Identifying and Minimizing Impacts of Weather on Marine Aquaculture in Atlantic Canada

Report on Roundtable Discussions

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Introduction

Weather is recognized as a key concern and source of risk in marine work, including aquaculture. However, the nature of weather concerns vary considerably with geography and season, and between industries or even individual operations. In order to share knowledge and assess weather-related needs in Atlantic Canada's aquaculture sector, a pair of roundtable discussions were convened by Memorial University of Newfoundland & Labrador (MUNL) researchers in the spring of 2023. These events brought together aquaculture representatives (operators, managers, buyers, and industry association representatives), safety professionals, and marine meteorologists, for the purpose of exploring the impact of weather on aquaculture operations, infrastructure, and personnel. Additional consideration was given to strategies for managing weather risk, ranging from site selection and infrastructure design through to the use of marine forecasts for operational decision-making.

This report provides a summary of the ensuing discussion. It serves as both a reference for participants and a starting point for further research.

Participants

Together, the two roundtables attracted roughly 20 participants, with representation from all four Atlantic provinces (New Brunswick, Newfoundland and Labrador, Nova Scotia, and Prince Edward Island). Over a third (~37%) were representatives of the aquaculture industry (managers; engineers; industry organizations; buyers/distributors); another third (~32%) represented federal government agencies with mandates related to the marine environment (Environment & Climate Change Canada [ECCC], Transportation Safety Board of Canada [TSB], Canadian Coast Guard); 26% were academics; and the remaining 5% were representatives of labour and safety organizations. Industry representatives included people with experience farming salmon, trout, mussels, and oysters; specific expertise included operations management, market considerations, fish biology & care; infrastructure design; government regulation; and environmental stressors. By contrast, some participants from other sectors had no prior experience with aquaculture directly, but increasingly recognize the industry as an important consideration in either policy development or service delivery (e.g. marine meteorologists with ECCC).

Background

The roundtables on aquaculture and weather were designed as a starting point for further research, planned for late 2023/early 2024. Prior research on the management of weather risks in fisheries provides another useful reference, including insight into key weather risks; weather-driven decision-making on fishing vessels; and competing factors that fishers must consider along with weather. However, while similarities certainly exist, fishers primarily consider weather as a concern for i) workplace health and safety and ii) damage to vessels and gear. In this context, weather is largely manageable by avoiding dangerous conditions. By contrast, aquaculture operations must also consider impacts on fixed marine infrastructure (e.g. cages, rafts, longlines) and, critically, the stocks of finfish and shellfish (hereafter collectively referred to as fish stocks) housed within or upon this infrastructure; for these elements of an operation, simple avoidance of weather is unfeasible, and alternative strategies are required. Operators must balance consideration of environmental impacts on worker/operations management, infrastructure, fish biology, and potentially the surrounding environment (e.g as a consequence of escapes).

Opening statements by industry representatives emphasized that sustained fish growth is a primary concern for aquaculture operators, and essential for the economic viability of a specific aquaculture site. This introduces seasonally-varying pressures to access sites: to supply feed during peak growth periods (e.g. summer/fall for salmon), collect seed for subsequent seasons (e.g. shellfish), or to combat health risks (e.g. parasite treatment; preparation for cold season). High winds and waves can limit site access for these purposes, indirectly impacting fish growth and and/or health; locations with frequent bad weather during key seasons may be considered unmanageable and, consequently, economically unfeasible. Weather (both meteorological and oceanographic[1]) can also impact fish stocks directly; for example very high water temperatures may require limitations on feedings and parasite treatments for salmon, while increasing risks of oxygen depletion and mass fish mortality events. Shellfish operators also point to high temperatures as a mortality risk, as well as a factor driving biofouling (sea squirt/tunicates) and outbreaks of bacteria (vibrio) & toxic algae, respectively increasing maintenance costs and limiting sale of affected stocks. Shellfish operators must also consider weather on surrounding land, as heavy precipitation events can drive microbial spikes, rendering stocks unfit for sale and prompting temporary closures.

Managing the operational and biological impacts of weather on marine aquaculture requires constant, careful review of available meteorological/oceanographic monitoring and prediction systems by both aquaculture workers and managers. This includes assessing weather concerns as they occur (‘nowcasting’), and reviewing marine forecasts and weather model output (prediction resources) to anticipate and prepare for oncoming weather. To a large extent, this effort is dependent on the resources and personnel of the ECCC (along with other national weather services), who i) maintain the network of weather stations and buoys necessary to assess current conditions, and ii) combine these observations with remotely sensed data (satellites, radar) to inform their predictive model simulations. Whether accessed through ECCC directly or via third-party visualization tools, the aquaculture industry’s use of this information to reduce the impacts of weather on personnel, infrastructure, and fish stocks directly aligns with ECCC’s mandate to facilitate weather-informed decision-making. However, given ECCC’s broad mandate and diverse audiences, direct interaction with aquaculture end-users remains limited; as with other sectors (e.g. fisheries), increased interaction has the potential to benefit both ECCC meteorologists and forecast end-users by identifying opportunities for collaboration and informing ECCC’s efforts to deliver ‘impact-based’ weather forecasts and climate projections.

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[1] We add this to stress that we are considering all concerns related to the marine environment, whether driven by the atmosphere (meteorological; e.g. winds, storms, visibility etc.), the ocean surface (marine heatwaves; tides), or both (waves, icing). Sometimes referred to collectively as *metocean* conditions.

Discussion was guided by the following questions:

1. **Weather & Environmental Risks:** How can weather-related ocean conditions impact aquaculture infrastructure, fish health, and worker safety?
2. **Sources of Information:** What sources of information are used to plan for weather impacts?
3. **Using Weather/Climate Information:** How are you using forecasts and climate information in your organization?
4. **Forecast Quality:** What makes for a 'good' forecast resource, in your experience?

Actual conversations were, however, much more free-flowing and interactive than these prompts might suggest. The following sections summarize and organize content of the two roundtable session discussions, while highlighting key and recurring themes.

Planning & Decision-making

Although the original intention of the roundtables was to explore aquaculture's response to weather (short-term phenomena, lasting several days to weeks), participants frequently drove discussion towards climate concerns (longer term considerations; years to decades). While weather discussion focused on types of events (e.g. storms, heatwaves), climate was often referenced indirectly; for example, in terms of favorable or unfavorable conditions for aquaculture, or as important context for specific weather events (e.g. Hurricane Fiona; Sept. 2022). The nature of the decisions influenced by weather versus climate information are necessarily very different: managing weather requires responsive (but temporary) shifts in standard operations, while climate informs long term planning such as site selection or infrastructure design/placement. To reflect these differences, the following section examines climate- and weather-driven decision-making separately. In each section, specific environmental concerns are identified, along with strategies for managing associated risk.

Climate & Planning

The degree to which aquaculture operators collect and/or review climate data prior to commencing operations varies; in the case of shellfish, the presence of a farmed species in the natural environment often provides sufficient confirmation that the climate is suitable for aquaculture. As the size and complexity of an operation increases, climate analysis is more likely to feature in early planning and design stages. When it is employed, climate data will be used to select optimal sites, and may inform infrastructure design. Regardless of whether they indicated that climate factored in site selection, the majority of aquaculture participants expressed concerns about the impacts that climate change might have on their existing operations. These concerns provided further context on favorable and unfavorable conditions for certain species.

Early Planning & Site Selection

Participants with marine salmon operations explicitly reported using climate data for site selection, cage placement, and cage design. Using a combination of modeling products, reanalyses (combinations of observations and model output), and on-site observations, salmon operators look for sites that are i) most conducive to fish growth and ii) minimize weather-driven work interruptions. According to roundtable participants, the primary concerns in planning stages are *winds*, *waves*, and *currents*.

Winds and waves were viewed as a risk to personnel and equipment, preventing safe work on service vessels and complicating interactions between vessels and net-cages. Several participants suggested that neither winds nor waves posed significant concern to fixed infrastructure, outside of increasing the risk of damage due to vessel/infrastructure collisions. The fact that Atlantic salmon cages withstood Hurricane Fiona (a record-breaking storm in Atlantic Canada) was provided as evidence of this resilience, which was attributed to high international standards for cage design. However, the same participant noted that frequent work disruptions due to winds have led operators to abandon some remote sites; although biologically suitable, the wind/wave climate around these sites made them operationally unfeasible.

Currents were described as a more complex consideration for the planning of salmon operations. As with winds and waves, strong currents complicate interactions between vessels, cages, and workers, increasing safety and infrastructure risks. However, they also require biological consideration. Strong currents can exhaust fish, slowing growth and impacting health, while weak currents limit the removal of wastes and replenishment of oxygen within cages, amplifying potential health risks.

Although participants did not cite *water temperatures* (T_w) as a factor in site selection, they clearly indicated that warming trends present a significant concern for operations. Temperatures exert a strong and complex influence on fish growth, health, and quality; paying close attention to climatology (seasonality; mean values; variability and extremes) when selecting sites can therefore have significant economic benefit. In at least one case, this benefit has motivated a review of ocean model simulations to better understand relationships between local T_w and winds. A brief summary of water temperature concerns follows, presented separately for fin- and shellfish.

> **Finfish Operations:** Salmon growth rates depend on water temperature, and are consequently seasonal. While growth is minimal during cold periods (winter), it increases rapidly as T_w rises from spring through autumn. Operators adjust feeding schedules to match this seasonality; although missed feedings are not a particular concern during the cold (low-growth) season, they have a much greater economic impact when water is warm, with each missed feeding representing a delay in the time it takes to get fish to market. However, warmer seasons also introduce health risks, such as reduced oxygen levels in the water (particularly acute during marine heatwave events) and increased incidence of harmful parasites (sea lice) and algal blooms. Colder seasons bring lower

growth, but also reduce (or even eliminate) risks from parasites and low oxygen levels; however, periods of extreme cold (T_w < 0°C, or superchill) can also harm fish, allowing ice formation in gills. Participants suggested that salmon farms in Atlantic Canada are unique in facing risks from both extreme high and low T_w events, and must contend with greater T_w variability than counterparts in other regions of the globe. Managing this variability requires seasonal adjustments to the feeding and medical treatment of fish, as well as careful environmental monitoring.

Shellfish Operations: Most discussion of water temperatures in the context of shellfish focused on the negative (and diverse) impacts of recent warming trends. In extreme cases, high T_w can cause shellfish mortality (e.g. T_w > 30°C for oysters). While these conditions are a rising concern in some shallow and/or near-shore areas, less pronounced warming can also influence fat content, reproductive cycles, and incidence of bacterial contamination (*Vibrio* spp.), potentially reducing the shelf-life, size, and marketability of farmed shellfish. Warming temperatures are also increasing the rate of biofouling on shellfish infrastructure (lines; cages etc.), with invasive tunicates (sea squirt) cited as a notable concern in Nova Scotia and PEI.

Shellfish operators also noted the negative impacts of reduced seasonal sea ice cover (a consequence of higher air and water temperatures) on their operations. In the past, sea ice served as vital natural infrastructure, providing access (by foot; snowmobile) to shellfish cultivation sites during the winter. It also served to protect infrastructure, damping waves and keeping larger floating ice offshore. While moving sea ice also presents a threat to infrastructure, this was described as a more manageable risk (e.g. using ice booms to block movement) than the larger icebergs and growlers. With shorter ice seasons and thinner ice when present, risks to infrastructure and personnel (during site access) are shifting.

Taken together, these concerns suggest that water temperatures are an important consideration in both the long-term management of existing aquaculture operations and the selection of new sites.

Weather & Operations

Regardless of long-term planning and climate trends, weather will inevitably cause disruptions to marine aquaculture operations. Fortunately, it is often possible to mitigate the impact of adverse weather by adjusting operations and/or preparing infrastructure. Time is, however, critical, and real-time identification of weather-related marine hazards may come too late to implement operational responses. Tools that allow operators to anticipate risks, such as marine forecasts and weather model visualization resources, extend opportunities for weather preparations and reduce the incidence of weather surprises. Consequently, these prediction resources are central to managing weather risks that cannot be eliminated through long-term planning or infrastructure design.

All aquaculture participants reported using marine observation and prediction resources, and some (e.g. salmon farms) collect their own observations at both existing and potential future sites. Observation resources include data collected from weather buoys, coastal climate stations (both maintained by ECCC), and websites offering visualizations of satellite observations (e.g. Umitron Pulse; https://www.pulse.umitron.com/). Prediction resources include both ECCC's marine forecasts and various web-based weather model visualization tools, such as Windy (windy.com). Several industry participants expressed particular enthusiasm for several (relatively new) web-based visualization tools (Umitron; Windy), citing the ability to get both a user-friendly geographic overview of weather conditions as well as site-specific information. Meteorologists at the roundtables noted that these visualization resources were potentially useful, but stressed that they show a fraction of the data (multiple model runs, observations, expert input etc.) that informs the standard (ECCC) marine forecast. As such, visualization tools and forecasts are complementary (rather than redundant) resources, and most effective when used together.

A majority of the discussion around weather focused on various impacts, and strategies for mitigating those impacts. These conversations are summarized below, with results separated by impacts within different aspects of aquaculture operations (infrastructure; fish stocks; personnel).

Personnel

Roundtable participants cited winds and waves as major safety concerns and the primary limits on travel to/work at aquaculture sites, but also pointed to additional weather concerns that often amplify safety risks such as icing on vessels and infrastructure, or freezing temperatures. These concerns closely resemble those of the fishing industry; while working locations and tasks are somewhat different, fishers and workers in marine aquaculture contend with the same highly variable (and frequently hostile) environment.

Fisheries and aquaculture also employ the same primary strategy for managing the health and safety impacts of adverse weather: avoidance. Aquaculture industry representatives stress that their vessels and employees simply stay on land when conditions are not favorable for work. On-site tasks such as feeding, medical treatments, harvests, and maintenance can all accommodate occasional, modest delays (e.g. lasting several days).

Should an aquaculture site experience frequent weather-driven delays, it may impact aquaculture productivity. Participants noted that frequent delays in feedings during the summer are a challenge for salmon operations, and can render a site economically unfeasible. Such delays were cited as a reason for prior closures in parts of Newfoundland, indicating that there is a limit to tolerance for (and feasibility of) weather avoidance as a management solution. There was some discussion of automated and remote feeding systems as a possible solution to these weather challenges, allowing regular feeding with fewer trips to aquaculture sites.

Infrastructure

Although the movement of the ocean itself poses some risk to static infrastructure at open-water aquaculture sites, roundtable participants suggested that motion of objects (vessels; ice) near infrastructure is a greater concern. When the impacts of waves on equipment (salmon cages, oyster cages, mussel lines, moorings) were raised, it was most often as a design consideration, and one that was largely solved (or solvable). As one participant noted, existing salmon cages, designed to international standards, weathered Hurricane Fiona, a record-breaking Canadian storm. Similarly, oyster farmers noted that temporarily sinking oyster cages to deeper levels had provided sufficient protection during past hurricanes (see *Health & Quality of Fish Stocks* below for caveats). Unfortunately, not all infrastructure is highly wave-resistant or easily moved; e.g. it isn't always feasible to sink long-line mussel infrastructure below the reach of surface waves. However, the general consensus during our roundtables was that the direct action of waves on infrastructure is not a primary, industry-wide concern.

By contrast, the movement of vessels (especially in rough waters) and floating ice (sea ice; icebergs) were presented as more pressing concerns for multiple industry sectors. Risks posed by vessels are largely under the operator's control (see Personnel risks), and can be managed by avoiding on-site work during rough weather. Operators have less control over thick ice (where/when present), but may use protective infrastructure designed to block ice entry to farm sites (e.g. ice booms employed by NL mussel operations).

Still, risks to infrastructure from weather can't be entirely eliminated, and over time damage from repeated weather events can accumulate and result in equipment failure. Operators manage these concerns with regular monitoring and maintenance of infrastructure. Additional monitoring around extreme events (e.g. hurricanes and 'weather bombs') may also be helpful - both in advance (if time allows) and in the immediate aftermath, in order to identify and address weaknesses quickly.

Health & Quality of Fish Stocks

In comparison with personnel and infrastructure, fish stocks are affected by a greater diversity of weather events. Specific concerns vary with species, geography, and infrastructure; depending on an operation's particular circumstances, stocks may be affected by waves, marine heatwaves, marine coldwaves (superchill), and/or precipitation.

Whenever waves threaten infrastructure, they also have the potential to impact the health and containment of fish. Participants suggested that waves were not a significant concern for salmon operations, as modern cages are sufficiently wave resistant and fish are free to swim to depths below wave action. Similarly, oyster operators indicated that temporarily sinking cages to greater depths during wave events is usually an effective mitigation strategy, protecting both infrastructure and existing stocks. However, sinking can expose oysters to indirect wave impacts during extreme events; e.g. coastal erosion by waves during Hurricane Fiona buried some lowered cages, causing oysters to suffocate. Mussel operators also indicate that it is not always possible to sink long-line infrastructure, particularly when weighted down with mature mussels; this leaves both equipment and stocks vulnerable to wave-driven damage.

Extreme temperatures (heatwaves; superchill events) are a widespread aquaculture concern, with the potential to drive mortality events (high death rates). When such events occur, they can have significant economic (lost product; clean-up costs) and environmental (acute release of wastes) impacts. In the case of salmon aquaculture, adjustments to work schedules can minimize mortality rates during marine heatwaves. Specifically, limiting interactions with fish encourages reduced activity and prevents asphyxiation; once a marine heatwave is identified, operators can cease feedings, medical treatments, and harvests until conditions improve. Shellfish operators must contend with both mortality and contamination risks (e.g. Vibrio bacteria) during heatwaves, but cannot improve outcomes by managing farm activity during an event. They may, however, still be able to mitigate impacts by shifting harvesting schedules ahead of an anticipated heatwave; by collecting (and potentially storing) stocks, lost income from a marine heatwave could potentially be minimized. Regular review of existing observation and prediction resources can enable such proactive measures, but may require careful interpretation and deliberate risk analysis as heatwaves are not explicitly addressed in standard marine forecasts.

Shellfish operators (oysters, mussels) identified precipitation events as a primary concern, largely due to the Canadian Shellfish Sanitation Program (CSSP). Administered jointly by the Canadian Food Inspection Agency (CFIA), ECCC, and Fisheries & Oceans Canada (DFO), the goal of the CSSP is to minimize the risk of contamination in shellfish harvested within Canadian waters; when water testing or background environmental conditions indicate high risk of microbiological or biotoxin contamination in an area, that area will be closed to harvesting. Given that runoff from surrounding land is a significant microbiological risk factor, heavy rainfall events will commonly trigger CSSP closures. These can last for weeks, leaving operations without income in the meantime. Closures can occur quickly, rendering recently harvested product unsellable; several participants referred to specific past instances when this has occurred, wasting large volumes of shellfish. Industry participants expressed several frustrations with CSSP procedures, including delays in communication of closures; decreased reliance on direct monitoring of water quality in favor of indirect proxies of contamination risk (e.g. observed or predicted precipitation); and a perceived excess of caution on the part of CSSP decision-makers. Some participants explicitly linked these frustrations with a need for better precipitation monitoring and prediction: their understanding was that CSSP closures were sometimes prompted by predicted (forecast) precipitation events that ultimately did not occur, prompting unnecessary economic losses that could have been avoided with more accurate information. Several participants identified “better” (presumably, more accurate) precipitation forecasts as a means of preventing unnecessary closures. Alternatively, prediction tools (whether improved or not) could be used by operators to anticipate precipitation-driven closures. Depending on forecast lead times, forecasts could facilitate pre-closure harvests (longer lead time before an event) or decisions to delay harvests to avoid stranding product in the event of a closure (shorter lead times).

Limits to Weather Planning

Although identifying and anticipating environmental challenges can empower aquaculture operators to accommodate impacts, various factors can hinder their ability to respond. These include limitations in i) observing and prediction resources; ii) context for anticipating impacts, and/or iii) available mitigation strategies.

The first of these limitations was referenced by industry participants, particularly in calls for improved precipitation monitoring and prediction in the context of government mandated (CSSP) shellfish closures (CSSP). ECCC referenced these concerns more broadly, while emphasizing that the limited availability of marine weather observations impedes their ability to assess current conditions; accurately predict future conditions; and evaluate forecast performance. The few available observation points (primarily a handful of weather buoys) are a vital resource, but expensive to maintain. It is possible to address observation/prediction limits by investing in an expanded ocean observation network; however the cost of any significant expansion is prohibitive for government agencies. An alternative (and likely more feasible) approach is for industry to either share costs or provide ECCC with data that is already being collected. Several aquaculture operators referred to observational capacity at work sites which, if shared, could provide vital additional context to ECCC forecasts and warning systems.

Even a perfectly accurate forecast is only useful if end-users understand what it means for them. With this in mind, ECCC is placing increased emphasis on delivering ‘impact-based forecasts’ that convey likely outcomes of high-impact weather events. The success of this effort will, in part, rely on the engagement of diverse end-users, who best understand ways that weather can adversely affect particular locations, activities, and infrastructure. Collaborative efforts between ECCC and the aquaculture industry have the potential to shape both the content of forecast products (adding relevant context) and the capacity for aquaculture operators to extract likely impacts from existing forecasts. This is particularly valuable given the challenges of climate change, which is bringing high impact events without clear antecedents and, therefore, uncertain impacts. Oyster operators in PEI provided an example from Hurricane Fiona (2022). With Fiona approaching, oyster operators employed a strategy that had served them well during other recent hurricanes (e.g. Dorian, 2019): submerging cages to protect them from wave action. However, stronger waves and heavy precipitation during Fiona led to unexpected rates of erosion and deposition of ocean sediments, burying many cages and suffocating enclosed stock.This provides a vivid example of novel events challenging established strategies for anticipating (and responding to) weather impacts.

While addressing the limits of ocean observation and prediction systems requires cooperation with weather service providers, aquaculture operators can adjust their mitigation strategies independently. However, it is worth noting that some of the strategies employed by operators conflict with one another: in particular, efforts to get ahead of weather (e.g. to prepare infrastructure or harvest/feed stock) complicate efforts to keep vessels and personnel away from weather hazards, particularly when weather hazards are rapidly approaching or arrival times are uncertain. Prediction resources can address this conflict to a certain degree, but must be used with caution and appreciation for the uncertainty inherent in any forecast product.

Preliminary Recommendations

The two roundtable discussions identified a few directions for future collaboration, offering potential benefits to both aquaculture operators and the ECCC's mandate to facilitate weather- and climate-related decision-making.

1) **Climate Projections for Longterm Marine Planning**
   Despite expressing diverse concerns regarding climate change impacts, industry participants indicated that they do not currently use climate projections for long-term planning (e.g. site selection, infrastructure design etc.); rather, they rely primarily on observational records & assessments of recent climate to determine whether sites have a suitable environment. Given the rate of current (and future anticipated) climate change, this can lead to decision-making based on outdated information. This risk can be mitigated by reviewing mid- to late-century projections from climate models, which can provide context for shifting frequencies and magnitudes of key weather concerns, including extreme storms; precipitation-driven shellfish closures; marine heatwaves; and superchill events. They can also provide guidance on future timing of biological processes influenced by water temperatures, such as fish growth, reproduction, and spread of disease/parasites. Relevant model projections already exist; however, they are not necessarily available in a format that is accessible and directly relevant to aquaculture concerns. Analysing, collating, and communicating climate impacts for widespread use in marine aquaculture will require substantial work, and is best performed as a collaborative effort between government (e.g. the Canadian Centre for Climate Services; Fisheries & Oceans) and industry. Such efforts may prove highly beneficial, reducing future climate surprises and enabling climate-resistant decision-making.

2) **Sharing Observational Data**
   Many aquaculture operators collect meteorological and oceanographic data on a continuous basis, but are not formally required to share this information with others (either within their industry or government). If made available to ECCC, this data could be used to evaluate forecast performance and adjust forecast products, improving forecast quality for all marine end-users. If these observations meet international standards, it may also be possible to incorporate them into the models that form the basis for marine forecasts, adding further value.

3) **Collaboration on Impact-based Forecasts**
   ECCC's Meteorological Service is placing greater influence on impact-based forecasts; that is, communicating what weather means for various end-users, in an effort to make their forecast products more relevant and actionable to end-users. This has been accompanied by new efforts to engage with end-users, in order to better understand

their needs, perspectives, and concerns[2] . Engagement has led to novel (and beneficial) interactions with fisheries end-users in Atlantic Canada, including expert input during high-impact decisions (e.g. the opening of lobster fisheries[3]) and informal restructuring of marine forecasts in response to user input[4]. The aquaculture industry may be able to realize similar gains by actively inviting ECCC collaborations (e.g. knowledge exchange sessions, workshops, or extending invitations to industry conferences etc.). Ultimately, all interactions between ECCC and industry have the potential to shape impacts-focused content in marine forecasts, regardless of how frequent or brief such interactions might be.

4) **Sharing Codes of Practice & Plans for Addressing Weather**
Preparing personnel for hazardous weather reduces the likelihood of adverse impacts and increases the efficacy of mitigation strategies. This includes providing appropriate equipment (protective equipment; floatation devices; personal locator beacons, physical barriers such as safety zones, etc.) as well as relevant training. Such training may include i) the use of protective equipment; ii) weather and forecast interpretation, to ensure hazards are identified early; and iii) emergency weather procedures, preparing personnel to implement mitigation strategies quickly and effectively once hazards are identified. Individual aquaculture operations typically develop their own formal and informal practices for managing weather hazards, which will by necessity differ between locations, scales of production, species being farmed, and equipment being used; consequently, there is no universal code of practice for weather management that can effectively be applied across Atlantic Canada. However, there are still opportunities for the aquaculture industry as a whole to learn from one another, if such plans are written and freely shared. Such written codes can also prove useful for service providers (e.g. ECCC), providing valuable perspective on how weather is monitored and managed.

Summary and Future Directions

Results of roundtable discussions provided useful regional context on the aquaculture industry's concerns with weather, climate, and environment. While the types of weather phenomena and impacts raised during roundtables closely track those discussed in recent academic literature, results suggest that further research in Atlantic Canada is necessary to address the i) the challenges of operating in an extremely variable environment (e.g. warm and cold temperature extremes; frequent storm activity), ii) local implications of climate change on weather management strategies, and iii) the combined impacts of environmental monitoring/prediction practices with industry regulation (e.g. CSSP shellfish closures). Building on these preliminary

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[2] An example of ECCC outreach material is included with this report, in a separate file (AqWx_additionalMaterial.pdf). This was a handout to be shared by weather office representatives at NS boat shows.

[3] Reid-Musson, E., J. Finnis, B. Neis. (2022) Bridging fragmented knowledge between forecasting and fishing communities: Co-managed decisions on weather delays in Nova Scotia's lobster season openings. *Applied Geography*, 133. https://doi.org/10.1016/j.apgeog.2021.102478

[4] Finnis, J. & E. Reid-Musson. (2022) Managing weather & fishing safety: Marine Meteorology and fishing decision-making from a governance and safety perspective. *Marine Policy*, 142. https://doi.org/10.1016/j.marpol.2022.105120

discussions should also provide service providers (notably ECCC) with context and engagement opportunities, facilitating ongoing efforts to refine and adjust products and practices to best serve their ever-evolving end-user communities.

Work will continue in 2023 and 2024 with a series of one-on-one interviews with aquaculture operators, service providers, and (potentially) agencies responsible for industry regulation. Interviews will be used to gain further, detailed insight into weather concerns and mitigation strategies, with reference to concrete examples and weather occurrences. Once completed, the summaries of this further work will be made publicly available, and shared with roundtable participants.