Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

National Capital Regional

Canadian Science Advisory Secretariat
Science Advisory Report 2025/008

SCIENCE ADVICE FOR HARMFUL ALGAL EVENTS IN CANADIAN MARINE ECOSYSTEMS: CURRENT STATUS, IMPACTS, CONSEQUENCES AND KNOWLEDGE GAPS

Figure 1A. Harmful Algal Event in the St. Lawrence Estuary caused mass mortality of marine mammals, fishes and seabirds in 2008.

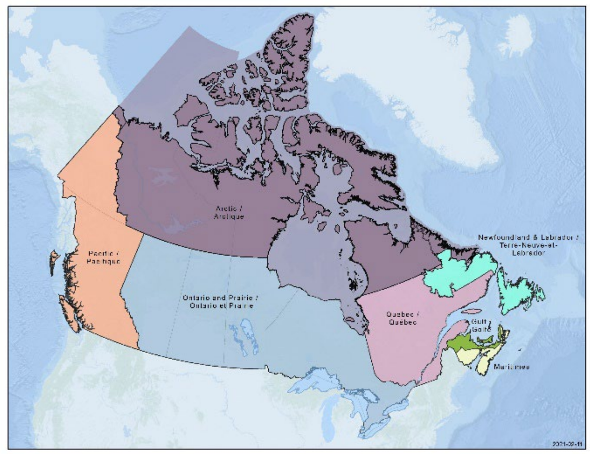

Figure 1B: Fisheries and Oceans Canada Administrative Regions

CONTEXT

One core responsibility of Fisheries and Oceans Canada (DFO) is to ensure healthy and productive marine ecosystems by protecting them from the negative impacts of stressors. Harmful algae are considered important ecosystem stressors, in particular when they reach high abundances in blooms, although some species are harmful even at low abundance. The extent and impacts of harmful algal events (HAEs) have not been systematically studied in recent years in Canadian marine waters, and in particular are poorly known in the Arctic Region.

The Ecosystem Stressors Program under DFO's Ecosystems and Oceans Science Sector requested science advice on the national scope of HAEs and their impacts in Canadian marine waters. The goals of this report are to: (1) review HAEs and their impacts in Canada's Atlantic, Arctic and Pacific marine waters, with a focus on trends over the past 30 years, 1987-2017; (2) determine areas or issues of particular or emerging concern with respect to impacts and consequences to Canadian marine ecosystems and how they may impact core DFO responsibilities; (3) identify key knowledge gaps that limit DFO's ability to evaluate or inform management decisions regarding the impacts and consequences of these HAEs; and (4) recommend actions to address these knowledge gaps.

This Science Advisory Report is from the March 12-14, 2019, national peer review on Harmful Algal Events in Canadian Marine Ecosystems: Current Status, Impacts and Consequences, and Knowledge Gaps. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.

SUMMARY

- Harmful algae (HA) are phytoplankton, and to a lesser extent sympagic algae species, with the potential to cause harm to organisms, food webs, ecosystems and human health via the production of phycotoxins, mechanical action, or hypoxia. As such, harmful algal events (HAEs) have emerged as an important stressor for marine ecosystems.
- HA species, phycotoxins, and HAEs in Canada's three oceans were reviewed based on Canadian published and unpublished reports. A 30-year time series of 593 Canadian records (1987 to 2017) from the Harmful Algal Event Database (HAEDAT) was analyzed for the Atlantic and Pacific coasts that showed recurring HAEs have been widespread. No HAEDAT records exist for the Arctic.
- To date, 70 harmful algal species (including 45 in the Arctic), known to have caused, or to have been associated with, HAEs on the coasts of Canada or elsewhere, have been reported in Canadian waters.
- A conceptual bow tie model was developed as a framework to link causes to outcomes of HAEs. It incorporates three natural drivers and five emerging anthropogenic pressures that influence the occurrence of HAEs in Canadian marine waters and was applied to identify national and regional knowledge gaps that might limit Fisheries and Oceans Canada's (DFO) ability to manage consequences of HA, especially those linked to DFO's mandate.
- Nationally, overarching knowledge gaps include limited HA monitoring, and limited understanding of the effects of specific emerging anthropogenic pressures that drive changes in HA species, phycotoxins, and bloom development and toxicity. These knowledge gaps prevent the development of effective predictive HAE models, which hinders our forecasting/hindcasting capability and hampers development of mitigation and prevention strategies.
- Information regarding the role of climate change, including extreme events and ocean acidification, on HAEs was identified as a key knowledge gap in Canada. Fundamental knowledge gaps exist in the Arctic Region, where there is a lack of basic information on the presence of HA and phycotoxins, and their impacts on species and ecosystems.
- Understanding the effects (including sublethal and cumulative) of HA and phycotoxins on the growth, physiology, reproduction and behaviour of marine biota is essential to evaluate impacts on food webs, ecosystems and human health, and consequences to species-at-risk, marine mammals, aquaculture, fishery and fish population health, ecosystem health, and food safety and security.
- Monitoring of phytoplankton and phycotoxins should be continued and expanded by developing novel methods, and using new and existing capacity and partnerships. This is especially important for areas where information is lacking, particularly the Arctic.

BACKGROUND

One core responsibility of Fisheries and Oceans Canada (DFO) is to ensure healthy and productive marine ecosystems by protecting ecosystems from the negative impacts caused by humans, invasive species, and other stressors. Harmful algae (HA) are phytoplankton, and to a lesser extent sympagic, i.e., sea ice-associated, algae species with the potential to cause harm to organisms, food webs, ecosystems and human health. Harmful algal events (HAEs), often called "red tides", may occur when HA reach high abundances in blooms, although many species can also cause harm at relatively low numbers. Mechanisms of harm include production of phycotoxins, mechanical action, or hypoxia. Because of their great ecological significance as threats to ecosystem structure and function, HA in Canadian waters have been identified as Ecologically and Biologically Significant Species. DFO responsibilities potentially affected by HAEs include species-at-risk, marine mammals, aquaculture, fishery and fish population health, ecosystem health, and food safety and security. HAEs have emerged as important stressors of marine fisheries and ecosystems and are listed by the DFO Ecosystem Stressors Program as a priority ecosystem stressor requiring further study in Canadian marine waters. At the same time, coastal marine activities have increased, including commercial and recreational vessel traffic and coastal development related to aquaculture, oil and gas, tourism and other industries. A particular concern is for the marine ecosystem in the Arctic, where increasing vessel traffic and climate change could affect the prevalence of HA and the likelihood of HAEs. The extent and impacts of HAEs in Canadian marine waters have not been systematically studied in recent years, and are poorly known in the Arctic. Most reports at the ecosystem level have been incidental to other studies, which results in incomplete understanding of causes, impacts and consequences.

The Ecosystem Stressors Program under DFO's Ecosystems and Oceans Science Sector requested science advice on the national scope of HA incidences and their impacts in Canadian marine waters, including the identification of knowledge gaps and areas or issues of particular concern to Canadian marine ecosystems. The objectives of this document are to: (1) review HAEs and their impacts in Canada's Atlantic, Arctic and Pacific marine waters over a 30-year period from 1987 to 2017; (2) determine areas or issues of particular or emerging concern with respect to impacts and consequences to Canadian marine ecosystems and how they may impact core DFO responsibilities; (3) identify key knowledge gaps that limit DFO's ability to evaluate or inform management decisions regarding the impacts and consequences of these HAEs; and (4) recommend actions to address these knowledge gaps.

ANALYSIS

Harmful algae and harmful algal events in Canada's marine waters

HAEs and their impacts in Canada's Atlantic, Arctic and Pacific marine waters were reviewed. Information on HA species, phycotoxins, and HAEs in Canada's three oceans was obtained from published and unpublished reports and data. An extensive review of marine HA and phycotoxins of concern to Canada was presented at the meeting and later published (Bates et al. 2020). A 30-year time series of records from the Intergovernmental Oceanographic Commission/International Council for Exploration of the Seas/North Pacific Marine Science Organization (IOC/ICES/PICES) Harmful Algae Event Database (HAEDAT), which includes HA data (species observations linked to the HAE and/or phycotoxin concentration, when available), management actions (shellfish closures), fish kills or extreme events, was analyzed for the Atlantic and Pacific coasts. This time series study was presented at the meeting and later published as part of Canada's contribution to a Global HAB Status Report (McKenzie et al. 2021). No HAEDAT records exist for the Arctic, as there has never been a phycotoxin or HA monitoring program in that region.

The following phycotoxins were considered:

1. Amnesic Shellfish Toxin (AST): domoic acid (DA), responsible for Amnesic Shellfish Poisoning (ASP), produced by 28 of the 58 diatom species of the genus *Pseudo-nitzschia*.
2. Paralytic Shellfish Toxin (PST): saxitoxin (STX) group toxins, responsible for Paralytic Shellfish Poisoning (PSP), produced by some dinoflagellates of the genus *Alexandrium*.

3. Diarrhetic Shellfish Toxin (DST): okadaic acid (OA) group toxins, responsible for Diarrhetic Shellfish Poisoning (DSP), produced by some dinoflagellates of the genera *Dinophysis* and *Prorocentrum*.

All Canadian event data (593 records) were extracted from HAEDAT and summarized to examine the spatial and temporal distribution of HAEs. As HAEDAT records are based primarily on closures of harvest areas caused by phycotoxin levels exceeding regulated standards for AST, PST, and DST in monitored shellfish populations, and reported fish kills attributed to HA, they do not necessarily represent all HAEs. A comprehensive report of three decades of HAEs in Canada (McKenzie et al. 2021a) used HAEDAT to evaluate status and trends.

To date, 70 harmful pelagic and sympagic (sea-ice associated) algal species have been reported in Canadian waters. On the Atlantic and Pacific Canadian coasts, 27 HA are known to have caused, or to be associated with, HAEs; the other 43 species are known to have caused, or to be associated with, HAEs outside Canada or to produce phycotoxins in the laboratory. In the Arctic, among the 45 harmful pelagic and sympagic algal species reported, 16 are known to have caused, or to be associated with, HA events on the Atlantic or Pacific coasts of Canada, and the other 29 species are known to have caused, or to be associated, with HA events outside Canada or in the laboratory. See McKenzie et al. (2021, 2024) for tables that list these species and their location in Canada, and for a description of their mechanism of impact.

A review of the Canadian HAEDAT records from 1987 to 2017, together with other Canadian data and publications, showed that reoccurring HAEs have been widespread on both the Atlantic and Pacific coasts (Figures 2, 3). PST events on the Atlantic coast occurred annually in the Bay of Fundy and the Estuary and Gulf of St. Lawrence. Multi-year events occurred throughout the remainder of the coast. (Figure 2A). HAEs caused by AST and DST were commonly reported in all Atlantic provinces (Figure 2B, C). Several marine species mortalities caused by HA were reported in Atlantic coastal waters, with wild marine species killed in the Estuary and Gulf of St. Lawrence (2008) and farmed salmon deaths in Nova Scotia (2000) and New Brunswick (2003, 2004) (Figure 2D) (McKenzie et al. 2024). PST events occurred annually along the Pacific coast, including multi-year events in the Strait of Georgia (Figure 3A). HAEs caused by AST have occurred since 1992 throughout the Strait of Georgia, west coast of Vancouver Island, and north coast areas and Haida Gwaii. DST events were commonly reported along the Pacific coast since 2011 (Figure 3B, C). Marine species mortalities caused by HA are an annual occurrence in the Pacific Region, impacting farmed salmon, and have been caused by several different HA species (Figure 3D) (McKenzie et al. 2024).

HAEDAT data are not available for the Canadian Arctic and no HAEs have yet been reported there. In waters adjacent to the Canadian Arctic, PST was detected in marine mammals (Whales, Seals, Sea Lions, Walrus, and Sea Otters) sampled along the coast of Alaska and the eastern tip of Russia. *Pseudo-nitzschia* blooms have also been reported from the Far Eastern seas of Russia and the presence of low levels of AST (0.3 µg DA g^{-1} tissue) in Scallops was detected during a bloom of *P. seriata* in the Beaufort Sea, suggesting HAEs can occur in the Canadian Arctic as well.

Additional information beyond this HAEDAT summary for the Canadian Atlantic and Pacific coasts, and a summary of HA for the Arctic, with detailed decadal comparisons, is provided by McKenzie et al. (2021, 2024). Regional maps (Figures 4, 5) provide a more complete picture of the widespread nature of HAEs as demonstrated by the locations of blooms and the detection of regulated and unregulated phycotoxins.

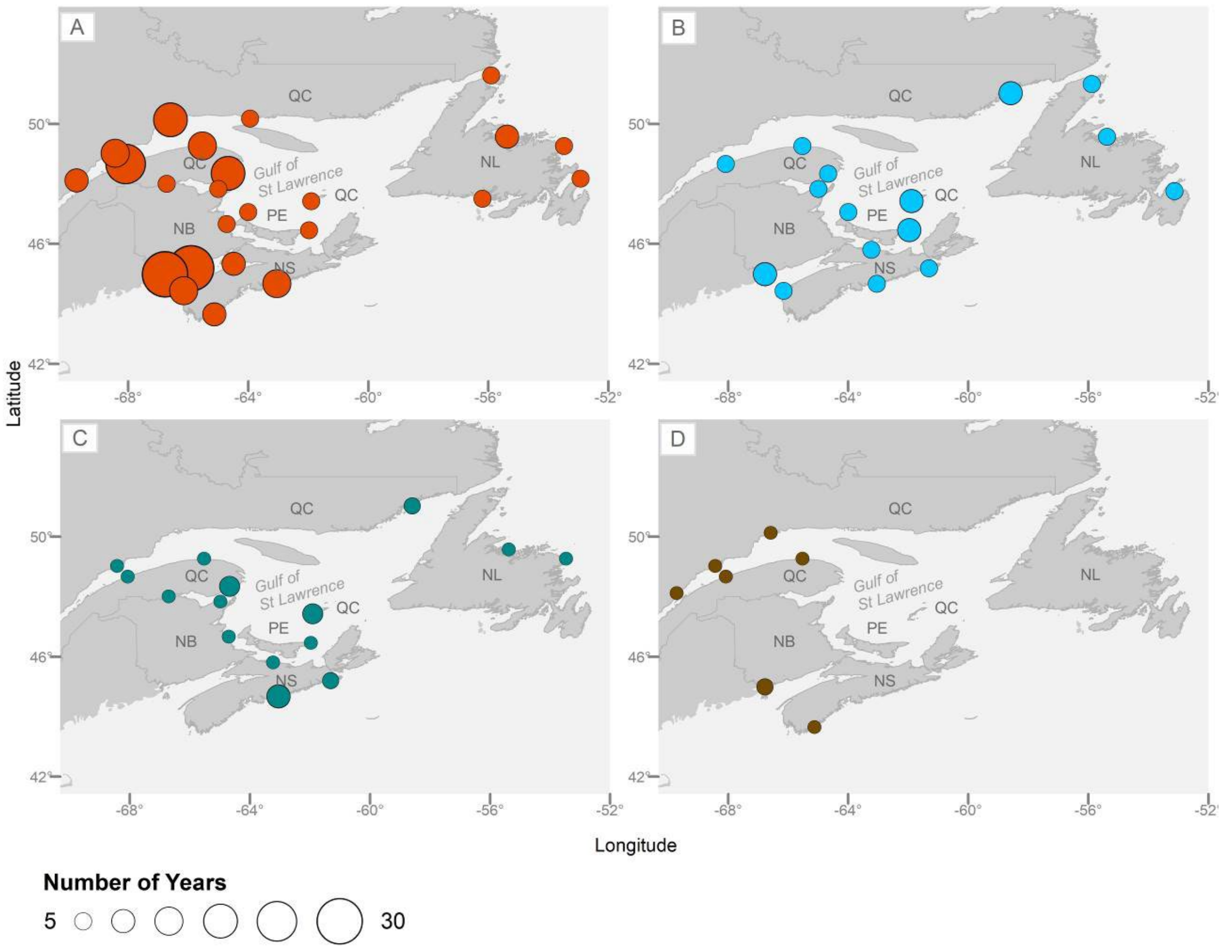

Figure 2. Atlantic coast. HAEDAT reports showing the distribution of (A) PST (red), (B) AST (blue), (C) DST (green), and (D) marine species mass mortalities events (brown), and extent of reoccurrence (size of circle), for 30 years of data reporting (1987-2017). Circles are associated with each HAEDAT grid code area and are not the exact location of the events NB: New Brunswick, NL: Newfoundland, NS: Nova Scotia, PE: Prince Edward Island, QC: Quebec.

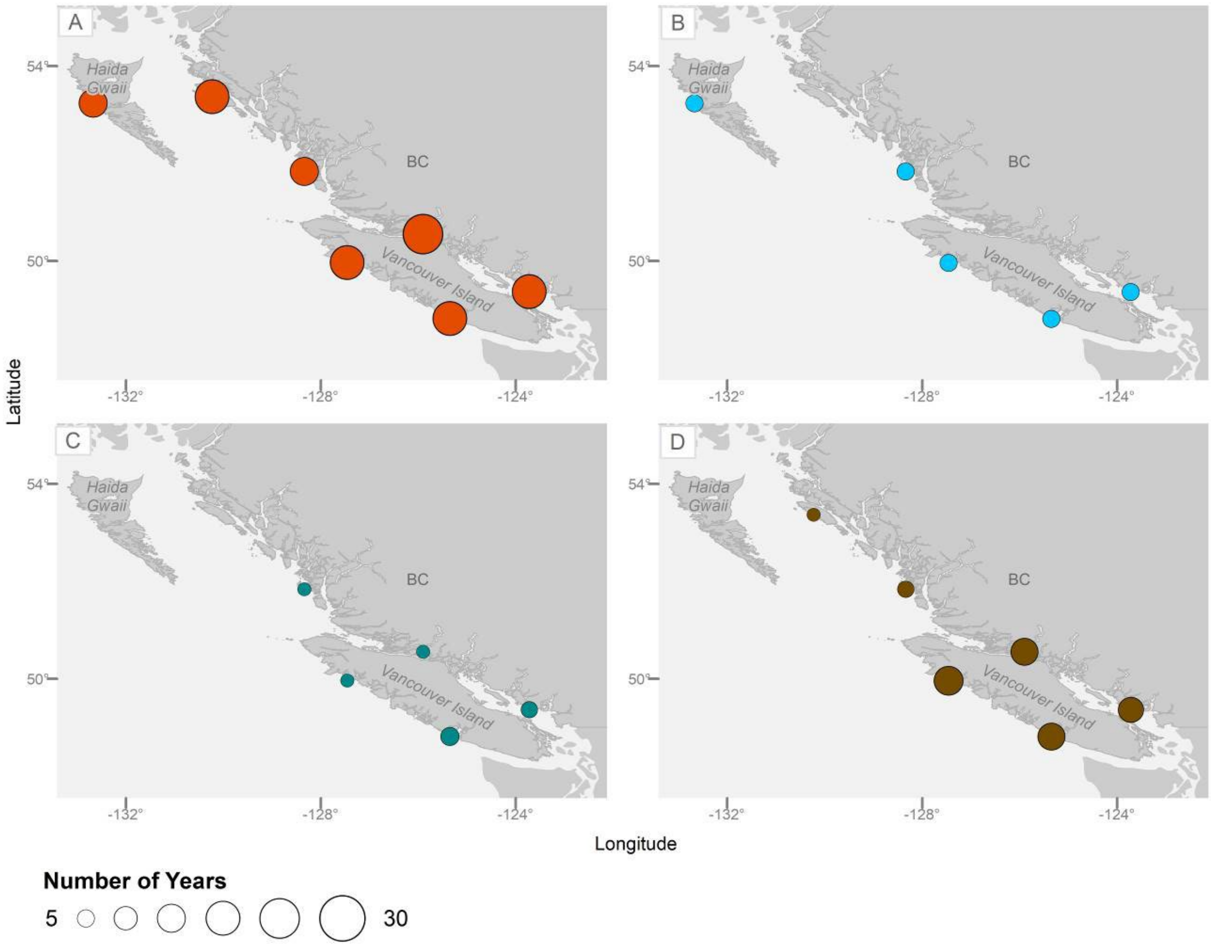

Figure 3. Pacific coast. HAEDAT reports showing the distribution of (A) PST (red), (B) AST (blue), (C) DST (green), and (D) marine species mass mortalities events (brown), and extent of reoccurrence (size of circle), for 30 years of data reporting (1987-2017). Circles are associated with each HAEDAT grid code area and are not the exact location of the events. BC: British Columbia.

Canadian Atlantic coast summary

For the Atlantic coast, when all reviewed HA and phycotoxin information is combined, including that contained in HAEDAT (Figure 4), the scope of the issue is clear, with varied and recurring events throughout the region see Bates et al. 2020; McKenzie et al. 2021, 2024 for examples). This highlights the extent to which future events could occur. At least 55 species of HA have been detected on the Atlantic coast, with 11 known to have caused, or to have been associated with, HAEs in Canada. Additional emerging phycotoxins include yessotoxins, azaspiracids, spirolides, pinnatoxins, gymnodimines and pectenotoxins, the latter being the only emerging phycotoxin to have a regulatory limit in Canada, as it is linked to DST (McKenzie et al. 2024).

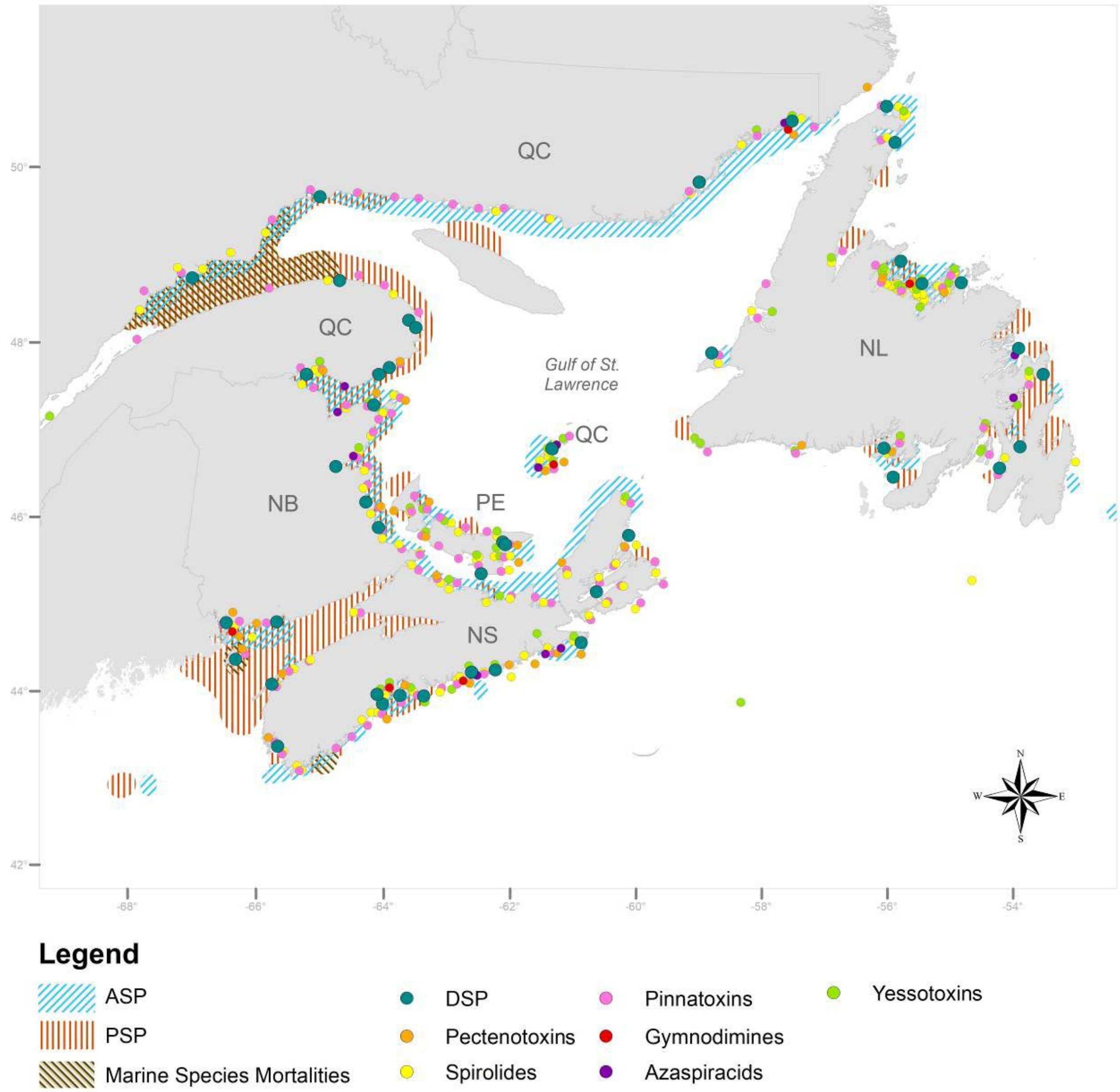

Figure 4. Atlantic summary of HA toxin detections. This map includes locations of emerging phycotoxins of global concern: pectenotoxins, spirolides, pinnatoxins, gymnodimines, azaspiracids, and yessotoxins. NL: Newfoundland and Labrador, NS: Nova Scotia, NB: New Brunswick, PE: Prince Edward Island, QC: Quebec. McKenzie et al. 2024.).

Canadian Pacific coast summary

The Pacific coast (Figure 5) also showed varied events recurring throughout the region (see Bates et al. 2020; McKenzie et al. 2024), which, as in the Atlantic region, highlights the extent to which future events could occur. Phycotoxins have been reported along almost all parts of the BC coast, although some remote areas off Vancouver Island and the northern mainland, as well as offshore waters, are rarely if ever sampled. At least 53 species of HA have been detected on the Pacific coast, with 19 known to have caused, or to have been associated with, HAEs in Canada. Additional emerging phycotoxins (Figure 5) include yessotoxins, azaspiracids, spirolides, pinnatoxins, gymnodimines and pectenotoxins, the latter being the only ones to have a regulatory limit in Canada (McKenzie et al. 2024).

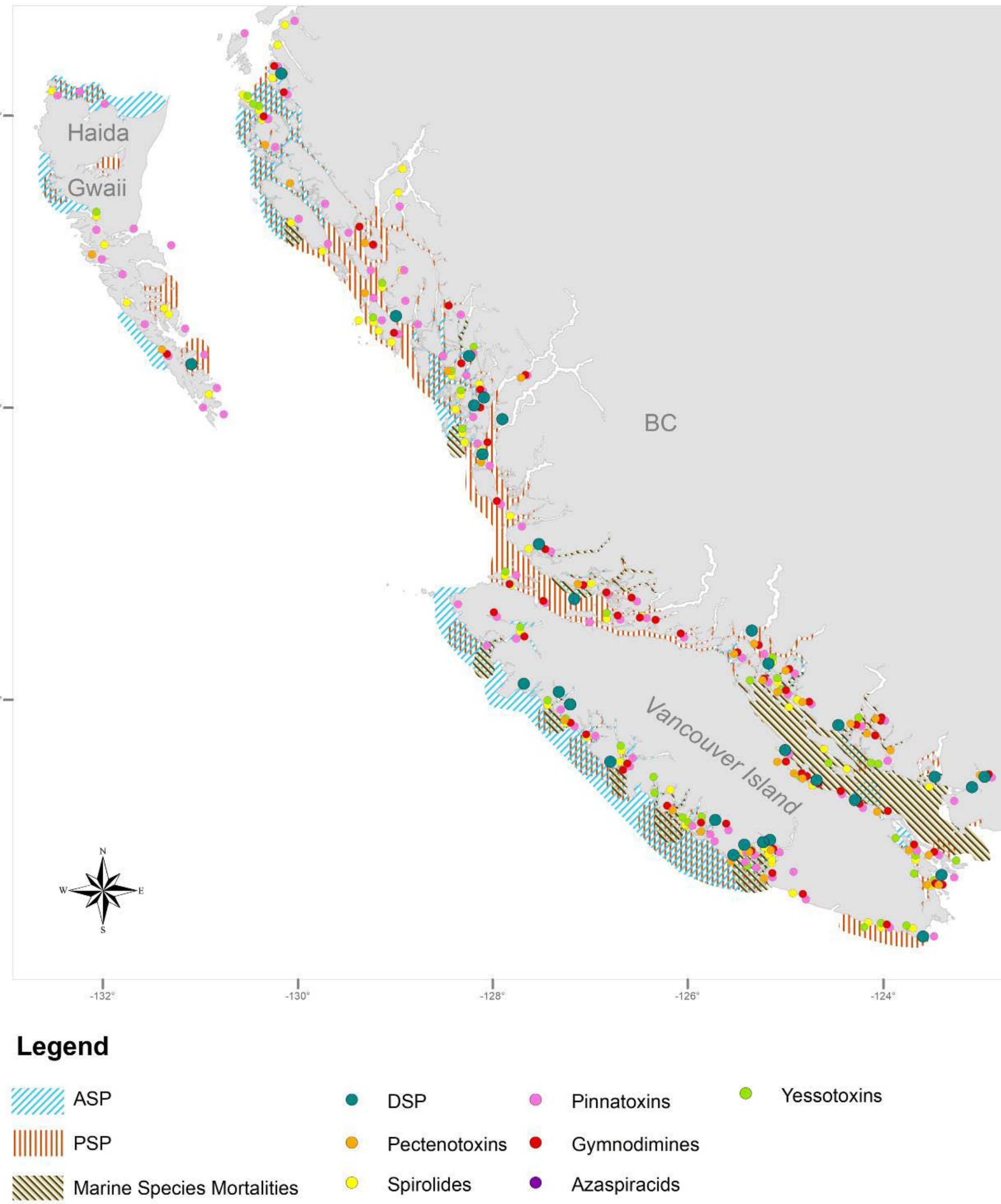

Figure 5. Pacific summary of HA toxin detections. This map also includes locations of emerging phycotoxins of global concern: pectenotoxins, spirolides, pinnatoxins, gymnodimines, azaspiracids, and yessotoxins. BC: British Columbia. McKenzie et al. 2024.

Canadian Arctic coast summary

Throughout Canadian Arctic and sub-Arctic regions, including sites within the Hudson Bay Complex (Hudson Bay, Hudson Strait and Foxe Basin), the eastern Arctic (southern Davis Strait to northern Baffin Bay and Nares Strait), the western Arctic (Beaufort Sea), the Canadian Archipelago, including Amundsen Gulf and Franklin Bay, and the Canada Basin, 45 harmful pelagic and sympagic (sea-ice associated) algal species have been identified (Figure 6). Of these, 16 species are known to have caused, or to be associated with, HA events on the Atlantic or Pacific coasts of Canada. The other 29 species are known to have caused, or to be associated with, HA events outside Canada or in the laboratory. Species distribution information was compiled from a literature review and various unpublished datasets to identify potentially toxic or harmful phytoplankton and sea-ice species present in the Canadian Arctic see Bates et al. 2020; McKenzie et al. 2021, 2024).

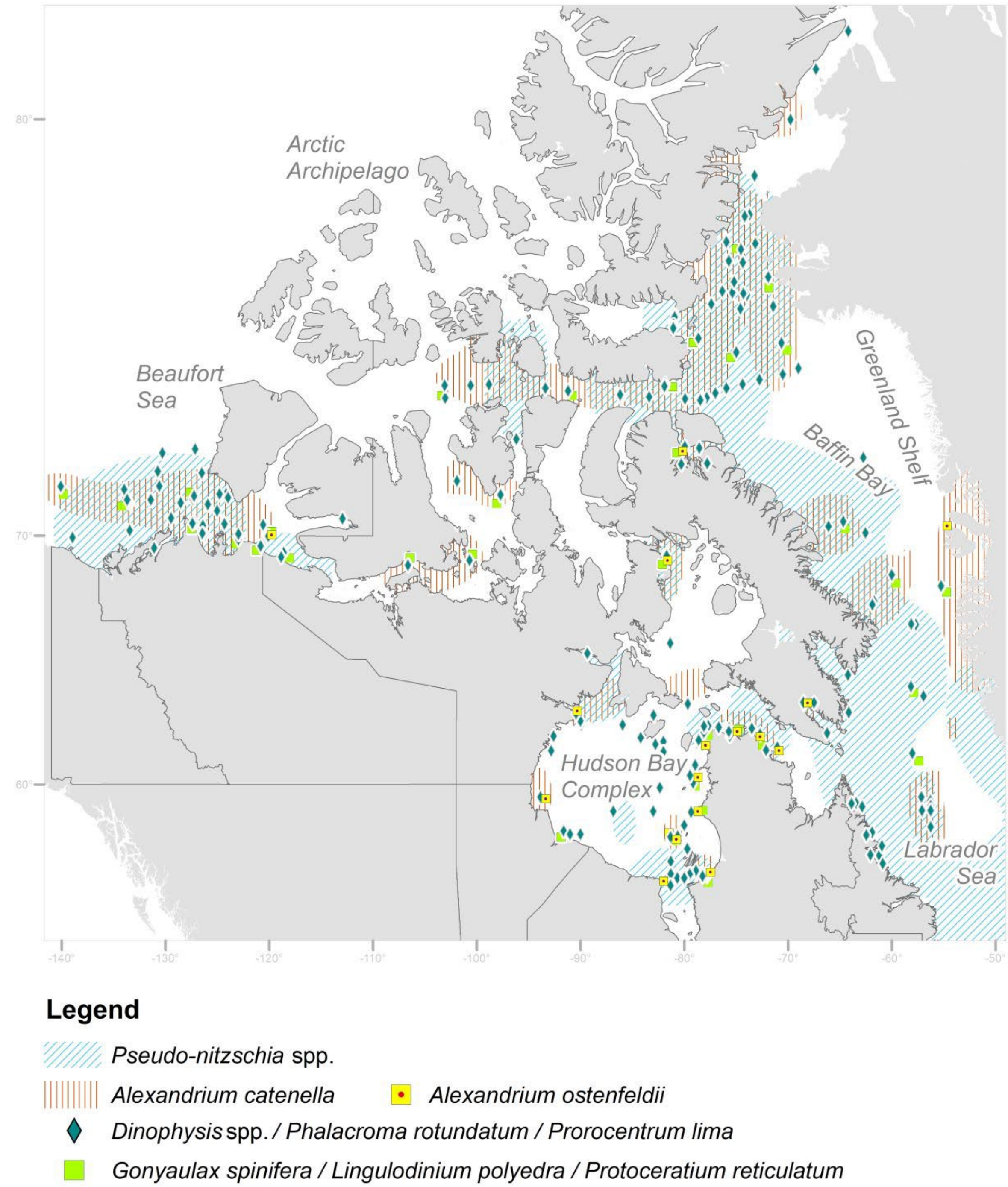

Figure 6. Potential HA species present in the Arctic, and known to produce PST, AST, and DST elsewhere in the world. Additional potential phycotoxin producers are also included: Gonyaulax spinifera*,* Lingulodinium polyedra *(for yessotoxins),* Alexandrium ostenfeldii *(for spirolides). McKenzie et al. 2024.*

Drivers, pressures, impacts, and consequences of HAEs

A conceptual bow tie model was developed as a framework to guide the identification of areas or issues of particular or emerging concern with respect to impacts and consequences of HAEs to Canadian marine ecosystems and how they may impact core DFO responsibilities. The model was applied to identify key knowledge gaps that may limit DFO's ability to evaluate or inform management decisions regarding the impacts and consequences of these HAEs.

The conceptual bow tie model

The conceptual bow tie model (Figure 7) links causes to outcomes of HAEs. The model was applied during the CSAS workshop, when participants identified national and regional key knowledge gaps that might limit DFO's ability to manage consequences of HAEs specifically linked to DFO's mandate.

Bow tie analysis is a risk assessment and management tool that can be used in an ecosystem management context. It is a structured approach that organizes information from a variety of sources to determine knowledge or management gaps and to prioritize risk management actions. In its simplest form, as used in the present document, a bow tie model is "*a simple diagrammatic way of describing and analyzing the pathways of a risk from hazards to outcomes and reviewing controls*". The "knot" of the bow tie, at the centre of this model, is an undesired event, the HAE. Surrounding the HAE are its potential "mechanisms of effect" (phycotoxins, mechanical damage, and hypoxia) that may lead to the event.

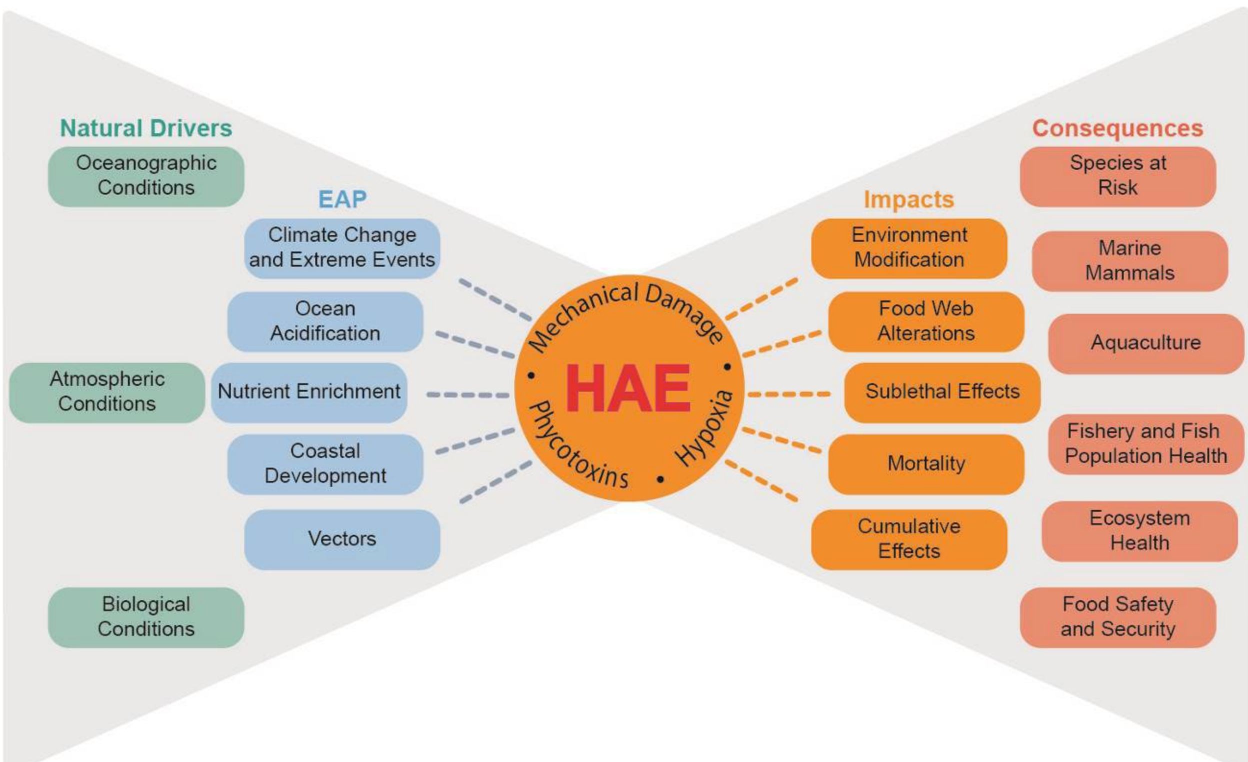

Figure 7. Conceptual bow tie model showing causes (natural drivers and Emerging Anthropogenic Pressures; EAP), at left, which may lead to a harmful algal event (HAE). The outcomes (impacts and consequences) of a HAE are shown at the right.

The conceptual bow tie model framework incorporated three natural drivers (oceanographic, atmospheric, and biological conditions) and five emerging anthropogenic pressures (climate change and extreme events, ocean acidification, nutrient enrichment, coastal development, and vectors (of introduction or spread)) that influence the occurrence of HAEs in Canadian marine waters. Canadian HAEs have been shown to lead to impacts or potential impacts (environmental modification, food web alterations, sublethal effects, mortality, and cumulative effects) and consequences relevant to DFO responsibilities (species-at-risk, marine mammals, aquaculture, fishery and fish population health, ecosystem health, and food safety and security). The mechanisms of these impacts include phycotoxins, mechanical damage, and/or hypoxia.

General knowledge gaps

There is limited understanding of factors that control phytoplankton growth dynamics especially what environmental conditions trigger HA to form blooms, and what controls the magnitude and persistence of the bloom. Further, the ability to precisely and rapidly detect HA in Canada is limited. Traditional methods to identify HA and phycotoxins are more widely available on the Atlantic and Pacific coasts but the Arctic remains a major gap. Novel methods to detect and monitor HA in Canadian marine waters are available and could improve early detection and monitoring programs in each of Canada's three oceans.

There is a lack of knowledge with which to build predictive models of HAEs, including growth rates of HA in their natural environments (both now and under future climate scenarios), their response to physical processes, and the link between germination of cysts and blooms. The effect of climate change and ocean acidification on HA is an emerging issue worldwide, including in Canadian waters, where temperatures (and other conditions) are predicted to change more rapidly at higher latitudes than the global average (McKenzie et al. 2024). Also, there is limited knowledge of what environmental conditions trigger the production and release of phycotoxins, how they persist and potentially accumulate in sediments, and their impact on organisms, food webs, and ecosystems. A better understanding of the effect of specific drivers is required in order to predict the possible impacts of climate change, improve our forecasting/hindcasting capability, and develop mitigation measures and prevention strategies.

Regional knowledge gaps

In Canada, HA species and impacts vary by region, so knowledge gaps and priorities vary among regions. For example, the role of climate change and ocean acidification on recurring HAEs was identified as a key knowledge gap in Atlantic waters while the role of extreme events as a driver of HAEs was a key question in Pacific waters. Several knowledge gaps were identified for all Canadian marine waters but the principal knowledge gaps are in the Arctic, which lacks information about the presence of HA and phycotoxins, extent and frequency of HAEs and possible cumulative effects of phycotoxins in the food web, including harvested species.

Recommendations to address knowledge gaps

1. Research is needed to fill the critical knowledge gaps about HA and the emerging anthropogenic pressures that drive HAEs in Canadian marine waters (the left side of the bow tie model – the drivers of the event). These include the detection and distribution of HA; integration and expansion, where necessary, of phycotoxin monitoring; and better understanding how emerging anthropogenic pressures alter HAE dynamics (bloom initiation and duration). This information will support the overall goal of more accurate predictive models of HAEs in order to provide an early warning system for management purposes.
2. Knowledge about what HA species and phycotoxins are present is essential in order to anticipate what harm might occur, the HAE (the central knot or risk event in the bow tie

model). A list of existing relevant long-term data sets should be compiled that could be leveraged for analyses of phytoplankton patterns and trends for HAE. Increased communication with partners and development of standardized operating procedures should facilitate knowledge and technology transfer, particularly linking HA and phycotoxin data.

3. Understanding the effects of HA and phycotoxins (including sublethal and cumulative) on the growth, physiology, reproduction and behaviour of marine biota is needed to evaluate their impact on food webs and ecosystems, and their consequences to species-at-risk, marine mammals, aquaculture, fishery and fish population health, ecosystem health, and food safety and security (the right side of the bow tie model – impacts and consequences of the event).
4. Monitoring of phytoplankton and phycotoxins should be continued and expanded where it currently exists, and expanded to other regions of concern, using new and existing capacity and partnerships. This is particularly important for areas where information is lacking, including the Arctic. Along with traditional methods to identify HA and phycotoxins, novel methods to detect and monitor HA in Canadian marine waters should be considered. Monitoring programs using existing methodologies can assist the ground-truthing of new technologies.

Sources of Uncertainty

The HAEDAT dataset was initiated in 1987. It is a considerable resource and summarizes a large quantity of data, some of which are no longer accessible. It captures some long-term regional and temporal changes in HAE distributions. One must acknowledge, however, that HAEDAT has limitations and should be treated with caution. For example, there are gaps in the data, inconsistent reporting prior to 2000, and a dependence on CFIA phycotoxin monitoring, which is designed to protect human health and not to monitor HABs and investigate its causes and consequences.

The bow tie models developed here are meant to serve as a starting point to link drivers of change to HAE impacts. The level of information varied for each of Canada's three Oceans and future iterations would benefit from additional expert opinion beyond those that attended the CSAS meeting. Such an exercise could reduce uncertainty around key relationships that would improve mitigation and management decisions.

CONCLUSION AND ADVICE

The review of HAEs and their impacts in Canada's Atlantic, Arctic and Pacific marine waters over the past 30 years identified areas and issues of emerging concern with respect to impacts and consequences to Canadian marine ecosystems and how they may impact core DFO responsibilities. National knowledge gaps included limited HA and phycotoxin detection and variable uncertainty around the effects of specific emerging anthropogenic pressures (climate change, ocean acidification, nutrient enrichment, coastal development, and vectors of introduced HA) on oceanographic, atmospheric and biological conditions that drive changes in HA species, phycotoxins, and bloom development and toxicity. This was especially true in the Arctic, which lacked information about the presence of HA and phycotoxins, extent and frequency of HAEs and possible cumulative effects of phycotoxins in the food web, including harvested species. These knowledge gaps prevent the development of effective predictive HAE models, which hinder forecasting/hindcasting capability and hamper development of mitigation and prevention strategies.

Monitoring of phytoplankton and phycotoxins, where it currently exists, should be continued and expanded, using new and existing capacity and partnerships. One advantage of such a monitoring network would be an early warning system that would increase predictive capacity for HA as ecosystem stressors, enabling mitigative or preventive actions to ensure healthy and productive marine ecosystems.

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SOURCES OF INFORMATION

An extensive review of marine HA and phycotoxins of concern to Canada was presented at the meeting and later published (Bates et al. 2020). As well, the 30-year time series of records from the Intergovernmental Oceanographic Commission / International Council for Exploration of the Seas/North Pacific Marine Science Organization (IOC/ICES/PICES) Harmful Algae Event Database (HAEDAT) was presented at the meeting and later published as part of Canada's contribution to a Global HAB Status Report (McKenzie et al. 2021).

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THIS REPORT IS AVAILABLE FROM THE:

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ISSN 1919-5087
ISBN 978-0-660-76300-2 Cat. No. Fs70-6/2025-008E-PDF

Correct Citation for this Publication:

DFO. 2025. Science Advice for Harmful Algal Events in Canadian Marine Ecosystems: Current Status, Impacts, Consequences and Knowledge Gaps. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2025/008.

Aussi disponible en français :

MPO. 2025. Avis scientifique sur les proliférations d’algues nuisibles dans les écosystèmes marins du Canada : état actuel, effets et conséquences, et lacunes dans les connaissances. Secr. can. avis sci. du MPO. Avis sci. 2025/008.