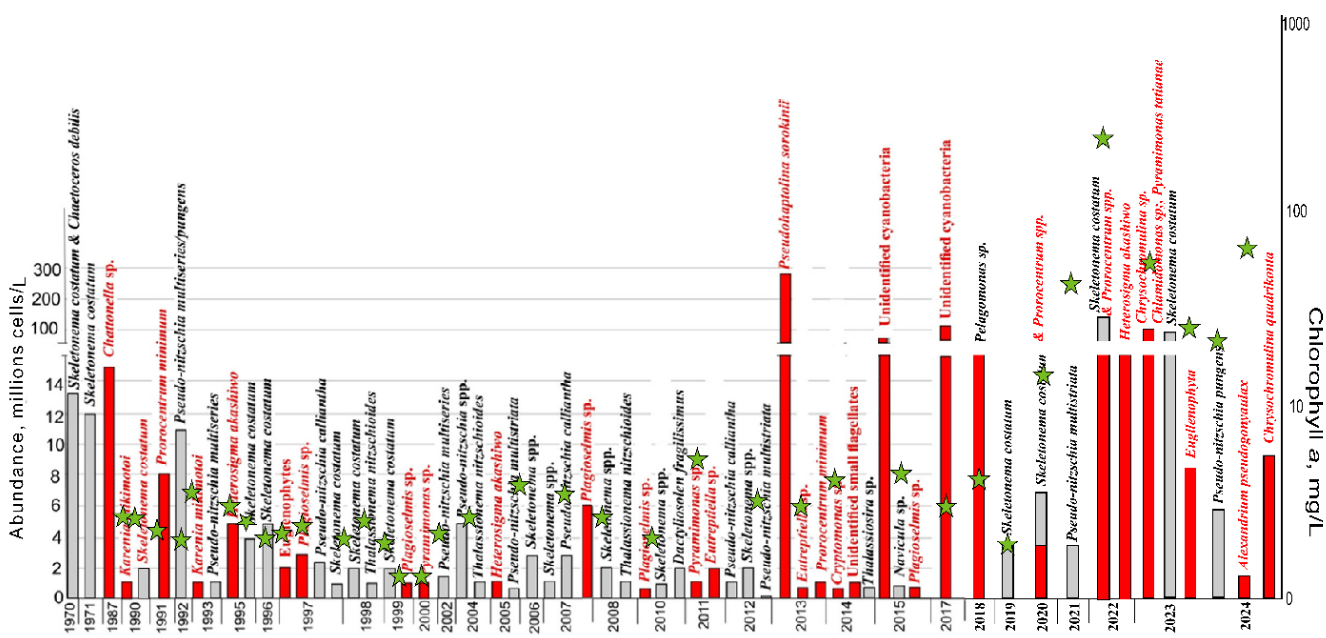

Figure 9. Long-term dynamics of phytoplankton density at the monitoring station in Amursky Bay from the 1970s to the present. Density, mln/cell l^{-1} (scale on the left); chlorophyll a, mg/l^{-1} (scale on the left and green stars). Gray columns are the density of diatoms, red columns are the density of non-diatom plankton.

D. Japan

Reported by: Yoichi Miyake, Natsuko Nakayama, and Setsuko Sakamoto (Japan Fisheries Research and Education Agency) and Mitunori Iwataki (University of Tokyo)

1. Historical and Recent Trends

The number of HABs events decreased in the Seto Inland Sea in the 1980s and 1990s in conjunction with efforts to reduce nutrient inputs. Over the last several decades, there are on average 100 HABs events per year (Figure 10). This trend is in contrast with the Kyushu region in southwest Japan where HABs events have been gradually increasing (Figure 10), resulting at times with substantial impacts on fisheries.

2. Fish and Shellfish Killing HABs

The major HAB species causing fish and shellfish losses in Japanese waters are *Chattonella spp. (Cha)*, *Karenia mikimotoi (Km),Margalefidinium (Cochlodinium) polykrikoides (Cp)*, *Heterocapsa circularisquama (Hc)*, and *Heterosigma akashiwo (Ha)*. Major HAB disruptions reached almost 18 million USD in the Kysuhu region during 2023 (Figure 11). In Yatsushiro Sea, blooms of mixed species (*Chattonella* spp., *Karenia mikimotoi*, and *Cochlodinium polykrikoides*) began to cause fisheries damages in 2023.

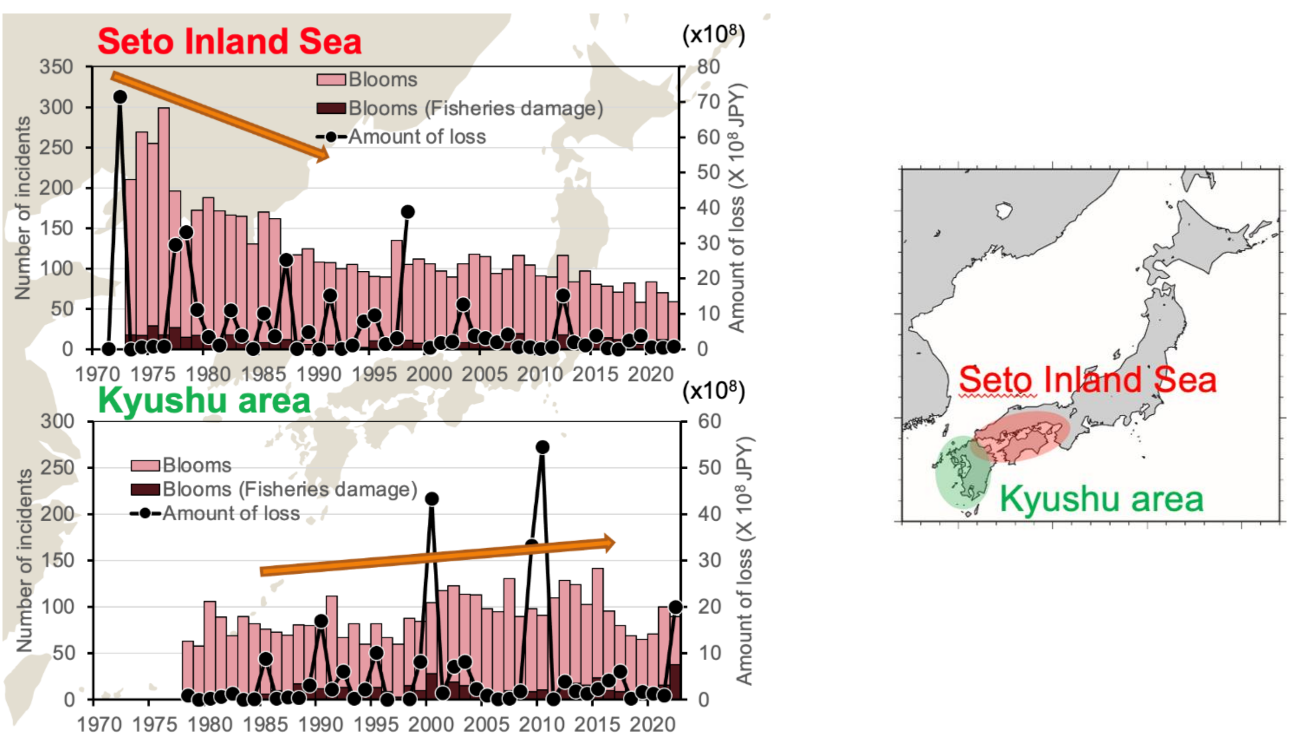

Figure 10. Historical trends in HABs in the Seto Inland Sea and the Kyushu region of Japan, with their locations shown in the inset map.

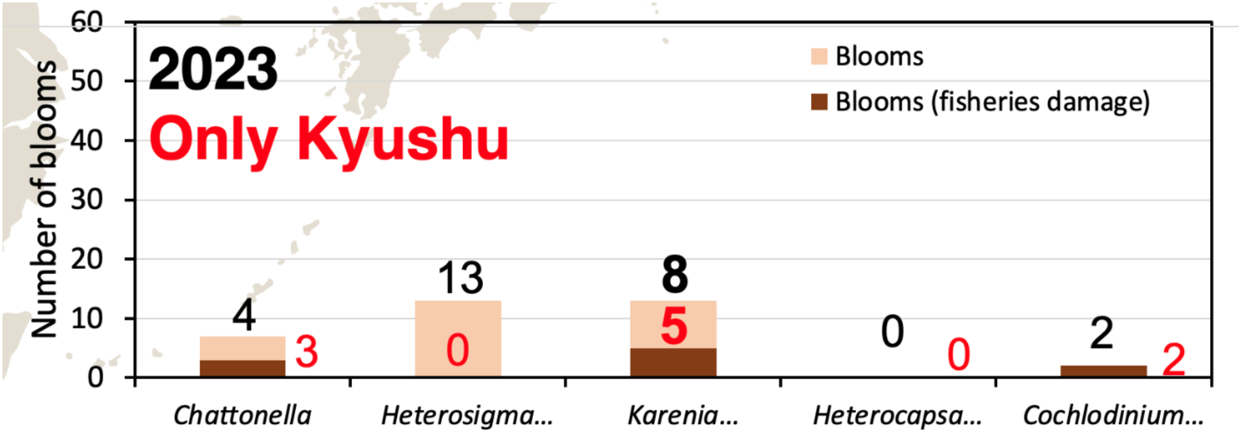

Figure 11. The occurrence of fish and shellfish killing HABs in the Kyushu region during 2023, showing the proportion of those HABs that resulted in fisheries damage.

3. Shellfish Poisoning

Both paralytic shellfish poisoning (PSP) and diarrhetic shellfish poisoning (DSP) are regular events in Japan. PSP is attributed mainly to *Alexandrium catenella* in Northern Japan, and *Alexandrium pacificum*, *Alexandrium tamiyavanichii*, *Alexandrium ostenfeldii*, and *Gymnodinium catenatum* in Western Japan in 2023. This was the first time that PSP closures have occurred in Western Japan waters.

The major species responsible for DSP are *Dinophysis fortii* and *Dinophysis acuminata*. A number of other *Dinophysis* species are monitored as well although there have been no cases of shellfish intoxication so far associated with them. The numbers and locations of PSP and DSP closures are shown in Figure 12.

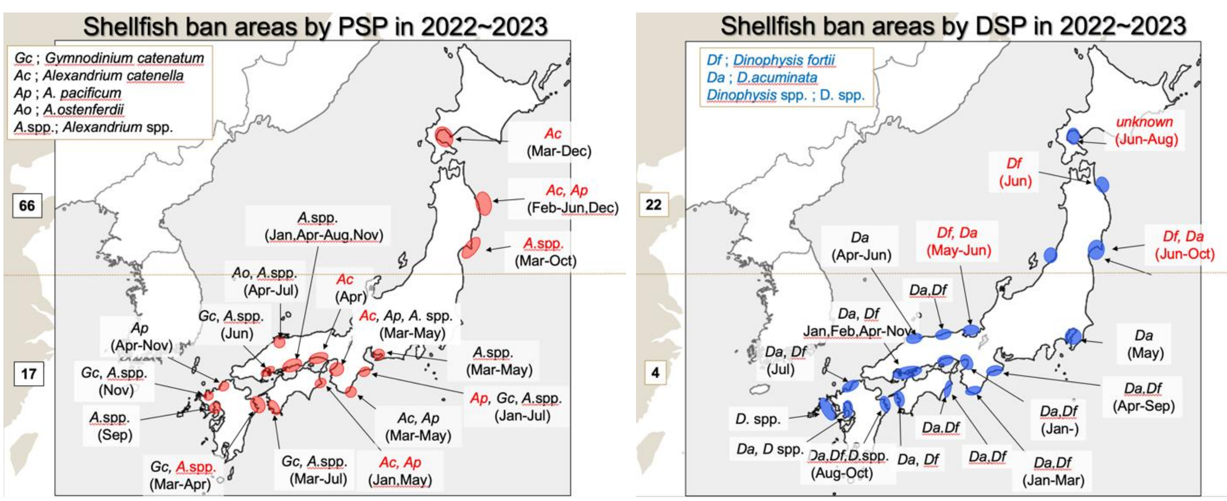

Figure 12. The distribution of shellfish closures due to PSP and DSP in Japan during 2022–2023.

E. Korea

Reported by: Minji Lee
Prepared by: Minji Lee, Tae-Gyu Park, Moonho Son, Seokhyun Yoon (National Institute of Fisheries Science, Korea)

1. Introduction

Since the initiation of harmful algal bloom (HAB) monitoring in 1972, Korean coastal waters have experienced recurring and severe blooms of *Margalefidinium polykrikoides* beginning in the 1990s. However, the dynamics of these blooms have shifted significantly in recent years due to the influence of climate change. To better understand these changes, we examined the trends of HAB in Korean coastal waters over the past five years.

2. HAB Occurrences in 2020–2023

In 2020, a precautionary advisory for *M. polykrikoides* was issued from August 31 to October 10 in the southern coast of Korea. In 2021, an advisory was issued only the central part of the southern coastal waters (between Goheung and Yeosu) from August 10 to October 15, but it did not escalate to a warning due to the sustained dominance of competing organisms and the unusual northerly winds, which minimized coastal aggregation effects. In 2022, a large bloom of *M. polykrikoides* occurred between August 26 and September 30, spreading across the southern coast, prompting a rapid escalation from an advisory to a warning. Although the region was directly affected by Typhoon Hinnamno during this period, sea temperatures remained relatively stable, and strong easterly winds mitigated the westward spread of the bloom. Timely monitoring and advisory issuance prevented significant economic damage. In 2023, various species such as *Noctiluca scintillans*, *Tripos furca*, *Mesodinium rubrum*, *Akashiwo sanguinea*, *Prorocentrum* spp., and *Heterosigma akashiwo* were observed. Notably, there were no occurrences of *M. polykrikoides* blooms during this year.

3. HAB Occurrences in 2024

In 2024, a localized bloom of *M. polykrikoides* occurred alongside *T. furca* from August 9 to 28; however, it dissipated without significant spread. During this period, an unusual high-temperature event persisted, with surface water temperatures exceeding 28°C for over a month (maximum 30°C). In the early phase of this event, phytoplankton descended below the surface, but as the period continued, the biomass across all water layers drastically decreased. Photosynthetic efficiency (Maximum Quantum Yield), particularly at the surface layer, was extremely low, and the overall phytoplankton activity was significantly reduced. By late September, the indirect effects of a typhoon led to water column mixing, which eliminated the high-temperature layer, resulting in a resurgence of diatom populations. It is hypothesized that the extreme high temperatures caused by climate change prevented the proliferation of *M. polykrikoides*. Furthermore, there has been no recorded economic damage due to HABs in the past five years, indicating substantial shifts in HAB dynamics in this region over the past two decades. The extended periods of coastal high temperatures are anticipated to further alter HAB patterns and ecosystem structures in Korea.

4. HAB Trends Changing Due to Climate Change

Considering the ongoing impacts of climate change and recent trends, a wider variety of HABs is expected to emerge in the future. The decline in *M. polykrikoides* bloom frequency observed over the past few years is likely to persist due to elevated sea temperatures and reduced nutrient levels. Additionally, the recent blooms of various algae species are expected to continue, with species such as *Tripos furca*, *Akashiwo sanguinea*, *Noctiluca scintillans*, and *Mesodium rubrum* continuing to cause blooms. Furthermore, there is an increasing emergence of toxic subtropical species that were previously unseen in Korea. As a result, the rising sea temperatures caused by climate change highlight the growing need for research on ciguatera fish poisoning, which has not yet occurred in Korea.

5. Advanced Monitoring Technologies

Ongoing monitoring and research efforts have provided valuable insights into the dynamics of HABs in Korean coastal waters. They emphasize the importance of integrating advanced technologies to improve the accuracy and efficiency of HAB detection and response. We are conducting research on advanced monitoring technologies such as aerial surveillance using hyperspectral cameras and drone-based monitoring to enhance HAB detection and characterization. Additionally, we are continuously developing predictive models based on big data and AI. The reduction in economic damage caused by HABs in recent years highlights the effectiveness of these efforts. However, the diversity of species and environmental conditions requires adaptive management strategies to mitigate the impact of future HAB events.

F. China

Reported by: Pengbin Wang

A. Red tide

According to China Marine Disaster Bulletin, 46 red tide events were recorded in the coastal waters of China in 2023, covering a total area of 1466 square kilometers (Table 3). Compared with the recent ten years, the number of red tide events in 2023 is lower than the average, with the accumulated area of red tides being 27% of the average (Table 4, Figure 12). In 2023, a total of 22 species of algae were the dominant species that caused HABs in the coastal waters of China. Among them, *Prorocentrum donghaiense* was the most dominant species, causing the largest number of red tides and the largest cumulative area, which is 11 times and 768 square kilometers, respectively.

In terms of regional distribution, the East China Sea has the largest number of red tides and the largest cumulative area, which is 24 times and 1016 square kilometers, respectively. From the distribution of coastal provinces (autonomous regions, municipalities directly under the Central government), the number of red tides in Zhejiang and Fujian was the largest, with 11 times each; and the cumulative area in Zhejiang was also the largest, with 767 square kilometers. In terms of seasonal pattern, the red tide was found the most in Spring and Summer (Figure 13). During May and June, 2023, the largest single red tide event occurred in coastal waters of Taizhou, Zhejiang

Province, with a maximum area of 345 square kilometers. From July 2 to 5, 2023, a bloom with *Margalefidinium polykrikoides* as the dominant organism was discovered in the waters northwest of Daqu Island, Wenzhou, Zhejiang Province, covering an area of 2 square kilometers, which caused the death of large yellow croaker in the breeding area and caused direct economic losses of 450,000 yuan. (CMDB, 2023).

Sea area	Number of red tide events	Accumulated area of red tides (km^2)
Bohai Sea	9	304
Yellow Sea	6	122
East China Sea	24	1016
South China Sea	7	24
Total	46	1466

Table 3. Statistics of HABs found in various sea areas in China in 2023

Year	Number of red tide events	Accumulated area of red tides (Km^2)
2014	56	7 290
2015	35	2 809
2016	68	7 484
2017	68	3 679
2018	36	1 406
2019	38	1 991
2020	31	1 748
2021	58	23 277
2022	67	3 328
2023	46	1 466
Average	50	5 448

Table 4. The number and cumulative area of red tides discovered in China's sea area in the past decade

A summary of the HABs in 2023 in Zhejiang, Tianjin, and Liaoning autonomous regions is presented in Table 5, along with the timing, major species, and aerial extent of these events.

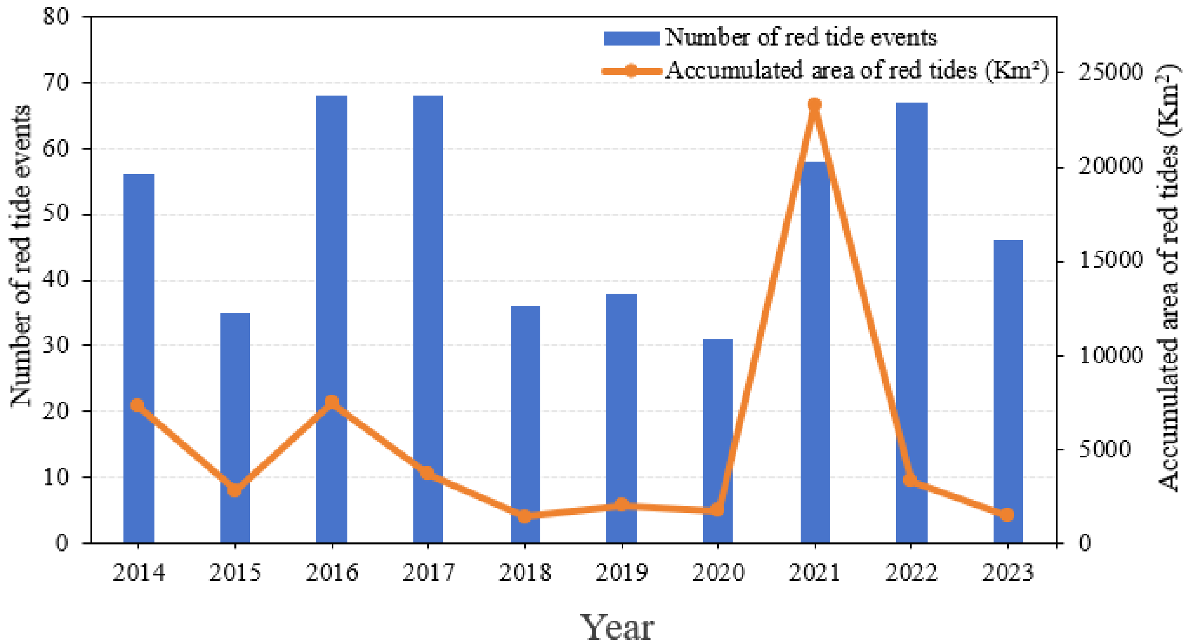

Figure 12. The number and cumulative area of red tides discovered in China's sea area in the past decade

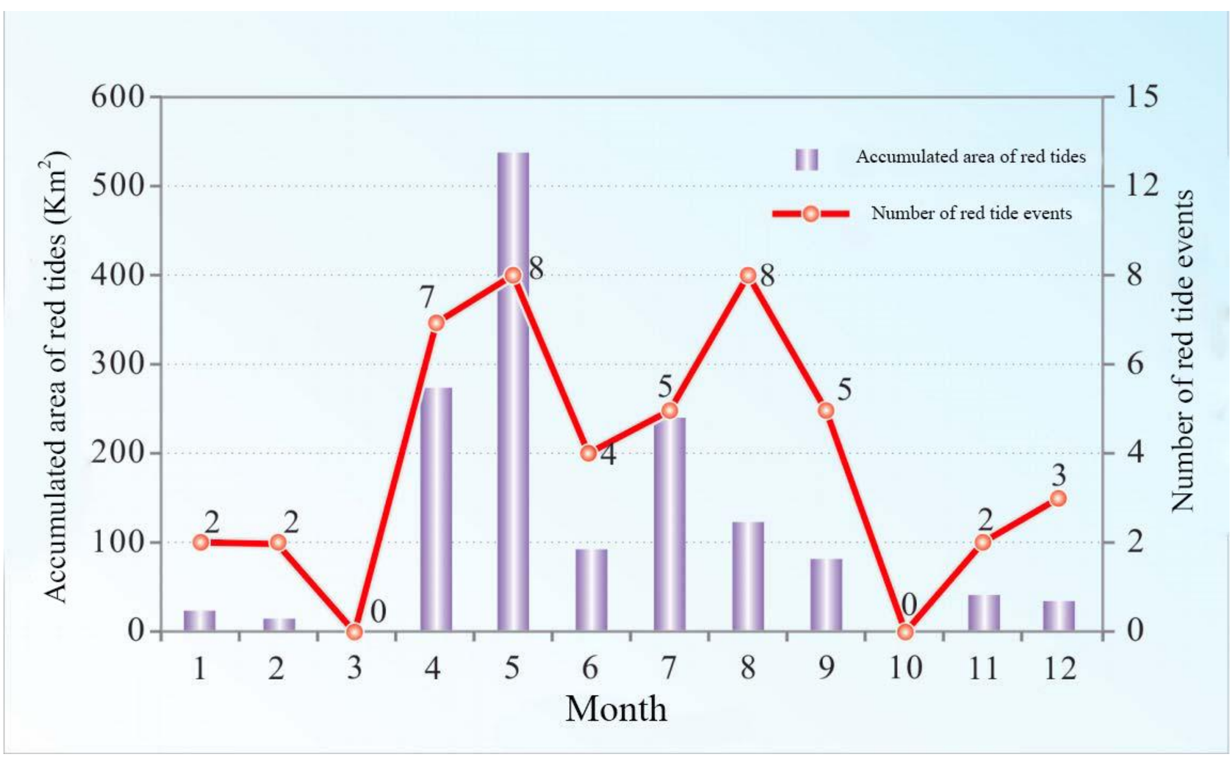

Figure 13. Monthly frequency and cumulative area of red tides in 2023

Province (autonomous region, municipality)	Start and end time	Discover the sea	Red tide dominant organisms	Red tide types	Area (km²)
Zhejiang	April 29th-May 28th	Wenzhou Nanji Sea Area	*Prorocentrum donghaiense*	harmful red tide	145
Zhejiang	May 16th -June 5th	The northwest waters of Ningbo Yushan Islands	*Prorocentrum donghaiense*	harmful red tide	110
Zhejiang	May 24th-June 5th	Taizhou Linhai, Dachen Island, Sansuan Island,Sea area around Pishan Island	*Prorocentrum donghaiense*	harmful red tide	345
Zhejiang	July 2th-5th	The sea area northwest of Daqu Island, Wenzhou	*Margalefidinium polykrikoides*	harmful red tide	2
Tianjin	July 26th-November 13	The sea area near Tianjin	*Scrippsiella acuminata Margalefidinium polykrikoides Skeletonema costatum*	harmful red tide	136
Liaoning	September 14th-15th	From Dalian Port Postal Terminal to Centennial Bay	*Alexandrium tamarense*	harmful red tide	0

Table 5. Statistics of major red tide events in 2023. Note: (1) The area in this table refers to the red tide area in the sea areas under the jurisdiction of the province (autonomous region, municipality directly under the central government), and only red tide processes with a maximum area of more than 100 square kilometers (inclusive), harmful red tide processes, and red tide processes that cause direct economic losses are listed; (2) This table only lists the three dominant red tide organisms with the highest density in the sea area near Tianjin; (3) The area of harmful red tide from the Postal Terminal of Dalian Port in Liaoning Province to the Centennial Bay is 0.015 square kilometers.

B. Green tide

From April to August 2023, the green tide affected the Yellow Sea and the coverage area reached the maximum on June 25—about 998 square kilometers. *Ulva prolifera* is the causative species of green tide. Compared with the recent ten years, the green tide of *Ulva prolifera* in 2023 has the characteristics of big scale, wide distribution, and southward location. The maximum coverage area and distribution area of *Ulva prolifera* green tide were the highest in the past ten years, respectively flat 1.74 times and 1.38 times the average (Figures 14, 15, 16). The occurrence of green tide of *Ulva prolifera* in the Yellow Sea of China in the past decade is shown in Figure 17.

Figure. 14. Green tide distribution in the Yellow Sea on May 27, 2023

Figure 15. Green tide distribution in the Yellow Sea on June 25, 2023

Figure 16. Green tide distribution in the Yellow Sea on August 9, 2023

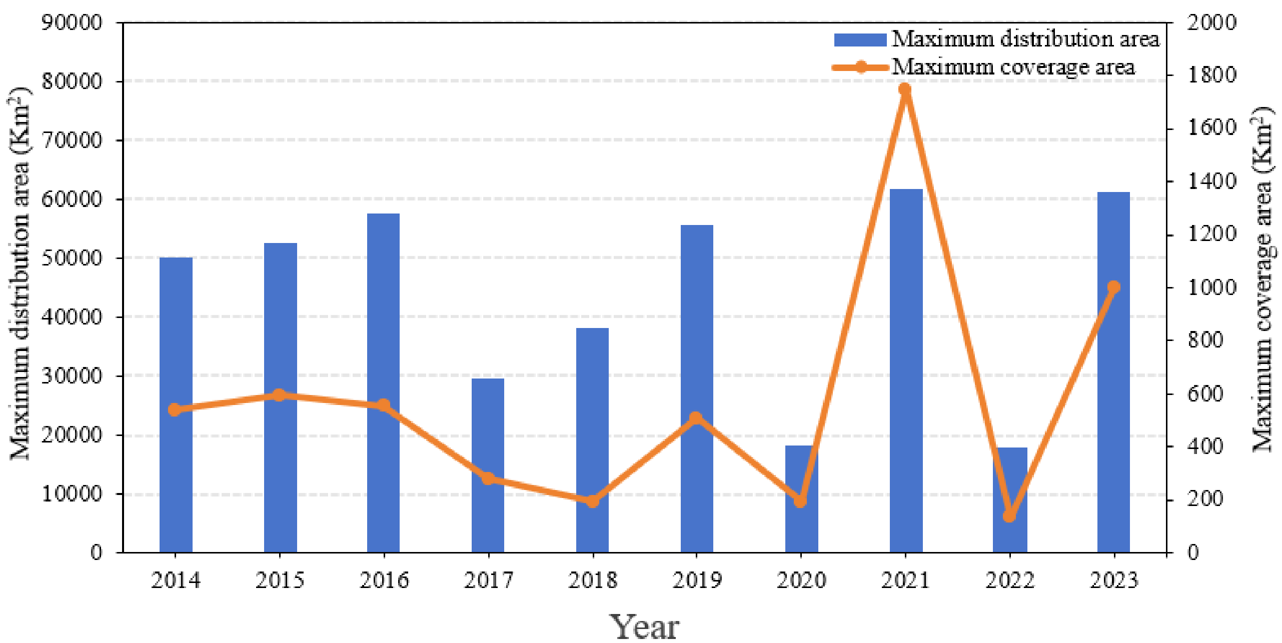

Figure 17. The occurrence of green tide of Ulva prolifera in the Yellow Sea of China in the past decade

AGENDA ITEM 3
Workshop Proposals for PICES 2025

Workshop on Rapid Detection Technologies for Harmful Algal Toxins

Conveners: Natsuko Nakayama, Japan (nakayama_natsuko37@fra.go.jp), Misty Peacock, USA (mpeacock@nwic.edu), Andrew RS Ross, Canada (Andrew.Ross@dfo-mpo.gc.ca), Pengbin Wang, China (algae@sio.org.cn), Vera Trainer, USA (verat@uw.edu), William Cochlan, USA (cochlan@sfsu.edu), Mark Wells (mlwells@maine.edu)

Corresponding Convener: Mark Wells (mlwells@maine.edu)

Regulatory testing of shellfish for toxins is the foundation of safe and secure shellfish sales around the world. However, the distance aquaculture facilities often are far from regulatory testing labs, which leads to expensive delays in analyses and other increased operational costs. Rapid toxin testing that can be performed at hatcheries and harvesting sites enables informed decisions regarding harvesting strategies. Although a limited number of rapid-test technologies have been available for some time, recent scientific and technological progress has led to improvements in near real-time detection of toxins using rapid tests. For example, the enzyme-linked immunosorbent assay (ELISA) has been modified for some toxins to allow for less expensive, single sample quantitative analysis. In other cases, strip tests that are similar to COVID tests now are available to provide qualitative results that allow shellfish farmers to make strategic decisions (e.g., delaying harvest if toxins are detected). But even with these new technologies, challenges remain to implementing them on an effective operational basis, in particular due to different toxin isomers present in shellfish in different geographic regions. Each method also has technical constraints in terms of its efficiency, accuracy, and the needed expertise of operators, along with operational costs. There is a need to share current experiences, advances, and limitations of rapid detection methods for toxins and HAB organisms, including molecular probes, ELISA analysis, quantitative PCR essays, high-throughput sequencing, and remote sensing techniques. This workshop will bring together researchers, industry members, and government experts on regulatory limits and associated risks, to explore existing and new directions for rapid toxin testing. It will combine focused group discussions, example pilot studies, hands-on demonstrations towards promoting, adapting, and applying rapid detection technology for toxins. The long-term goal is to improve early warning and effective management of HABs in the North Pacific Region.

Potential Co-sponsors: GlobalHAB, IOC UNESCO, ISSHA, IUCN

Duration: 1 day

Potential Invited Speakers: TBD. One possibility is Anthony Odell (University of Washington) who has extensive experience with rapid toxin testing, and another would be an industry person who can speak about the real-world operational experience with current toxin testing kits on the market.

Outputs: Shorter-term goals include using the workshop as a basis for: 1) developing capacity building training courses for rapid assessment of HABs, 2) summary publications in a peer-reviewed journal as well as PICES Press, and 3) identifying the key foci for a future PICES working group proposal to join with WESTPAC to develop joint studies on emerging Rapid Detection Technologies for Harmful Algal Blooms (RDT-HAB).

Why now? Food security in this century increasingly will be depending on aquaculture resources that, in turn, are increasingly being threatened by HABs. The economic survival of global aquaculture is critically dependent on adequate and affordable insurance backing that, in turn, has rapidly dwindled due to mounting HAB-related economic losses (PICES Scientific Report (No. 59, 2020). Rapid toxin testing is a critically important tool that can help industry adjust their harvesting dynamics to minimize losses; one essential step to enable more responsive aquaculture management practices.

AGENDA ITEM 4
Topic Session Proposal 1 for PICES 2025

Changing Ecosystems in the North Pacific: Projections and Mitigation

Conveners: M. Wells, USA (mlwells@maine.edu), H. Saito, Japan (hsaito@aori.u-tokyo.ac.jp), Fei Chai, China (fchai@xmu.edu.cn), and Charles Trick, Canada, (charles.trick@utoronto.ca)

Corresponding Convener: M. Wells (mlwells@maine.edu)

Climate-driven changes in marine ecosystems already are being observed, and it is anticipated that the drivers of climate change will be greatly magnified by the end of the century. Changes in regional wind patterns, surface stratification, marine heat waves, and seasonal phenologies are combining to alter oceanographic conditions, with associated impacts on marine biogeochemistry, ecology, fisheries, and ecosystem services, and these changes threaten indigenous and cultural traditions. Reducing CO_2 emissions is essential, but this alone will not be sufficient to prevent potentially catastrophic impacts. To reduce the extant concentration of greenhouse gases, we will need to rely on atmospheric carbon dioxide removal (CDR) to create a negative net carbon emission. This is a crucial time to explore potential strategies for marine-based CDR (mCDR), which are being considered for both nearshore and offshore environments. Assessing the likely catastrophic changes that will occur in these systems without negative carbon emissions will provide the understanding needed to determine the relative benefits of any mCDR intervention. We invite presentations on projections of climate-induced changes in the North Pacific, including oceanographic, biogeochemical, ecological, fisheries, socioeconomic, indigenous, and cultural aspects. These collective insights will help to forecast the climate-driven trajectories of North Pacific marine ecosystems to better estimate the comparative impacts from implementing large-scale mCDR.

Location: TBD

Date: November, 2025

Invited Speakers: TBD, but the intention is to have one speaker forecast the future with no action and one speaker present one or more plans for mCDR (e.g., Fe fertilization, Ocean Alkalinity enhancement). It will be important to also invite representatives of indigenous communities facing emergent changes in the ecosystem to learn about these perspectives.

Co-sponsors:
FUTURE, FIS, BIO, POC, committee and HD, but we need to contact some of them. 1st priority FUTURE, then POC, then FIS, BIO, HD

Outputs: The output of this topic session and discussions will depend upon the breadth and depth of observations. The primary goal of the topic session is to begin developing comprehensive insight into projected accelerating shifts in the physical/biological systems of the Pacific Ocean over this century, along with the associated human impacts. This framework will be critical for the decision-making process on various mCDR approaches being considered. We envision that these presentations will be summarized in the first of a series of bi-annual or tri-annual PICES Press Reports or review papers on this topic that collectively summarize the evolving state of knowledge for the North Pacific region. The global scale of interest in this topic will require the production of a web-based synthesis integrating ideas and outlining the possible actions and barriers to implementation.

Topic Session Proposal 2 for PICES 2025
What can we learn about the occurrence of *Karenia* spp. blooms in the North Pacific?

Convenors: Pengbin Wang, China (algae@sio.org.cn), Charles Trick, Canada (charles.trick@utoronto.ca), Yoichi Miyake, Japan (miyakey1@affrc.go.jp)

Corresponding Convenor: Pengbin Wang, China (algae@sio.org.cn)

Karenia blooms have caused major economic and human impacts in western Pacific regions over the past few decades. Although they have been largely absent along eastern Pacific shores, several *Karenia* blooms recently have appeared there, raising questions about whether an expansion of their common range is underway. The underlying drivers of bloom development still are unknown, though they clearly are linked to warm and stratified surface waters. There is concern then that climate-driven increasing ocean temperatures and stratification are leading conditions to become more favorable for *Karenia* bloom development, especially at higher latitudes. This warming may have contributed to *Karenia* blooms recently appearing along eastern Pacific shores. Given that another common HAB species—*Heterosigma akashiwo*—shares many characteristics with *Karenia* spp., including motility (i.e., the ability to maximize light and nutrient availability), cyst formation and mixotrophy, it is particularly important to understand how these traits may contribute to *Karenia* spp. success over other phytoplankton under warming conditions. Accelerating our understanding of the potential trends in *Karenia* bloom expansion and intensification will hinge upon collaborative research, new monitoring approaches, and initiatives. We seek to begin this enhanced effort by welcoming presentations on the findings from laboratory, field, and monitoring studies, along with the perspectives they generate, of *Karenia* blooms in both the Pacific region and elsewhere. Through intercomparison of these observations and ideas we hope to gain critical insights into the underlying mechanisms driving these blooms, and thereby help us address the environmental challenges posed by *Karenia* blooms in the North Pacific.

Location: TBD

Date: November, 2025

Invited Speakers: TBD but the intention is to have one expert speak on current understanding of *Karenia* blooms, perhaps from a region outside the N. Pacific (e.g., southeastern USA).

Co-sponsors (unconfirmed but expected): GlobalHAB, IOC UNESCO, ICES WGHABD, NOWPAP, ISSHA

Outputs: The output of this topic session and discussions will depend upon the breadth and depth of observations. The primary goal of the topic session is increasing awareness of how *Karenia* HABs have been changing, and potentially expanding their range to the eastern Pacific. The secondary goal is to tap into expertise to set a framework to structure a workshop where these and other participants can focus on questions surrounding *Karenia* HABs.

Why now? The rates of change in higher latitude physical, chemical, and ecological systems are unprecedented in recorded human history. These changes are accompanied by a poorly understood transition of planktonic communities, including HABs emerging in previously "HAB-insulated" coastal regimes. There is a high level of awareness and impetuous for high latitude research among PICES nations, which offers a unique opportunity to enhance understanding of HAB expansion with adequate planning.

AGENDA ITEM 5
Iron Enrichment Experiments planned for NE Pacific

A summary of the rationale, need, and emerging design for ocean iron fertilization (OIF) experiments was presented by Mark Wells, who is a Steering Committee member of Exploring Ocean Iron Solutions for marine carbon dioxide removal (mCDR). ExOIS is an international, non-profit consortium of scientists based at the Woods Hole Oceanographic Institution (WHOI) organized to develop and conduct field-scale experiments to evaluate the efficacy and biogeochemical and ecological consequences of OIF at implementation scales. The purpose of ExOIS is to provide core quantitative data in order to evaluate whether, or whether not, OIF should become an accepted means for marine CDR. Details of ExOIS and the research and outreach plans can be found at oceaniron.org.

S-HAB Endnote 1

S-HAB participation list (both online and in-person meetings)

Members

Mark L. Wells (U.S.A., Co-Chair)
Pengbin Wang (China, Co-Chair)
Andrew RS Ross (Canada)
Charles Trick (Canada)
Svetlana Esenkulova (Canada)
Natsuko Nakayama (Japan)
Setsuko Sakamoto (Japan)
Takafumi Yoshida (Japan)
Yoichi Miyake (Japan)
Ryoko Yano (Japan)
Minji Lee (Korea)
Misty Peacock (USA)
William Cochlan (USA)

Members unable to attend

China: Chunlei Gao, Chunjiang Guan, Hao Guo, Qiufen Li, Douding Lu, Mengmeng Tong
Japan: Mitsunori Iwataki
Korea: Seung Ho Baek, Hae Jin Jeong, Kwang Young Kim, Tae Gyu Park, Moonho Son
Russia: Tatiana V. Morozova, Tatiana Yu. Orlova, Mikhail Simokon
USA: Vera L. Trainer

S-HAB Endnote 2

Agenda for the 2024 S-HAB Business Meeting

HAB-S Meeting, 9:00 - 12:00 Tuesday, October 27, 2024		
Time	**Presenter or host**	**Content**
09:00-09:05	Mark Wells & Pengbin Wang	Introduction by Section Co-chairs
09:05-09:10	All Participants	Greetings
09:10-09:15	All Participants	Approval of the Agenda
09:15-10:30	Participants	Country Report and Discussion (PPT available)
10:30-10:50		Break & Coffee
10:50-11:20	Mark Wells & Pengbin Wang	Workshop Proposal for PICES 2025
11:20-11:40	Mark Wells & Pengbin Wang	Topic Session Proposal for PICES 2025
11:40-11:50	Mark Wells	Iron Enrichment Experiments planned for NE Pacific
11:50-11:55	Participants	Group Photo
11:50-11:55	Mark Wells & Pengbin Wang	Close