2025 MAINE AQUACULTURE RESEARCH DEVELOPMENT AND EDUCATION REPORT

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EXECUTIVE SUMMARY

Is climate change a concern for Maine's aquaculture industry?

- The vast majority of respondents indicate that climate change is anthropogenic (human-caused) (87%). This percentage is significantly higher than results from a 2023 state-wide panel survey of the Maine general public, in which only 62% believed in anthropogenic climate change.
- Eighty percent of participants are concerned or very concerned about the effects of climate change on Maine's aquaculture industry.
- Nearly 70% of industry members (growers, industry service providers, and individuals in processing, distribution, sales and marketing) are concerned or very concerned about the effects climate change will have on their businesses in the next 5 years.

What climate change-related impacts are growers experiencing in Maine?

- The top five impacts that growers are experiencing are:
  - Extreme weather events (88%)
  - Warming waters (80%)
  - Changes in ice coverage (76%)
  - Changes in regulations (75%)
  - Increased fuel/energy costs (74%)
- Growers are confident that extreme weather, warming waters and changes in ice coverage are a consequence of climate change, however fewer believe that climate change is the cause of changes in regulations and increased fuel/energy.
  - Extreme weather causes power outages (fish), gear damage (all subsectors), more closures (shellfish) and infrastructure damage (piers (shellfish).
  - Warming waters cause shorter growing seasons (fish and seaweed), earlier glass eel runs (fish), increased difficulty in growing cold water species (seaweed), brittle shells (shellfish), bacterial and parasite risks (shellfish), and shifts in spawning patterns (shellfish)
  - Changes in ice coverage result in reductions in ice coverage, no ice formation, or changes in freeze-thaw cycles leading to increased freshwater input through the winter. This can lead to extended production seasons and growth windows (fish, shellfish), earlier glass eel runs (fish), a need for closer farm monitoring (shellfish), increased occurrence of invasive pests and predators (shellfish), lack of sustained dormancy resulting in more late winter/early spring mortality-starvation (shellfish), increased interactions/conflict with other working waterfront users (shellfish)

Other impacts experienced by growers include changes in:

- Biofouling (69%)
- Pests and predators (63%)
- Community (60%)
- Seasonality of other Maine fisheries (54%)
- Water quality (46%)
- Disease (27%)
- Positive impacts related to climate change include:
  - Increased growth window (fish)
  - Opportunities for growing warm water species (seaweed)
  - More nutrient runoff (seaweed)
  - Faster oyster growth (shellfish)
  - Less ice increases access and reduces gear damage (shellfish)

Are growers already adapting to climate change, and if so, how?

- Ninety percent of respondents indicate that climate adaptations are important or very important for the resilience of Maine's aquaculture industry.
- Sixty percent of growers are already changing their practices to adapt to a changing climate. Of these:
  - Most adaptations are self-developed through trial and error (62%)
  - Although 40% of growers learn about adaptations from other growers in their area
- To adapt to extreme weather, growers have had to:
  - Invest in generators (fish)
  - Use more durable gear (seaweed and shellfish)
  - Switch to heavier moorings (seaweed)
  - Change farm location to more protected area (seaweed)
  - Increase farm footprint to space lines further apart (seaweed)
  - Use helical anchors (shellfish)
  - Move operations to more protected areas (shellfish)
- To adapt to warming waters, growers are:
  - Using recirculating aquaculture systems (RAS),
  - Buying glass eels earlier (fish),
  - Managing stocking density,
  - Increasing water quality monitoring, and
  - Using more ice when harvesting (shellfish)
  - Changing farm location to deeper water (seaweed)
- To adapt to changes in ice coverage, growers are:
  - Adjusting schedules to shorter ice periods (fish)
  - Purchasing glass eels earlier in the season (fish)
  - Mitigating stress from higher summer temperatures (fish)
  - Sinking or delay overwintering of gear to address variable ice conditions (shellfish)
  - No longer sinking cages for winter (shellfish)
  - Adjust farm management practices (e.g. timing of first harvest or overwintering, changing location of farm activity) (shellfish)
- If cost were not a factor, growers are willing to:
  - Explore storm-resistant farm design (91%)
  - Use renewable energy to power farm equipment (90%)
  - Transition to electric powered equipment (85%)
  - Reduce plastic use in gear (76%)
  - Explore new species better suited for warmer waters (68%)

What makes it more difficult for industry to adapt to a changing climate?

- Barriers to adaptations for industry members (growers, industry service providers, and individuals in processing, distribution, sales and marketing) are:
  - High cost of adaptation (e.g. infrastructure, renewable energy)
  - Regulatory challenges, delays and inflexible leases,
  - Limited access to sustainable equipment,
  - Time constraints and manpower shortages,
  - Cultural resistance
  - Lack of R&D funding
  - Limited collaboration within the sector
  - Need for better education on climate risks
- There are differing perspectives on climate adaptation barriers between aquaculture growers and researchers, municipal officials, and NGOs:
  - Growers prioritize immediate, tangible challenges like regulatory delays, high costs, and operational strain
  - Researchers and officials focus on systemic, long-term solutions such as data gaps, policy reforms, and capacity-building initiatives

Recommended Research and Development foci

- Research and development needs according to industry members, ranked by order of importance:

1. Storm resistant gear
2. Climate resilient farm management
3. Selective breeding
4. Affordable on-farm devices for monitoring
5. Research on Maine climate impacts
6. Climate resilient site selection
7. Husbandry of emerging species
8. Market research on new species
9. Climate conditioning
10. Equipment that is less reliant on fossil fuels

- Other research and development needs identified by industry members are:
  - Predictive tools for weather/climate and farm management planning
  - Sector-wide environmental monitoring program
    - Most farmers are currently collecting temperature data (76%), and are most interested in monitoring chlorophyll levels in the future on their farm (56%). Growers are also interested in recording nitrate levels, wind and wave data, and storm surge data (48%). Seventy-one percent of farmers are willing to share their data with anyone.

Recommended Sector Development foci

- Sector development needs according to industry members, ranked by order of importance:

1. Increased community support
2. More funding opportunities for adaptations
3. More flexible leases
4. Faster leasing process
5. Grant writing assistance
6. More opportunities for knowledge exchange
7. Climate hub for climate resources specific to Maine
8. Development of an industry-wide resilience plan

- Other sector development needs identified by industry members are:
  - Streamlined regulations and faster lease process
  - Rebates and incentives for energy-efficient upgrades
  - Non-dilutive funding opportunities
  - Technical support and practical guidance
  - Better information access

Recommended Education foci

- The most trusted sources for information on climate change are scientists (92%), Maine research/academic institutions (89%), and aquaculture support organizations (85%).
- Top education and training needs for climate resilience, identified by industry members (growers, industry service providers, and individuals in processing, distribution, sales and marketing) are:
  - Practical guidance with actionable solutions
  - Opportunities for knowledge exchange/technology transfer
  - Accessible science on climate change, and impacts on aquaculture specifically
  - Training on:
    - Husbandry
    - Site selection
    - Lease and LPA applications
- A total of ten municipal representatives completed the survey. Of these respondents, 70% indicate that they would or might find helpful education about aquaculture helpful. Educational topics include:
  - Understanding the types of aquaculture viable in specific areas, and impacts on other fisheries and navigation
  - Environmental baseline study initiatives
  - Supporting transfer of information and knowledge between traditional commercial fishermen and aquaculturists
  - Supporting aquaculture in a balanced way to help communities

INTRODUCTION

Maine's aquaculture industry stands at the crossroads of opportunity and challenge as it navigates the impacts of a changing environment: As climate change continues to impact the Gulf of Maine, one of the fastest warming bodies of water in the world, the challenges facing aquaculture are growing (Pershing et al. 2015) . Rising temperatures, ocean acidification, extreme weather, and invasive species are reshaping marine ecosystems and impacting aquaculture growers and the long term ramifications of these shifts are not fully known. These changes also present opportunities for growth, adaptation, and collaboration across the sector, and aquaculture itself has a key role to play in promoting future climate resiliency.

Climate change threatens Maine's seafood production, cultural identity, economic integrity, and ecosystems: Climate change is no longer a theoretical concept. Climate change is happening and impacts are already being felt by Maine's coastal communities. In January 2024, Maine experienced two extreme weather events that caused significant damage to working waterfront infrastructure, seafood businesses, and coastal communities. While certainly not the first extreme weather that has impacted Maine in recent years, the magnitude of damage from these back-to-back events has brought climate change to the forefront of discussions about resilience of the working waterfront–a pillar of Maine's collective identity.

Extreme weather events are not the only climate impacts that Maine is experiencing. Changing oceanographic characteristics in the Gulf of Maine are impacting important wild fisheries and aquaculture (Moore et al., 2018; Balch et al., 2022). Researchers expect that with these oceanographic changes, regime shifts will become more frequent (Conversi et al., 2015). 'Regime shift' refers to the concept that ecosystems can change abruptly to alternative stable states (Scheffer et al., 2001), as opposed to experiencing continuous linear changes over time (Conversi et al., 2015; Doney & Sailley, 2013). Shifting distributions of fish and shellfish stocks, changes in marine species compositions within ecosystems, altered productivity of fish/shellfish stocks, introduction of invasive species, and warming waters are already being observed, with some researchers reporting the loss of some of its subarctic characteristics and increasing prevalence of mid-Atlantic species (Lotze, 2022; Pershing et al., 2021). Increasing prevalence of some invasive species, which can negatively impact commercially-relevant species, has also been observed. For example, the invasive European green crab has caused damage to populations of soft-shell clams (Mya arenaria; Whitlow 2010), and has contributed to the decline in blue mussel (Mytilus edulis) populations throughout the Gulf of Maine (Sorte et al., 2017). The climate story becomes even more complex when balancing endangered species and seafood production. For example, populations of North Atlantic right whales (Eubalaena glacialis) have been impacted by changes in the distribution of their prey (Pershing et al., 2021).

Maine's coastal communities whose economies, cultures, and societies are traditionally centered on the ocean and the commercial use of its resources are experiencing fundamental change and aquaculture is a potential avenue for diversifying seafood production and Maine's working waterfront (Cleaver et al., 2018; McClenachan et al., 2020).
Aquaculture plays a role in a climate-resilient working waterfront: Aquaculture has a role to play as an economic resilience-building strategy in coastal Maine communities.

Moreover, aquaculture does and will continue to play an important role in reducing the US seafood trade deficit, thus improving food sovereignty by providing locally-sourced, healthy protein options while also preserving working waterfront cultural connections, and maintaining a key economic life-line for rural, coastal communities.

Nonetheless there are climate threats for aquaculture too: Globally, climate-related threats to aquaculture include ocean acidification, invasive species, biofouling, infrastructure damage resulting from high-intensity weather events, increased frequency of extreme weather events, rising temperatures, and changing precipitation patterns (Maulu et al., 2021). However, to date there has been no systematic approach to understanding the climate impacts being experienced by Maine's aquaculture farmers.

The state is committed to improving climate resiliency: Maine's commitment to climate action is evident in the state's climate action plan, Maine Won't Wait, released in December 2020 and updated in 2024 (Governor's Office of Policy Innovation and the Future, 2024). Maine Won't Wait is a comprehensive strategy aimed at addressing the challenges posed by climate change while fostering economic growth and sustainability across various sectors, including aquaculture The plan recognizes the need to promote clean energy, reduce greenhouse gas emissions, create jobs and economic prosperity, strengthen resilience to climate impacts, and bring climate action to Maine people. Several of the seven strategies outlined in the plan are relevant to Maine's fisheries, aquaculture, and seafood industries including transition to clean energy (Strategy C), creating jobs and growing Maine's economy through climate action (Strategy D), protecting the environment and natural and working lands and water (Strategy E) and building healthy and resilient communities (Strategy F).

The strategies, recommendations, and actions relevant to Maine's aquaculture sector are outlined in Appendix A, many of which are directly applicable to building a resilient aquaculture industry. Clearly, climate resilience is a priority for the state, and this project provides a foundation of knowledge that can be used to inform strategies that contribute to meeting the state's climate goals.

Understanding the climate impacts on Maine's aquaculture sector: Surveys and interviews conducted in 2024 captured voices from across the state's aquaculture ecosystem, including growers, researchers, industry service providers, educators and government representatives, providing insight into the practical and policy level needs of the industry. This report represents a comprehensive effort to understand how Maine's aquaculture community is being impacted by and responding to changing environmental conditions and informs research, development and education priorities for sector resilience.

METHODS

Survey design
Survey questions were designed based on results from scoping interviews with aquaculture farmers in Maine during the summer of 2024 exploring climate-related impacts and adaptations. A total of 16 farmers were interviewed across sub-sectors (see Table 1). The interview guide is included as Appendix B. Interviews were recorded, transcribed, and thematically coded. The interviews provided key insight into what farmers are experiencing and identified important subsector differences. They also provided guidance on how to investigate adaptations. For example, asking farmers about responses to specific climate impacts they had identified provided more insight into their adaptations than simply asking what adaptations they had implemented on their farms generally. Thus, the scoping interviews informed both the content and the structure of the survey questions.

Table 1. *Number scoping interviews, categorized by sector.*

Sector	N
Oyster	5
Scallop	1
Mussel	1
Finfish	1
Hatchery	2
Land-based	2
Seaweed	4

The project team used Qualtrics XM Survey Software to create an online survey that they distributed to aquaculture stakeholders via email. The intention was to gather insight from the following stakeholder groups:

- Maine aquaculture growers
- Aquaculture industry service providers
- Aquaculture processors, distributors, sellers, marketers
- Aquaculture researchers and students
- Educators engaged with aquaculture curriculum
- State and Federal agency members
- Municipal Government & Committee members, Wabanaki Nations Government members, or Community Resilience Partnership Representatives

The survey included a variety of optional multiple choice and open-ended questions. Participants answered general questions and were then given a set of questions conditional on their self-identified sector. A list of all survey questions is included as Appendix C.

Sampling
To ensure inclusion of a wide range of stakeholders, a survey email list was compiled from the following sources with duplicates removed.

- A list of Maine registrants to the Northeast Aquaculture Conference & Exposition held in 2024: 530
- The Maine Aquaculture Association membership list: 150
- The University of Maine's Aquaculture Research Institute mailing list: 122
- A list of limited purpose and commercial aquaculture leaseholders: 369
- A list of K-12 educators working with the Maine Aquaculture Innovation Center: 696
- The Harbormasters Association membership list (sent by association member, number unknown)

Survey distribution
The project team distributed the survey through Qualtrics using the compiled survey email list on September 13th, 2024. We sent a reminder through Qualtrics on October 4th, and then again on October 31st 2024. The survey closed on November 15th 2024. The survey was also distributed in industry newsletters, local aquaculture organization email blasts, and in individual emails using an anonymous link generated by Qualtrics. Lastly, the survey link was posted to social media accounts of several aquaculture organizations. We received 300 responses, though some were incomplete. A total of 274 usable responses were secured.

Analysis
Closed-ended survey data were analyzed using StataBE Statistical Software. Open-ended questions were thematically analyzed to examine themes and patterns using Dedoose Qualitative Data Analysis Software and Excel. Each response was tagged with one or more themes, as appropriate. Analysis of themes was based on the number of times a theme occurred.

RESULTS

SAMPLE DEMOGRAPHICS

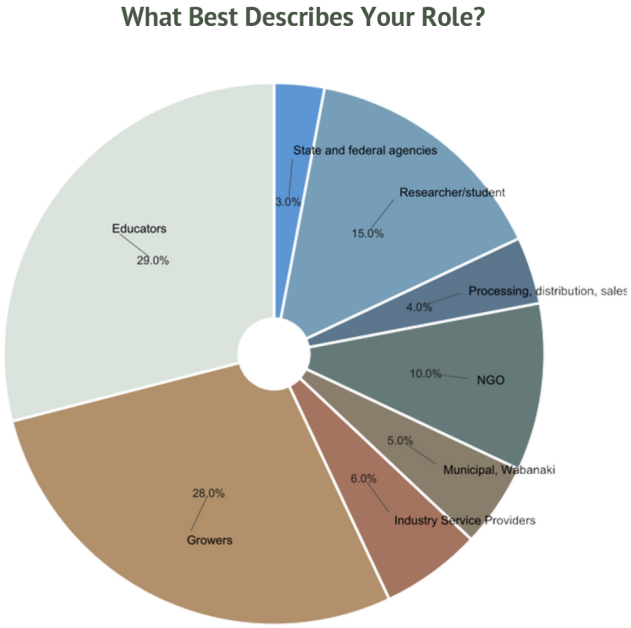

Figure 1. *Stakeholder group distribution of survey respondents across different stakeholder groups in the Maine aquaculture sector.*

Out of 274 participants, over half of the sample was made up of aquaculture growers (29%) and educators (29%). Researchers and students were the next largest group at 15% of the sample. About 57% of the total sample identified as women, though this is due to the high number of women educators who took the survey. Without including educators, the sample was 51% men and 49% women. One percent of the sample either identified as non-binary/third gender or preferred not to say. The average age of participants was 46 years old, and racial composition of the sample was reflective of Maine's population statistics, with 94% of respondents describing themselves as white. However, just over 4% of respondents were of Hispanic, Latino, or Spanish origin, which is higher than the state average of 2%. Our survey sample is highly educated, with 50% of respondents having earned graduate degrees, and another 38% having bachelors degrees. This is far higher than the Maine general public. In total, 88% of our sample held a bachelor's degree or higher, compared to 35% of Mainers more broadly. Aside from a larger portion of those in the municipal government, Wabanaki government, & community resiliency partnership group having an associate's degree, there was not significant variation between groups when comparing bachelors or higher and associates or less.

Participants are primarily concentrated in Maine's coastal counties, such as Cumberland, Hancock, and Lincoln. Inland counties like Penobscot and Androscoggin show moderate participation, likely driven by researchers, educators, and state or federal agency representatives engaged in aquaculture-related programs (Figure 2). Growers are predominantly located in Cumberland, Hancock, and Lincoln counties, which provide ideal coastal conditions for shellfish and seaweed farming. State and federal agencies, along with researchers, are primarily concentrated in Penobscot County where many state and regional offices are based. NGOs and industry service providers have a broader geographic presence, reflecting their outreach and support roles across the state. Overall, coastal regions dominate in representation due to their close ties to aquaculture activities, while inland regions are more involved in research, education, and policy.

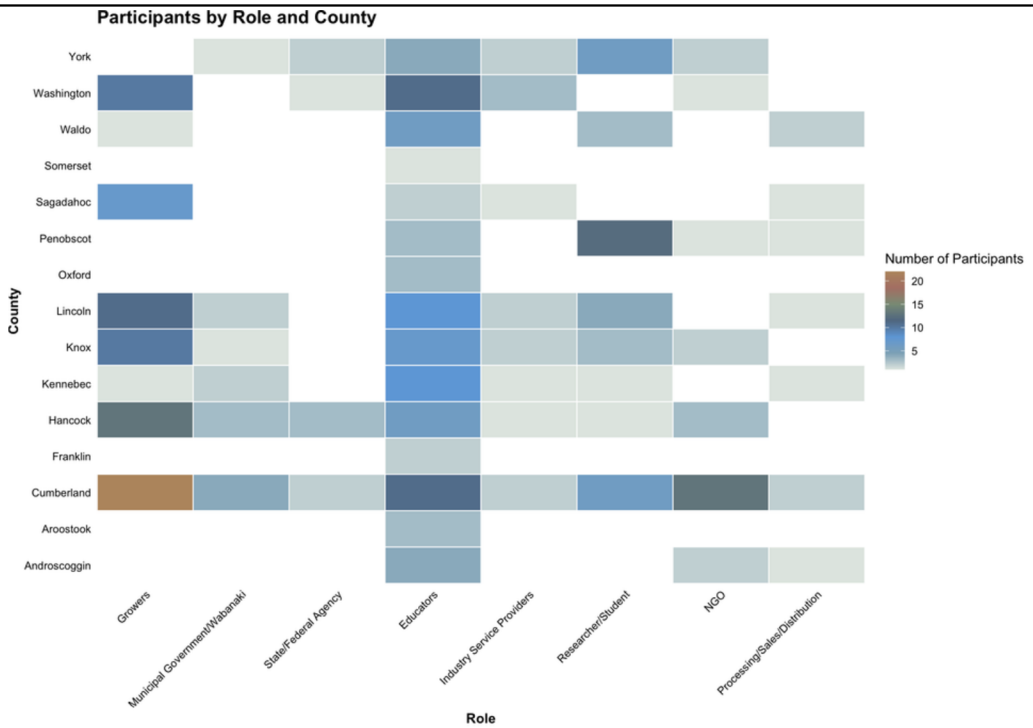

Figure 2. Geographic distribution of survey respondents by county, showing concentrations of participation.

GROWER DEMOGRAPHICS

We had a total of 78 farmers complete the survey, though not every farmer answered every question. The number of responses for each question is reported throughout.

Basic demographics: About 60% of growers who responded to the survey identified as male, while 40% identified as female. There were no growers who identified as non-binary/third gender. The average age of farmers was 45 years old. About 97% of farmers described themselves as white, with 3% describing themselves as either black, Native Hawaiian or Pacific Islander, or other. Three percent of growers said that they were of Hispanic, Latino or Spanish origin. Farmers were well educated, with 53% having earned a bachelor's degree, and an additional 29% having earned a graduate degree.

Farm role: Of the 78 farmers, 65% reported that they were the owner of their farm (Figure 4). Thirteen percent were farm managers, and less than 10% were farm crew, hatchery technicians, or administration.

Species: The majority of farmers who participated in the survey cultivate the Eastern Oyster (*Crassostrea virginica*) as their primary species (72%).

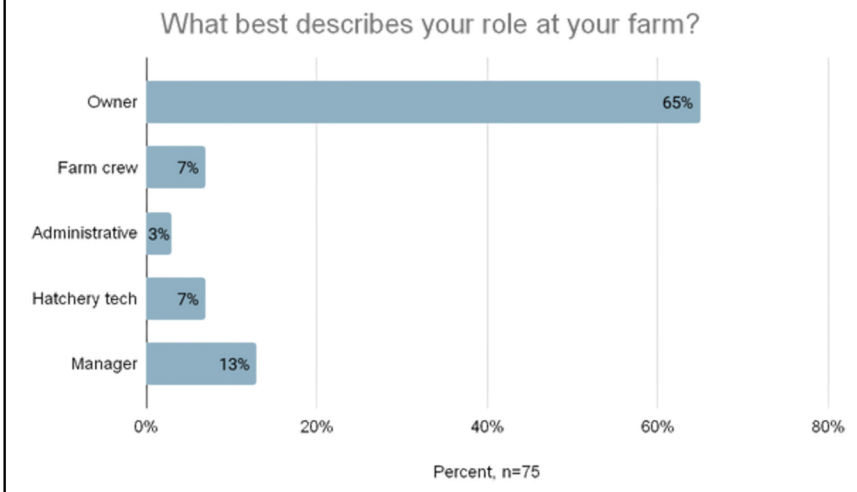

Figure 4. *Roles of survey respondents within their aquaculture farms*

Sugar kelp (*Saccharina latissima*) is the most commonly cultivated seaweed species, though respondents also cultivate dulse (*Palmaria palmata*), skinny kelp (*Saccharina angustissima)*, winged kelp (*Alaria esculenta*), and sea lettuce (*Ulva spp*). 12% reported cultivating sea scallops (*Placopecten magellanicus*), and 10% cultivate mussels (*Mytilus edulis*).

For comparative analysis of survey questions, we divided respondents into categories by sub-sector. Sub-sectors include:

- Shellfish: mussels, oysters, clams, scallops, and urchins
- Seaweed: sugar kelp, skinny kelp, winged kelp, dulse, sea lettuce
- Fish: salmon, eel, lumpfish, ornamental, yellowtail
- Shellfish & Seaweed: several farmers indicated that they farm both shellfish and seaweed.
- Shellfish & Fish: this captures farmers who farm both shellfish and fish.

Just over 57% of growers who responded to the survey grow shellfish. About 12% cultivate seaweed, and another 15% grow both shellfish and seaweed. Nine percent of growers cultivate fish, and one grower cultivates both shellfish and fish.

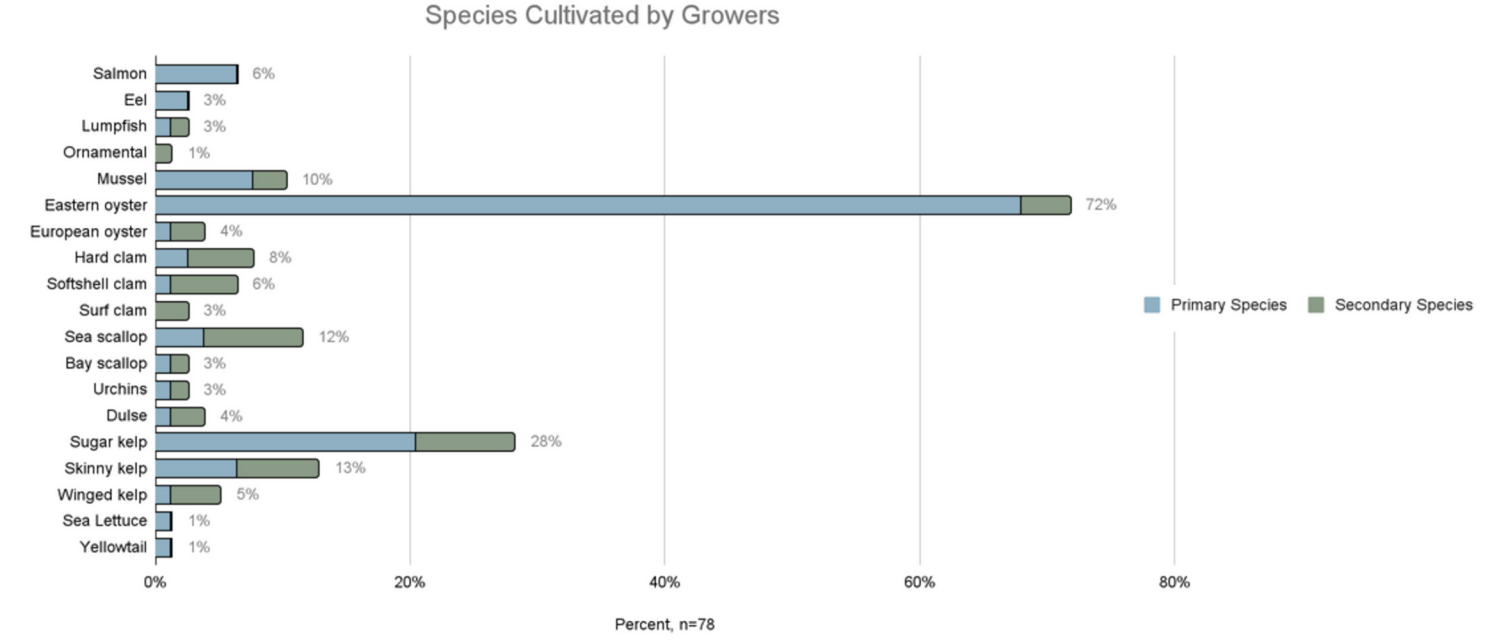

Figure 5: *Survey responses indicating the primary and secondary species cultivated by aquaculture growers.*

GROWER DEMOGRAPHICS

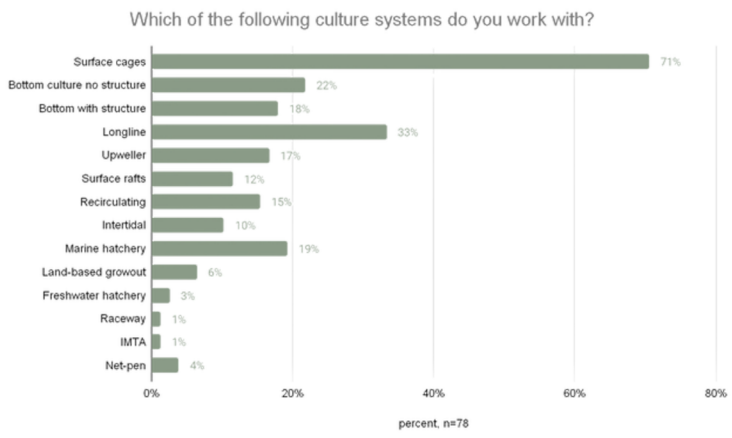

Figure 6: *Survey responses indicating the types of culture systems used by aquaculture stakeholders.*

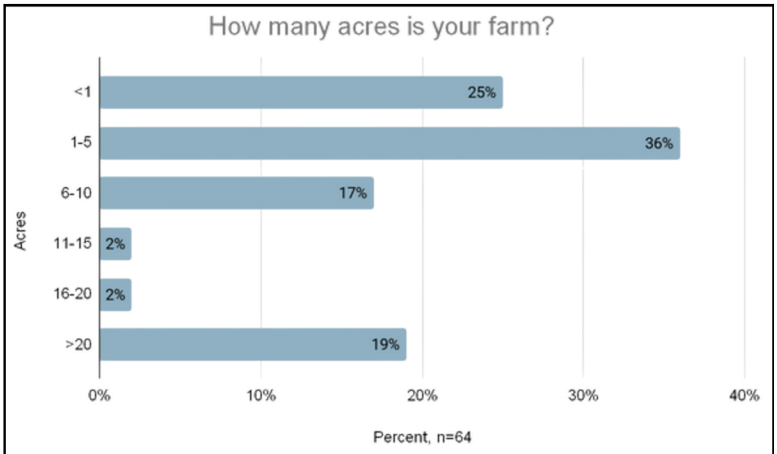

Figure 7. *Distribution of farm sizes among surveyed aquaculture growers in Maine.*

Culture Systems: Among farmers, surface cages are the most common culture system (71%), followed by longlines (33%), and bottom culture without structures (22%).

Size of farm: Size of the farm can be described in several ways, including the physical footprint of the farm (acreage) or the number of people a farm employs. Looking at acreage, the majority of farmers (61%) surveyed indicated that they farm on five acres or less, yet almost 20% operate on more than 20 acres. When broken down by sector, about 68% of shellfish farmers and nearly 90% of seaweed farmers operate on 5 acres or less. For those farming shellfish and seaweed, the majority (65%) farm on 6 or more acres, 29% operating on greater than 20 acres. Half of finfish farmers surveyed farm more than 20 acres. Acreage also varied by experience, with 80% of farmers who have been involved in aquaculture for fewer than 7 years operating on 5 acres or less, compared to 49% of farmers who had been farming for 7 or more years. Just over a quarter of more experienced farmers were operating on more than 20 acres, compared to only 8% of newer farmers. Thinking about farm size pertaining to the number of people employed, out of the 68 growers that responded to this question, 80% of growers reported having 5 or fewer employees in total working on their farm (including full and part-time year-round, and full and part-time seasonal). In fact, 15% reported having 0 employees, reflecting an owner-operator model. Only two respondents reported over 100 employees. Table 2 provides a breakdown of employee status, including full and part-time year-round, and full and part-time seasonal.

Length of time in the industry: Over half of farmers indicated that they had been involved in aquaculture for 7 years or more. Just over 30% had been involved in aquaculture between 3 and 6 years, and 17% had been in the industry for less than 3 years. These numbers are similar to what was found in the 2022 survey (Connolly et al. 2022). When broken down by subsector, 60% of shellfish farmers surveyed have been farming for 7 or more years compared to 33% of seaweed farmers. Finfish farmers were also more experienced, with 71% having farmed for 7 or more years. Those farming both shellfish and seaweed were evenly split, with 53% having been in aquaculture for less than 7 years, and 47% for 7 years or more.

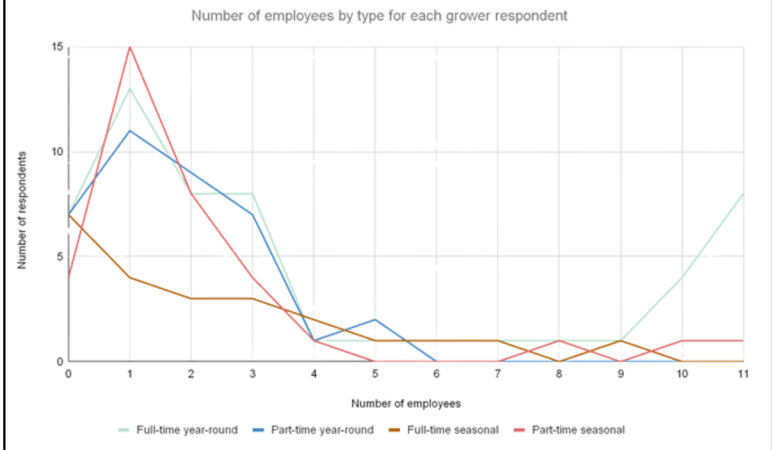

Figure 8. *Number of Farms for each employee type Breakdown of full-time, part-time, and seasonal employment in surveyed aquaculture farms*

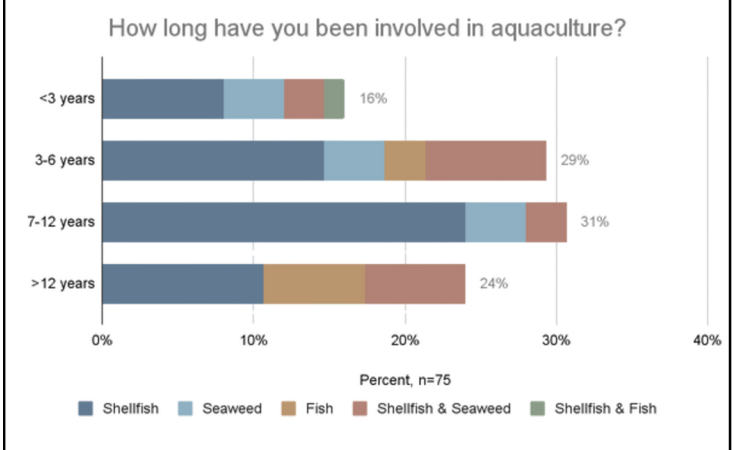

Figure 9. *Breakdown of aquaculture experience levels among growers by sector.*

AQUACULTURE'S ROLE IN A RESILIENT WORKING WATERFRONT

All respondents were asked for their opinion regarding what role aquaculture plays in climate resilience for Maine's working waterfront. This was an open question that was thematically analyzed. The top themes among all survey subgroups were **economic diversification and workforce stability** (n=75), and **environmental benefits and ecosystem services** (n=74).

For economic diversification and workforce stability, respondents described aquaculture as an important diversification strategy for those in wild-catch fisheries (especially the lobster fishery) who are increasingly threatened by a changing climate. They also discussed aquaculture's role in diversifying Maine's broader economy and reducing Maine's dependence on a single species. Additionally, respondents said that aquaculture can create year-round and stable job opportunities that attract younger generations. The following participant quote illustrates this theme:

> **Aquaculture plays a huge role in the resilience for Maine's working waterfront. With most of Maine's commercial fishing industry relying solely on a single species, lobster, that will likely see drastic stock decline in the coming 10-20 years, Maine is particularly at risk for major economic changes to large regions of the coast primarily in the midcoast and downeast regions that rely heavily on the working waterfront for their livelihoods. The individuals who currently participate in the commercial fishing industry have a great advantage to pivot into aquaculture as a means of retaining their traditional work in the marine industries while also providing a healthy, tractable, safe and delicious food product to the state, the US and internationally. As one of the national leaders in aquaculture workforce development, Maine is particularly well positioned to support a growing aquaculture industry. With Universities and institutions to educate individuals, workforce and apprenticeship programs to train and develop required skills and companies with jobs to employ these individuals, the growing aquaculture sector is attracting young individuals to learn, work and live with their families in Maine.**

This survey also provides evidence that aquaculture is being used by fishermen as a diversification strategy. About 35% of farmers in our sample were previously (16%) or are actively (19%) engaged in commercial fishing. About 69% of those growers are farming shellfish, 35% are farming seaweed, and 7% are farming fish. Broken down by years in the aquaculture industry, an even number of prior or current fishermen have been involved in aquaculture for less than 7 years and 7 years or more, meaning that at least among our respondents, they have been entering the aquaculture industry at a steady pace. Table 10 provides more information about the farmers who participate or participated in the wild-catch industry. Respondents' wild-catch species are in the column to the left, and the aquaculture subsectors are listed on the right side of the table (shellfish, seaweed, shellfish & seaweed, and finfish). A total of 19 farmers disclosed the species they fished commercially, though 26 farmers said that they have previously or are currently working in capture-fishing.

Table 1. ***Breakdown of surveyed farmers' commercial fishing experience and transition to aquaculture.***

Commercial Fishing Experience	**Farming**			
Species Category	**Shellfish**	**Seaweed**	**Shellfish & Seaweed**	**Finfish**
Crustaceans (lobster, crab, etc…)	3	1	1	3
Bivalves & Mollusks	3	0	1	0
Finfish (cod, tuna, pollock, etc…)	2	0	0	2
Seaweed	0	1	1	0
Other Invertebrates	2	0	1	0

AQUACULTURE'S ROLE IN A RESILIENT WORKING WATERFRONT

Environmental benefits and ecosystem services was the second most frequent theme. Respondents said that aquaculture can help to improve water quality, can sequester carbon, can help to create habitat and increase biodiversity, and can help protect shorelines.

> ***Bivalve and seaweed aquaculture can help improve nearby water quality and provide ecosystem services that could potentially help offset the negative impacts of climate change.***

Respondents across subgroups recognized aquaculture's value in mitigating climate impacts and enhancing ecosystem resilience.

Many also said that aquaculture is a sustainable food system. Aquaculture was viewed as a sustainable, low-carbon method of seafood production that can reduce pressure on wild fisheries and strengthen local food systems, especially as global food production faces growing challenges.

> ***More than that though, all aquacultured species in Maine have a much lower carbon footprint than most terrestrially farmed protein sources. We're helping to shift diets towards more climate friendly sources of food.***

While some respondents expressed uncertainty or limited knowledge, especially around aquaculture's role in directly mitigating extreme climate events or systemic challenges, overall sentiment was strongly positive. Stakeholders broadly recognize aquaculture as an important strategy to bolster climate resilience for Maine's working waterfront. Continued investment, inclusive planning, and coordinated policy are seen as essential to realizing its full potential.

CLIMATE BELIEFS

To gain a baseline understanding of participants' views on climate change, we included a question that asked participants whether they believe that climate change is happening (1) now, caused mainly by human activities, (2) now, caused by natural forces, or (3) is not happening at all. The vast majority of respondents believe in anthropogenic (human-caused) climate change (87%). This percentage is significantly higher than results from a 2023 state-wide panel survey of the Maine public, in which only 62% believed in anthropogenic climate change. There were no meaningful differences in perceptions by role (grower, researcher, educator, etc).

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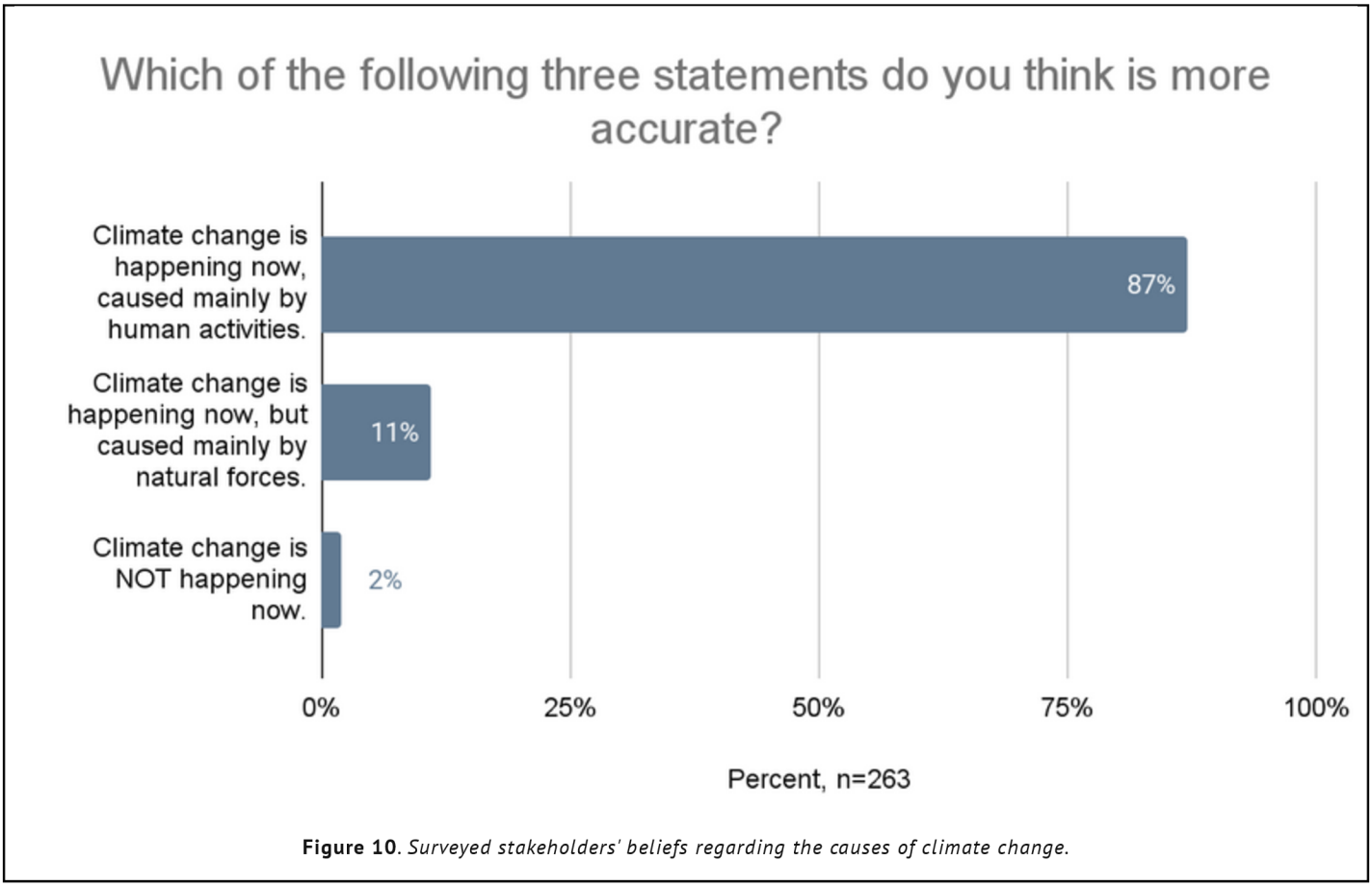


Figure 10. *Surveyed stakeholders' beliefs regarding the causes of climate change.*

About half (49%) of participants said that they were "concerned" about the effects of climate change on Maine's aquaculture industry, while 31% said that they were "very concerned." This question was asked of all participants. There were no meaningful differences in level of concern by role (grower, researcher, educator, etc.)

CLIMATE BELIEFS

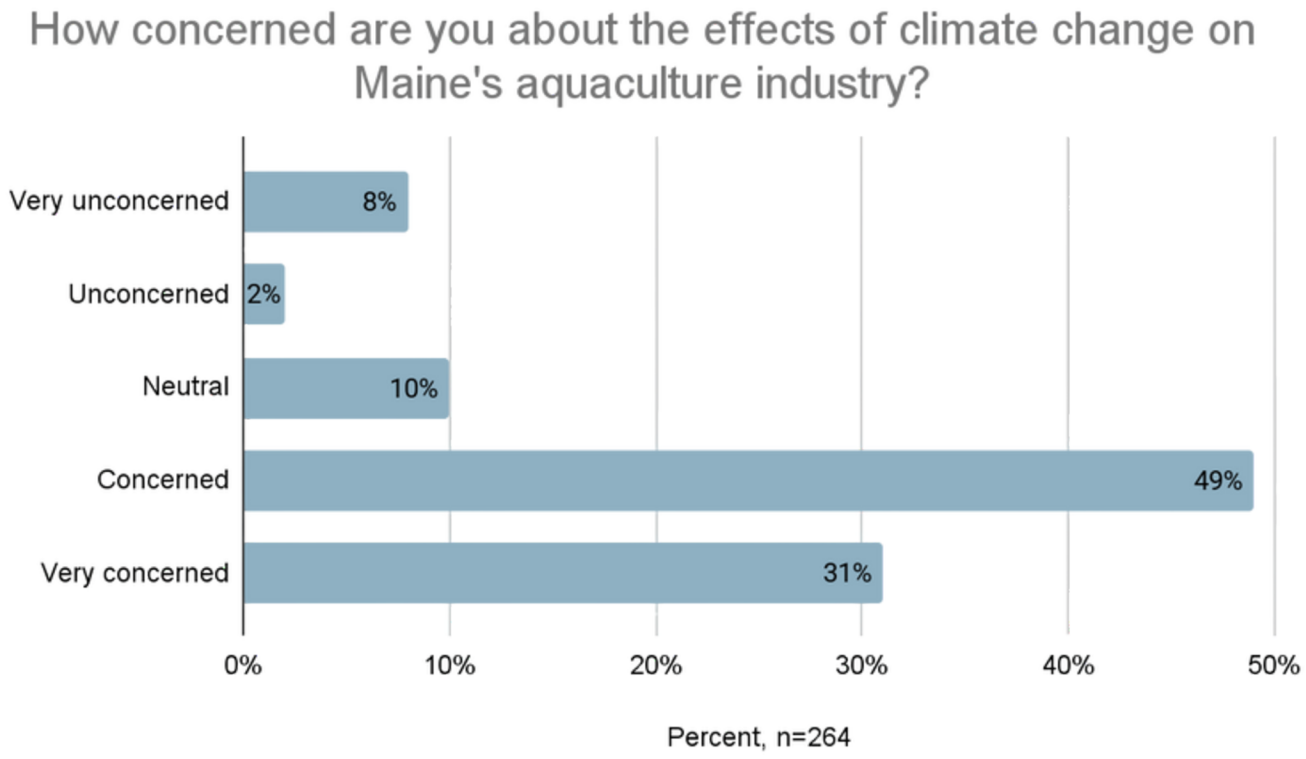


Figure 11. *Levels of concern among survey participants about climate change impacts on Maine's aquaculture industry.*

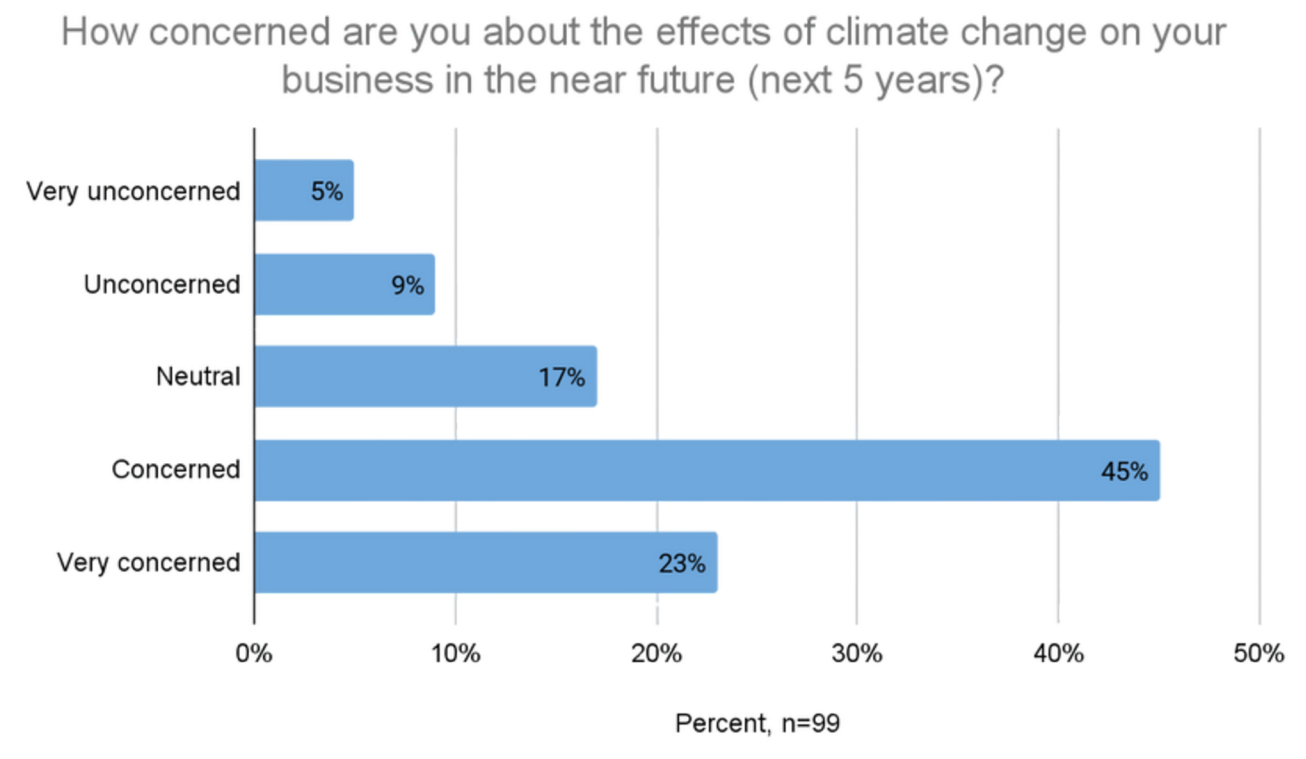


Figure 12. *Industry members' perceived risks and concerns regarding climate change's effects on their aquaculture businesses.*

We also asked growers, industry service providers, and respondents in processing, distribution, sales, and marketing how concerned they were about the effects of climate change on their business in the near future (Figure 11). Mirroring the general concern question, nearly half (45%) said that they were "concerned." A smaller number (23%) were "very concerned" compared to responses about the broader industry.

CLIMATE IMPACTS

To gauge what climate-related changes were impacting farmers, we designed a survey question focused on eleven changes identified in scoping interviews (Figure X). We first asked growers whether or not they were experiencing that impact. We also included several "other" options where participants could enter in other impacts they have experienced (Figure X). We then asked respondents whether they believed that the changes they were experiencing were related to climate change (Figure X), and lastly, we asked respondents to detail any positive or negative impacts from each climate-related change.

The impacts included were identified during scoping interviews with growers. The impacts that were experienced by the majority growers were extreme weather events (88%) and warming waters (80%), followed by changes in ice coverage (76%), changes in regulations (75%) and increased fuel/energy costs (75%). The least experienced impact was changes in disease.

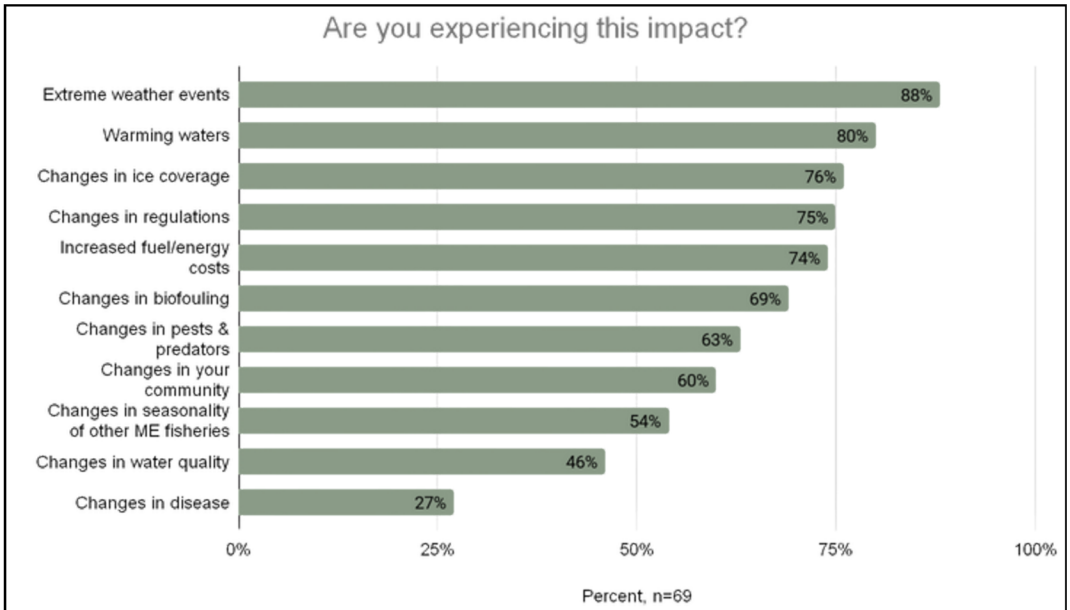


Figure 13. *Percentage of growers experiencing different climate-related impacts.*

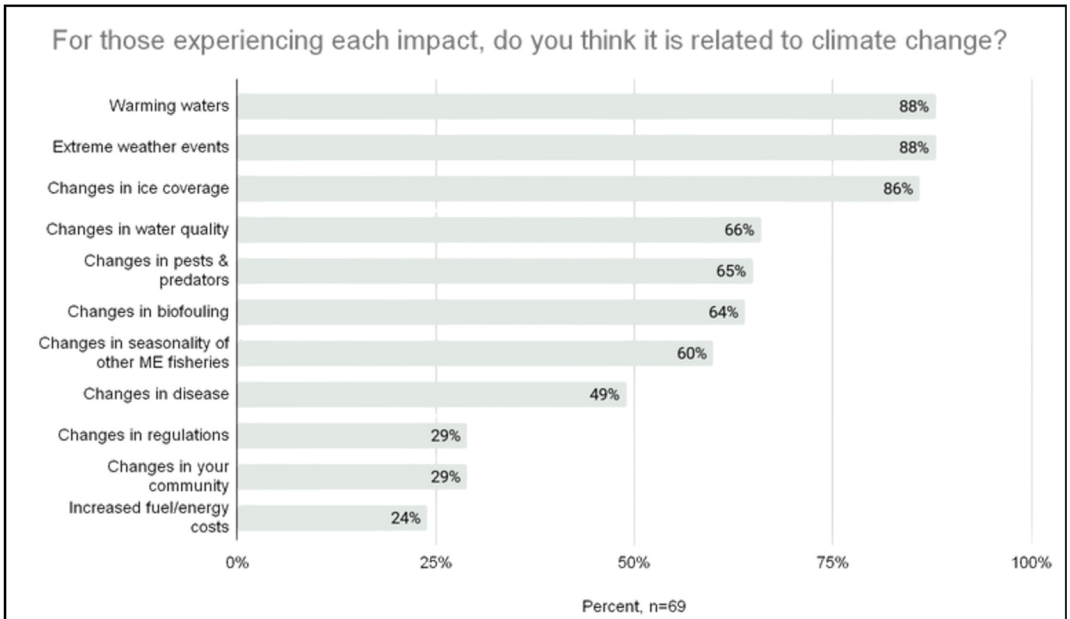


Figure 14. *Survey responses indicating whether aquaculture stakeholders believe specific environmental impacts are related to climate change.*

Following this, we asked farmers whether they believed that the changes they were experiencing were related to climate change (Figure 13). Farmers were confident that the top three changes they were experiencing: warming waters, extreme weather events, and changes in ice coverage, were a result of climate change.

However, they were less confident that increased fuel and energy costs, which nearly three quarters of farmers said they were experiencing, is a result of climate change. Similarly, they were also not confident that changes in regulations were due to climate change.

We also asked survey respondents to describe positive and negative impacts for each topic area. Table 3 outlines negative impacts reported by farmers for each topic area by subsector.
Recognizing that several climate-related changes offer benefits or new opportunities, we also asked farmers to outline any positive impacts associated with each change. Responses are summarized in Table 4.

Table 3. Summary of open-ended responses describing negative impacts resulting from a list of climate-related changes by subsector.

Impact	Fish Farmers	Seaweed Farmers	Shellfish Farmers
Biofouling n=38	More frequent fouling on nets and cages; increased labor.	None reported.	Severe: More sea squirts, mussels, heavier gear, labor-intensive cleaning; tunicates and sea squirts clog predator nets and weigh down gear.
Predators & Pests n=31	Seals attack fish crops, causing mortality.	*None reported.*	Green and blue crabs increase juvenile mortality; sea stars and birds/ducks impact gear.
Warming Waters n=27	Earlier glass eel runs	Warming waters are concerning for cold temperature species; Earlier harvests and shorter growing season.	Brittle shells; bacterial risks and concerns about parasites; Shifts in spawning patterns.
Extreme Weather n=39	Power instability; lost feeding days; gear damage.	Storms are more intense and unpredictable and can damage gear.	Gear damage, storms and flooding lead to closures causing harvest delays; Infrastructure destruction (piers/docks).
Water Quality n=16	Sub-optimal rearing conditions.	Impacts quality of seaweed crop.	Higher turbidity negatively affects oysters; leads to DMR reclassification; poorer WQ impacts consumer confidence; changes in salinity impact quality of product/taste of oysters; more closures from bacteria; more algal blooms.
Energy/Fuel Costs n=22	High costs for heating water and operating pumps.	Increased fuel costs.	Increased overhead, fuel bills; minimal price flexibility.
Diseases n=18	Increased fish loss; increased need for therapeutics which limits marketing products.	*None reported.*	Increased stress; disease outbreaks (e.g., MSX); unexplained larval losses; unexplained mortality during grow-out.
Ice coverage n=16	Earlier water temperature increase in the summer; earlier glass eel runs	*None reported.*	Suspected cause of increase in winter predation; shorter dormancy period which increases spring mortality; increase in use-conflict; more water movement leading to unexpected algae blooms; unpredictability year to year makes planning difficult
Changes in community n=21	New coastal residents can be susceptible to anti-aquaculture campaigning	Reduced infrastructure and access.	Increase in new summer residents that oppose aquaculture; increase in housing costs make it difficult for farmers and employees to live near the farm.
Regulations n=27	More complicated and restrictive.	Unable to have others working on LPA without license-holder present.	Frustration with Vibrio rule, slow approvals, and inconsistent enforcement; rapid regulatory changes.
Seasonality of other ME Fisheries n=12	Can increase overlapping uses	Fewer opportunities for diversification.	*None reported.*

Table 3. *Summary of open-ended responses describing positive impacts resulting from a list of climate-related changes by subsector.*

Impact	Fish Farmers	Seaweed Farmers	Shellfish Farmers
Biofouling n=4	None reported.	None reported.	Less/smaller mussel set.
Warming Waters n=24	None reported.	Opportunity for growing warm water species.	Faster oyster growth.
Extreme Weather n=3	None reported.	More rain/snowfall can lead to more nutrient runoff.	None reported.
Ice coverage n=21	Increased growth window	Increased access; less gear damage.	Less ice increases access and reduces gear damage; longer harvest season; less ice-related mortality.
Changes in community n=10	Increase in workforce; more talented workforce; increasing coastal population can bring more supporters.	None reported.	More customers; population growth along shoreline; more aquaculture farmers; more positive views of aquaculture.
Seasonality of other ME Fisheries	Can decrease overlapping uses.	More opportunities for aquaculture.	Increase in the availability of some species.

Lastly, we asked farmers whether they have experienced any changes in yield related to climate change. Figure 14 outlines farmer responses broken down by subsector. While 31% of farmers including all subsectors were unsure if changes they experienced were related to climate change, the largest proportion of shellfish farmers said that they were experiencing increased yield due to climate change, which aligns with responses outlined in Table 4. Specifically, shellfish farmers are seeing increased growth rates due to warming waters. The largest proportion of fish farmers and seaweed farmers said that they were seeing no changes in yield.

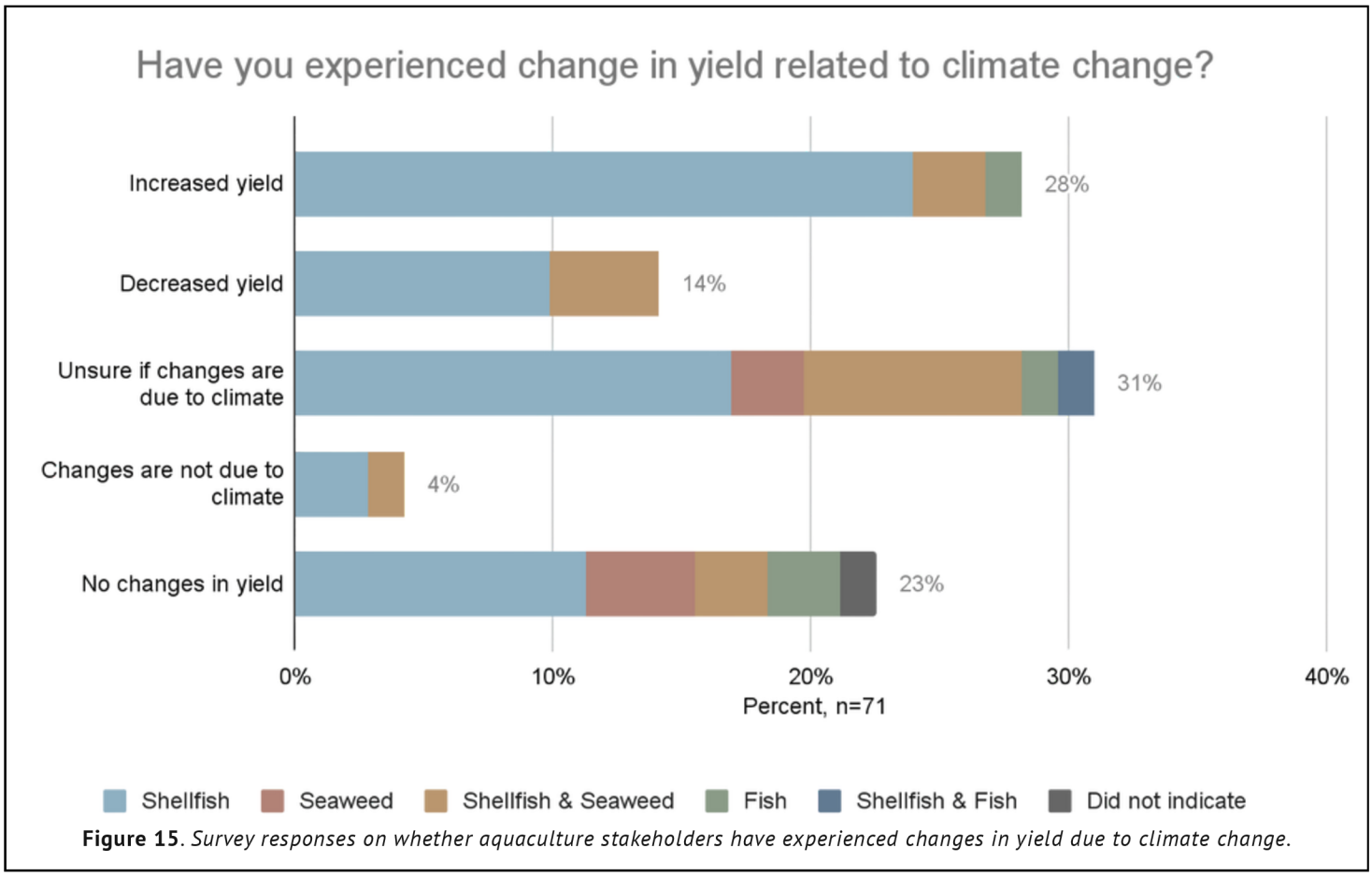


Figure 15. *Survey responses on whether aquaculture stakeholders have experienced changes in yield due to climate change.*

Out of 25 respondents who listed their affiliation as an industry service provider or processing, distribution, sales, and marketing, 68% said that climate change is affecting their business. The majority of respondents in processing, distribution, sales, and marketing said that changes in timing or availability of species was affecting their business (71%). They also discussed changing environmental conditions (57%), including the intensity of storms, sea level rise, ocean acidification and warming water temperatures.

Respondents who identified as industry service providers said that they are affected by environmental conditions (40%), specifically the intensity of storms and sea level rise, and changes in the demand for their service (40%). Both groups also mentioned increased costs and availability of materials and changes in regulations.

CLIMATE ADAPTATIONS

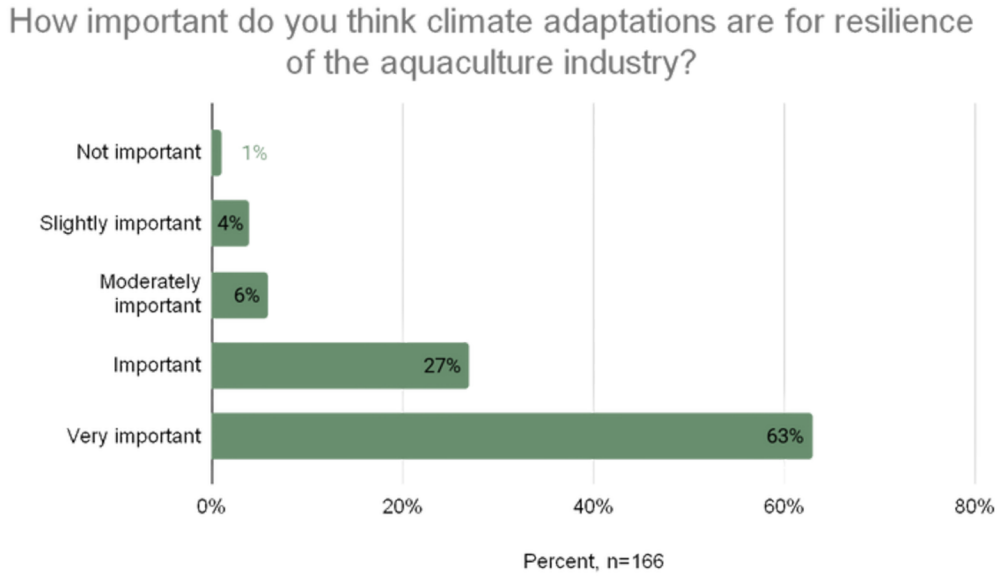


Figure 16. *Importance of adaptations for industry resilience*

Respondents agreed that climate adaptations are important for resilience of the aquaculture industry. Figure X visualizes the degree of importance. Ninety percent of respondents said that adaptations are important or very important. When broken down by respondent affiliation, most groups were in agreement. Municipal officials and Wabanaki government representatives felt less strongly, with only 67% agreeing that adaptations were important or very important. However, the sample size for this group was limited (n=12) so results are not generalizable or representative.

DEFINING CLIMATE ADAPTATIONS

All respondents were asked the following open-ended question: what does climate adaptation mean to you? Out of 141 responses, most participants said that climate adaptation is the "ability to make changes in response to a changing environment" (n=88). Respondents described reacting to changes in storm frequency/intensity, sea level rise, and warming waters.

Climate adaptation refers to adjusting behaviors, systems, and practices to minimize the negative impacts of climate change and take advantage of any potential opportunities it presents. It involves developing strategies to cope with and respond to changing environmental conditions, such as rising temperatures, altered precipitation patterns, sea level rise, and increased frequency of extreme weather events

Respondents also understood climate adaptation as proactive or preventative actions that can better prepare against future climate threats and opportunities (n=36). For example, one respondent said that climate adaptation "is building opportunities for the longterm climate future, not just the current climate status or return to the status quo." Improved infrastructure was often used as an example of planning ahead (n=16). However these views were not mutually exclusive, with 12 respondents explicitly saying that both reactive and proactive approaches are necessary for successful adaptation.

It means being forward thinking about what could be coming and trying to prepare for that. It also means being nimble and able to adjust quickly to the rapid changes we are seeing.

Lastly, respondents also specifically brought up the use of current available science to make informed adaptation decisions (n=16). For example, one respondent said that climate adaptation is "using a data-based approach to understand the trends in climate patterns and then creatively modeling systems to function in the new predicted futures (environmental, social, economic, etc.)."

GROWER ADAPTATIONS

To better understand what aquaculture farmers in Maine are doing on their farms to adapt to environmental changes, we first asked growers to describe their operation's climate adaptations (if any), and how well these adaptations did or did not work in an open-ended question.

Fifteen growers responded, describing a wide array of adaptations. Farmers reported making changes to their farm site, including moving sites to better areas (n=2), gear modifications (n=1), electrifying equipment (n=2), reducing plastic use (n=2), and exploring new raw materials (n=1). Three farmers described making changes to their infrastructure, including raising structures to account for sea level rise. Three farmers also described seeking out more resilient strains or exploring new species. Lastly, one farmer discussed increased monitoring of environmental parameters for more informed planning, and another farmer was building depuration tanks that could "assist as holding tanks in the event of area harvesting closures for our farm as well as others."

To further explore adaptations, we used a strategy developed during pre-survey scoping interviews. During these interviews, we found it most effective to discuss adaptations in response to specific environmental changes, so we also included a set of questions that prompted farmers to describe changes made in response to specific impacts. Often, farmers would describe small but important changes in their practices that did not come to mind when just asking them about adaptations broadly. Table 5 summarizes the responses broken down by subsector. The prompted impacts mirror those explored in Tables 3 and 4, but rather than describing the effects of the impact, farmers described their adaptations. Seaweed farmers detailed fewer adaptations than other subsectors (Table 5). They also reported fewer negative impacts (Table 3). In part, this may be due to the smaller sample size of seaweed farmers, though the number of fish farmers was also small and they reported nearly every impact and detailed adaptations for each. This data suggests that seaweed farming is currently less vulnerable to climate impacts than shellfish and finfish aquaculture.

GROWER ADAPTATIONS

Table 4. *Summary of open-ended responses describing adaptations to a list of climate-related changes by subsector.*

Impact	Fish Farmers	Seaweed Farmers	Shellfish Farmers
Biofouling n=26	Wash grow-out equipment more frequently.	No reported adaptations.	Severe: Frequent flipping, drying gear, labor-intensive cleaning; combatting tunicates and sea squirts; pressure washing and drying predator nets; having a duplicate set of equipment that is clean.
Predators & Pests *n=15*	Use better deterrent equipment.	No reported adaptations.	Off-bottom culture; protective gear for juveniles; hazing techniques for birds; drying shells to control pests.
Warming Waters n=22	Buy glass eels earlier in the season; use RAS for better temperature control; adjust feeding to optimize growth.	Changing farm location to deeper water.	Manage density; use buoys for monitoring; increased ice use during harvesting to combat extreme temperatures.
Extreme Weather n=32	Invest in generators and engineered equipment that can better withstand extreme weather.	More durable gear setups and heavier moorings; change farm location to more protected area or increase farm site size to space lines further apart.	Switch to helical anchors; use stronger gear; move operations to more protected areas.
Energy/ Fuel Costs n=16	Optimize pumps and heat recovery systems; purchase energy efficient equipment.	No adaptations reported.	Adopt solar panels; reduce trips in the boat to minimize fuel use; more carpooling to farm; use electric motors and equipment.
Diseases n=9	Vaccination and robust fish health monitoring.	No reported adaptations.	Monitor for Vibrio and adopt disease-resistant shellfish lines.
Ice Coverage *n=15*	Adjust schedules to shorter ice periods; purchase glass eels earlier in the season; mitigate stress from higher summer temperatures.	No reported adaptations.	Sink or delay overwintering of gear to address variable ice conditions; some no longer sink cages for winter; adjust farm management practices.
Changes in Community *n=9*	Educate neighbors to prevent misinformation.	Advocate for working waterfronts and coastal sustainability.	Focus on climate education and making seafood accessible to local communities; advocate for working waterfronts.
Regulations *n=15*	Advocate for more favorable legislative changes.	*No reported adaptations.*	Follow new changes in regulations; increase tracking and records; advocate for favorable changes.

We then asked growers how they were learning about climate adaptations. Responses are visualized in Figure 16. Most growers said that they self-developed adaptations through trial and error (62%). Forty percent said that they learned from other farmers in their area, and another 31% said that they learned from farmers in other places. Interestingly, collaboration with researchers and extension were the least cited responses. These results highlight the innovativeness of farmers and the importance of collaboration with other growers. The limited role of researchers and extension in the transfer of grower climate adaptations to date suggests that there is an opportunity for these groups to play a larger role in knowledge sharing and adoption of adaptations in the future.

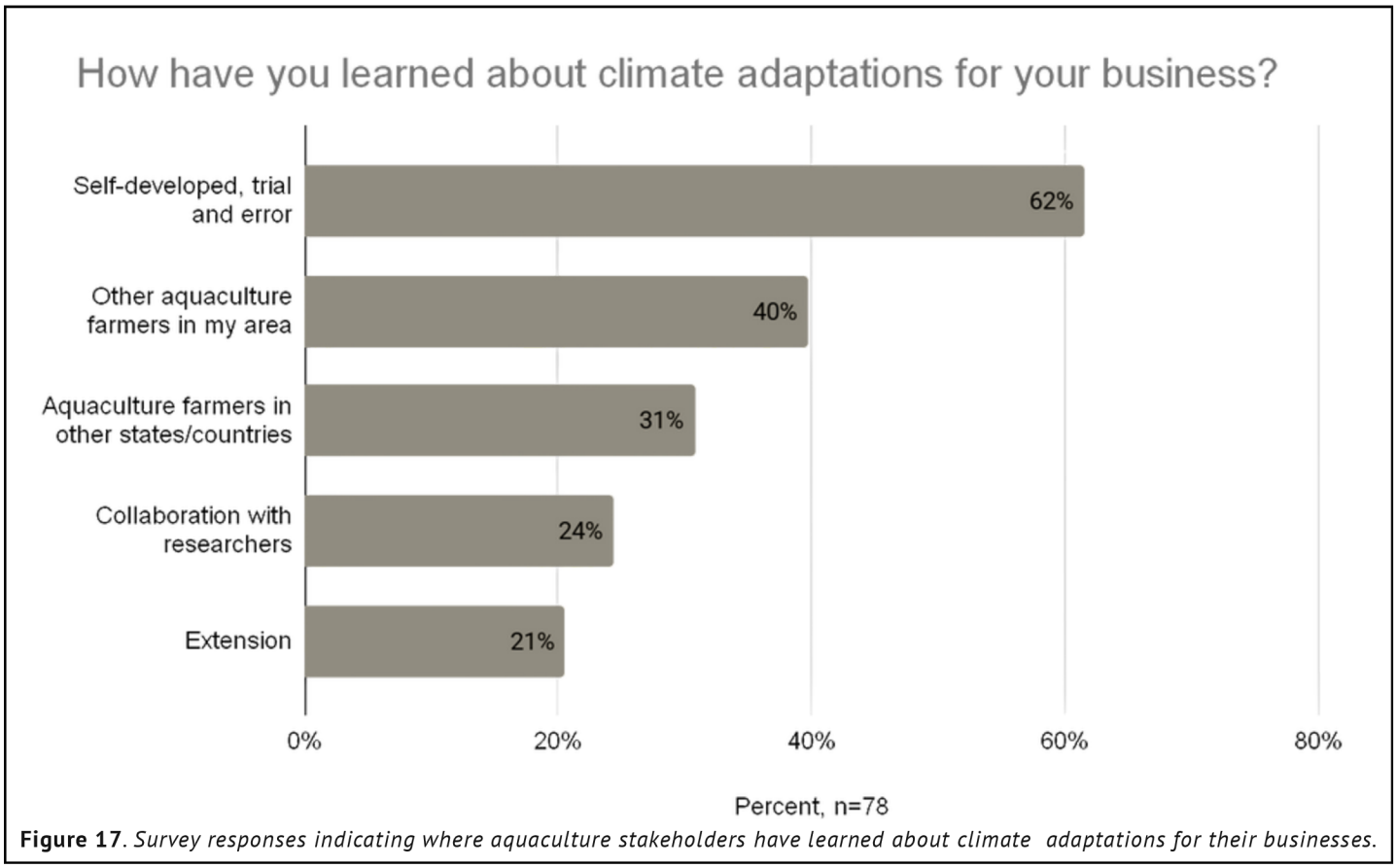


Figure 17. *Survey responses indicating where aquaculture stakeholders have learned about climate adaptations for their businesses.*

We also assessed growers' willingness to explore or adopt various resilience strategies if cost were not a barrier. Farmers were most willing to explore storm/climate resilient farm design (91%). This aligns with results from the series of questions that explored climate impacts. All subsectors are experiencing infrastructure and gear damage due to extreme weather, so it is logical that growers are most interested in resilient farm design. Renewable energy-powered equipment was also of interest (90%), as high energy costs were cited across all subsectors. Similarly, farmers were interested in electric-powered equipment (85%). About three quarters of growers surveyed said that they would be willing to reduce their plastic-use, and just under 70% said they would be willing to try new species better suited for warmer climates.

Finally, we assess growers' plans for future adaptations using an open-ended response question. Out of the 34 farmers who responded, seventy-five percent said that they do have adaptation plans for the future. Adaptation plans include incorporating solar or electrifying boats and equipment (n=9), incorporating new species (n=4), diversifying business models (n=4), trialing new husbandry practices (n=3), adding or increasing seaweed production (n=3), increasing monitoring (n=3), and reducing plastics (n=2).

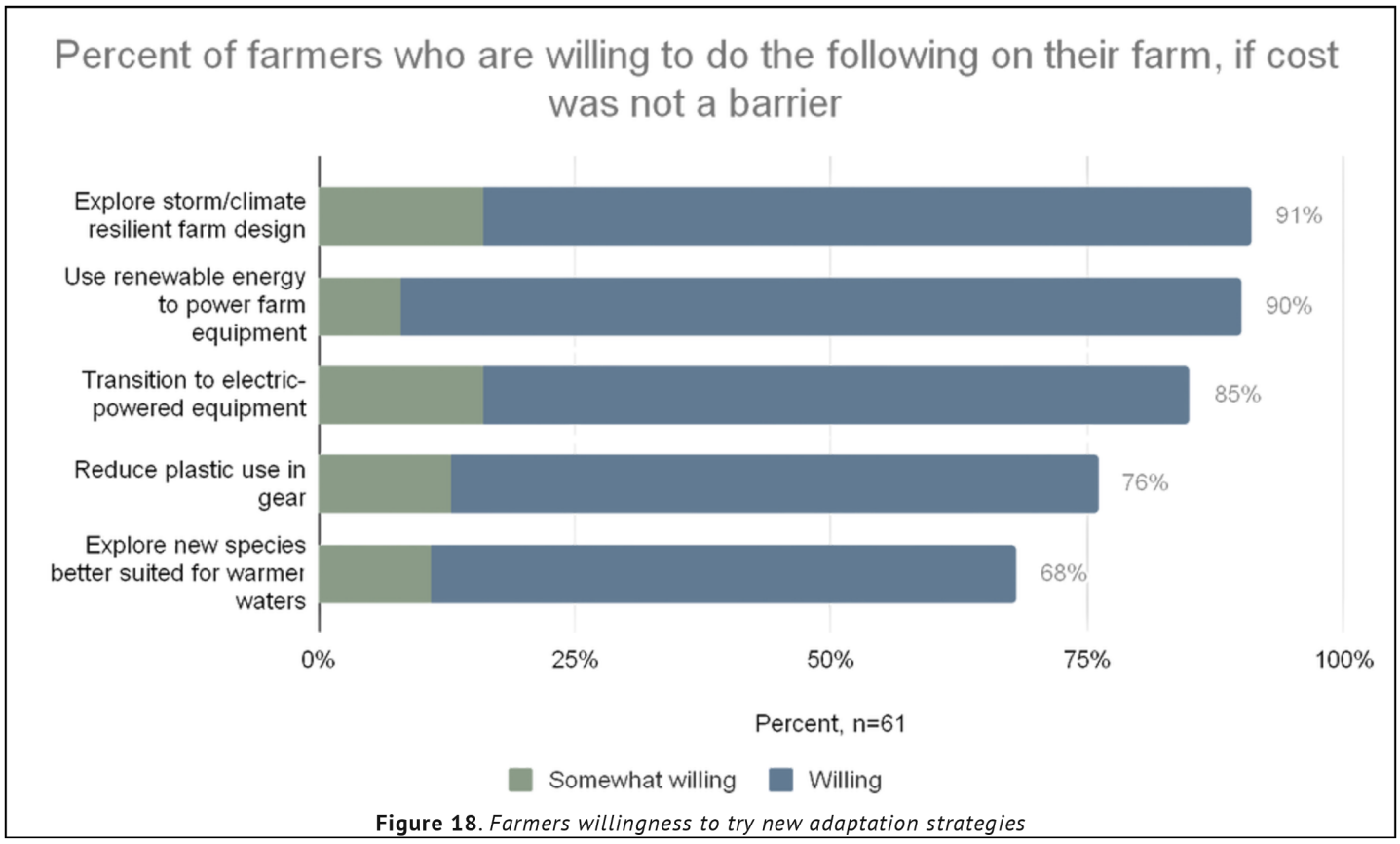


Figure 18. *Farmers willingness to try new adaptation strategies*

CLIMATE DATA, MONITORING, AND INFORMATION SOURCES

CLIMATE DATA & MONITORING: GROWERS

To assess what type of climate-related data information would be useful to aquaculture farmers, we asked the grower subgroup what climate-related information would be most useful in planning and managing their businesses. Out of 49 grower responses, the two primary themes that emerged included specific environmental conditions that farmers are interested in (Table X), and data specifications (Table Y). Data specifications include descriptors like "localized" or "forecasting." In many cases, these themes co-occurred, which is shown in Table Y. For example, growers specified that they would find "forecasting" data (data specification) useful in relation to storms/weather (environmental condition).

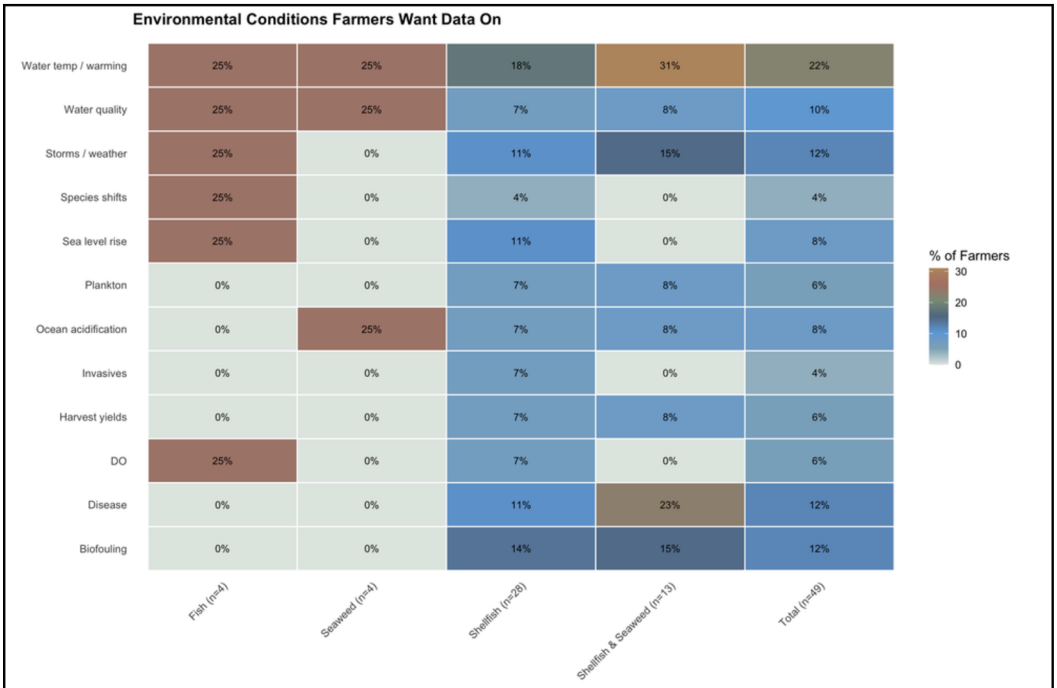


Figure 19. *Environmental conditions (farmers, n=49)*

Figure 19 outlines the most frequently cited environmental data desired by farmers, broken down by subsector. Percentages provided are within each subsector. For example, 18% of shellfish farmers who responded cited water temperature as important information. However, it is important to note that the small sample sizes, specifically for finfish and seaweed farmers make it difficult to compare subsectors. The *total* column contains the percentage of growers across all subsectors who mentioned each topic.

Table 5. Desired environmental condition information across groups

	Water temp. (n=11)	Storms (n=6)	Biofouling (n=6)	Disease (n=6)	Water quality (n=5)
Localized	18%		17%		
Longitudinal	18%		17%	17%	20%
Forecasting	36%	83%	17%	50%	
Action items / guidance	9%		50%	17%	

For environmental conditions, the most highly cited information desired was related to water temperatures and warming, with 22% of farmers across all subsectors saying that water temperature data would be useful in planning and managing their businesses. About 36% of those who wanted water temperature information specified that forecasting data would be most useful. A higher percentage of farmers growing both shellfish and seaweed cited water temperature as important. Information on storms and weather, biofouling, and diseases were the second most cited topics (12%). About 83% of those who said storms and weather, and 67% of those who said information on diseases specifically requested forecasting and modeling data related to those topics. For those who were interested in data related to biofouling, 50% wanted guidance or specific action items related to mitigation. Lastly, 10% of respondents cited water quality topics, including salinity. The remaining, less frequently cited topics are listed in Table X by subsector.

CLIMATE DATA & MONITORING: NGOS, RESEARCHERS, GOVT. AGENCIES

To gauge alignment across groups, we also asked respondents who identified as NGO members, researchers, or government officials what climate-related information they thought would be most useful for aquaculture farmers. Table Z summarizes the environmental conditions they believed aquaculture farmers would want information on, along with grower responses (percentages calculated within groups). Researchers and government agents were well aligned with farmers. The most frequently cited topic for all three groups was water temperature. Researchers and government agents also identified storms / weather information as useful, in line with farmers. Interestingly, NGO members identified diseases as most useful, though this was also identified as one of the second most important topics by growers.

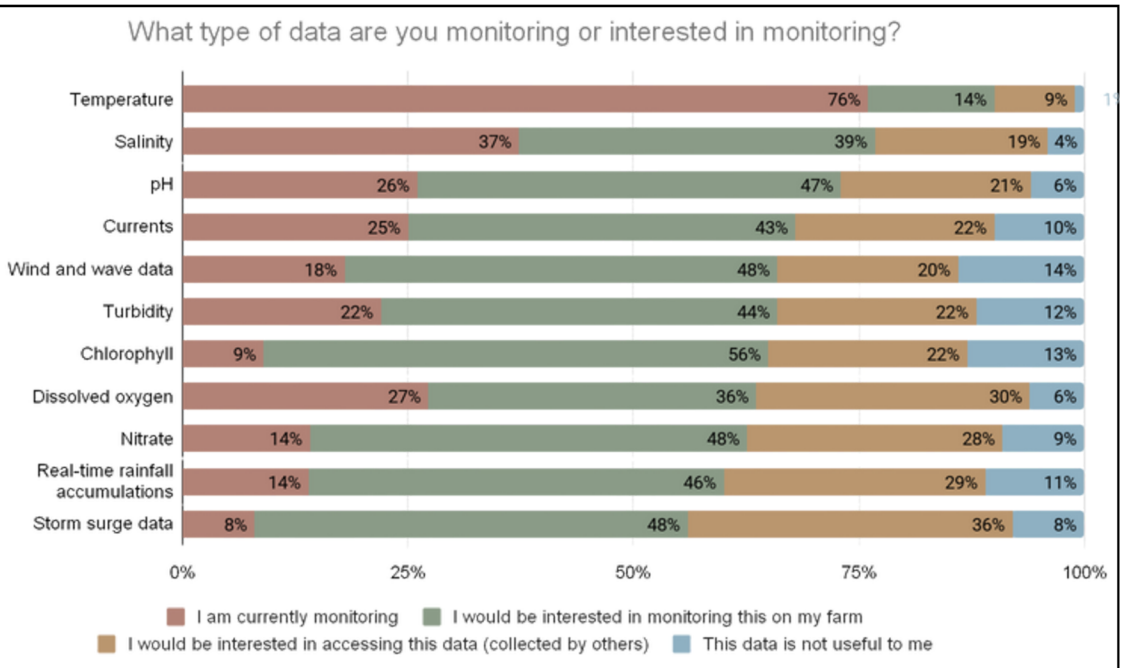


Figure 20. *Survey responses on the types of environmental data aquaculture stakeholders are currently monitoring, interested in monitoring, or would like to access if collected by others.*

We also prompted growers to select whether they are currently monitoring or would be interested in monitoring a variety of parameters as shown in Figure 18. The majority of farmers said that they are already monitoring temperature on their farm (76%), followed by salinity (37%), and dissolved oxygen (DO) (27%). The parameter that is most desired (56%), and least monitored (9%), is chlorophyll.

Also highly desired are nitrate levels (48%), storm surge data (48%), and wind and wave data (48%).

Following this, we asked farmers whether they would be willing to share the environmental data they are collecting. Out of 70 farmers, 71% said that they would share their data with anyone. Seventeen percent said that they would be willing to share their data with other aquaculture farmers, and only 11% said that they would not share environmental data.

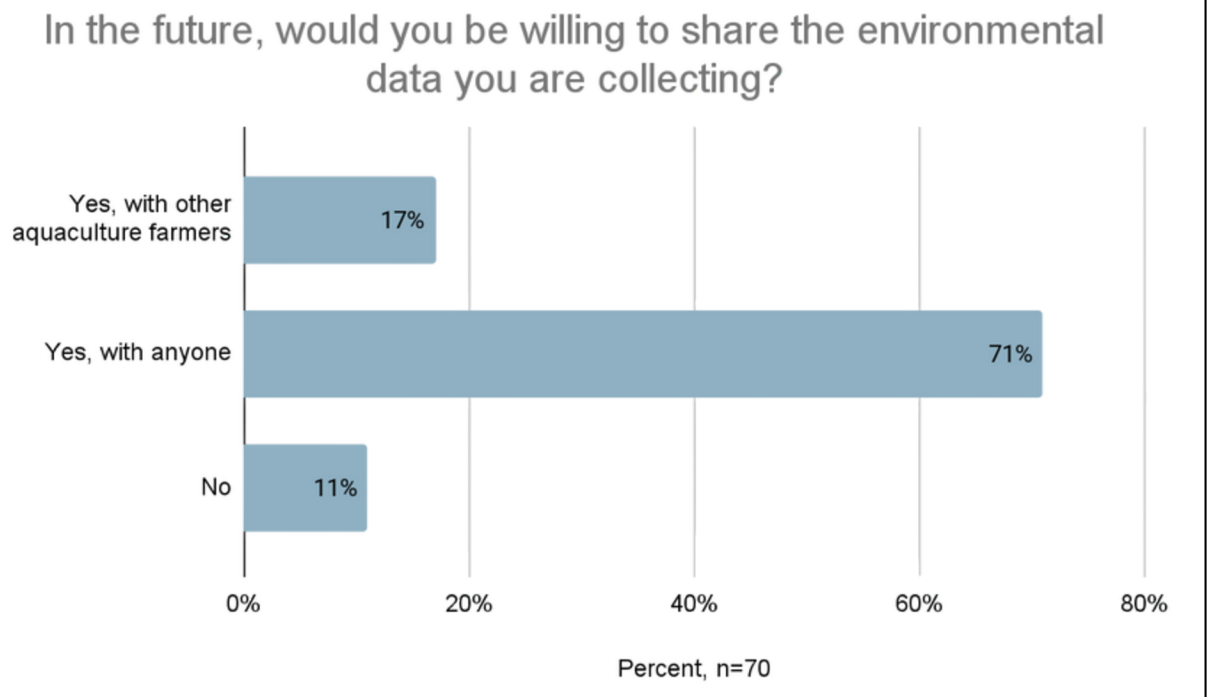


Figure 21. *Responses from aquaculture stakeholders on their willingness to share the environmental data they collect.*

TRUST IN SOURCES OF INFORMATION ON CLIMATE CHANGE

Lastly, all respondents were asked how much trust they have in different groups for information related to climate change. Figure 21 visualizes the degree of trust broken down by aquaculture industry (grower, industry service providers, and processing, distribution, marketing and sales) and non-industry respondents (NGOs, researchers, municipal officials and Wabanaki government representatives, federal and state agents). Across both groups, scientists garnered the highest trust (90% among industry and 93% among non-industry). Maine-based research and academic institutions also scored high, especially with non-industry participants (92%), pointing to the strong credibility of local expertise. Aquaculture support organizations and farmers were similarly well-regarded by both groups, with little variation, indicating a shared appreciation for peer-based and operational knowledge.

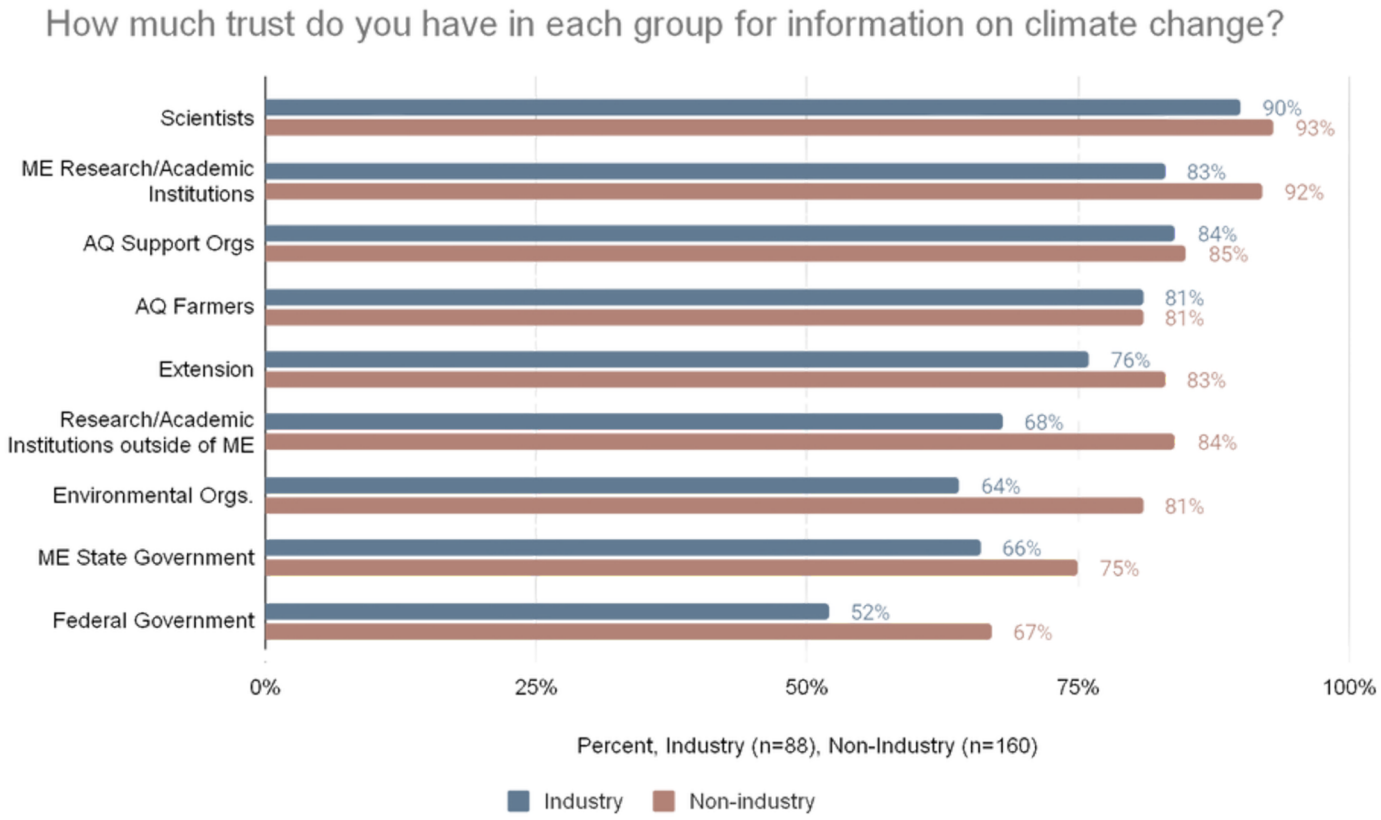


Figure 21: *The degree of trust in various groups for information on climate change, broken down by industry members and non-industry members.*

However, notable gaps appear between industry and non-industry respondents regarding extension services, out-of-state academic institutions, environmental organizations, and government agencies. For instance, only 52% of industry respondents trust the federal government, compared to 67% of non-industry participants. Similarly, environmental organizations were trusted by 64% of industry respondents versus 81% in the non-industry group. These disparities suggest that while scientific and local academic sources maintain a stronghold of trust across the board, institutional trust (particularly toward regulatory and advocacy entities) varies significantly between stakeholder groups. This pattern aligns with data from farmers specifically, who reported higher trust in scientists, local academic institutions, and aquaculture peers, while expressing notably lower trust in government agencies and environmental organizations. These findings suggest that farmers and industry professionals may be more inclined to trust regionally embedded experts and practitioners over external institutions. This insight is important for tailoring communication strategies, and emphasizing collaboration with locally trusted sources may be more effective for outreach and engagement with industry audiences.

BARRIERS AND ENABLING FACTORS

To assess the challenges associated with implementing climate adaptations to aquaculture businesses, we asked growers, industry services providers, and respondents who identified as part of processing, sales, distribution or marketing two open-ended questions. First, we asked two open ended questions:

- What are the biggest barriers to implementing climate adaptations for your business?
- What would make it easier to implement climate adaptations for your business?

Across these groups, financial constraints were the most commonly cited barrier to implementing climate adaptations. Respondents consistently highlighted the high cost of necessary adaptations, such as renewable energy infrastructure or climate-resilient gear, as a significant challenge (n=47). Mirroring this, when asked what would make it easier to adapt, many expressed a need for financial assistance in the form of grants, 0% loans, or tax credits (n=40), with one participant emphasizing "we cannot take on more debt and thus would require grants" to make these adaptations feasible.The second most commonly cited barrier to adaptation– regulatory barriers– was raised particularly among growers. Delays in securing or amending leases, as well as inflexibility in lease agreements were cited as particularly challenging (n=12). One grower explained that they "waited 8 months on an amendment to the farm lease to change mushroom anchors to helical," which hindered their ability to adapt quickly. Also notable among growers was the need for better access to research, climate resilient gear and equipment, and practical guidance, with one respondent suggesting that predictive tools like "future weather forecasts" would greatly aid planning. Table 6 summarizes the barriers and enabling factors cited by each group.

Table 6: *Summary of barriers and enabling factors for implementing climate adaptations across different aquaculture industry sub-sectors.*

Category	Barriers	Enabling Factors
Aquaculture Growers Barriers: n=48 Enablers: n=44	Costs; lack of renewable energy infrastructure (power sources for charging); regulatory delays and inflexible leases; focus on immediate stressors; limited access to climate-resilient gear/equipment; time constraints and manpower shortages.	Funding (non-repayable preferred); streamlined regulations and faster lease processes; government support for funding and innovation; predictive tools for weather and planning; practical guidance.
Industry Service Providers Barriers: n=9 Enablers: n=8	High costs of R&D; time required to get 'buy-in' from growers for new products	Funding (non-repayable preferred); dedicated funding for R&D and infrastructure; increased partnerships; tax credits; better tools and information access.
Processors & Distributors Barriers n=7 Enablers n=8	High costs of R&D; challenges of adapting production cycles; regulatory challenges	Funding (non-repayable preferred); rebates and incentives for energy-efficient upgrades; non-dilutive funding opportunities.

To assess whether researchers, municipal officials, regulatory agents and NGO members–those who can help to address barriers–are aligned with industry members, we asked these groups:

- To the best of your knowledge, what would make it easier for aquaculture farmers to adopt climate adaptations?
- To the best of your knowledge, what are the biggest barriers to implementing climate adaptations for farmers?

Results to these questions are summarized in Table 7.

Table 7: Key barriers and enabling factors for the aquaculture sector to implement climate adaptations, as identified by researchers, municipal officials, regulatory agents and NGOs.

Category	Barriers	Enabling Factors
Researchers Barriers: n=28 Enablers: n=28	Costs; limited access to climate-resilient gear/equipment; knowledge gaps; regulatory delays; environmental constraints; social resistance; loss of working waterfronts; market pressures; focus on immediate stressors.	Grants and financial assistance; improved knowledge sharing and training; streamlined regulations; better infrastructure; government leadership and support; community support; localized data; proof of concept for adaptations.
Municipal Officials Barriers: n=9 Enablers: n=9	Costs; knowledge gaps; community resistance; outdated policies; limited capacity; limited government leadership.	Grants and financial assistance; technical assistance; streamlined regulations; community support; localized data.
Regulatory Agents (state & federal) Barriers: n=7 Enablers: n=7	Costs; regulatory/permitting constraints that limit adaptation; site availability.	Grants and financial assistance; localized data; streamlined regulations.
NGOs *Barriers: n=21* *Enablers: n=21*	Costs; knowledge gaps; time and capacity limitations; uncertainty related to adaptation efficacy; regulatory/permitting constraints that limit adaptation; social resistance; focus on immediate stressors.	Grants and financial assistance; technical assistance; improved knowledge sharing and technology transfer; streamlined regulations; community support; proof of concept for adaptations.

While all groups recognized that lack of funding and regulatory challenges were the top barriers, there were some differences between subgroups (Table X). Growers were well aligned with regulatory agents with regards to funding. Interestingly, regulatory agents pointed out regulatory challenges at a higher percentage than other groups (43%). Also notable, were subgroup differences related to the theme knowledge gaps. Researchers in particular often cited knowledge gaps as a major barrier to adaptation. For example, one respondent said that a barrier was "limited knowledge of species and environmental impacts." Another said "not knowing the rate and stability of changes." Municipal officials and NGOs also cited knowledge gaps, though to a lesser extent. Interestingly, growers and regulatory agents were again aligned related to knowledge gaps, with neither group recognizing knowledge gaps as a barrier to adaptation. However, growers did point out that practical guidance would help enable adaptations. Lastly, researchers, municipal officials, and NGOs all cited community support, saying that "growing social license" is an important enabling factor for farmers.

Table 8. Comparison of adaptation barrier themes mentioned by each growers, researchers, municipal officials, regulatory agents, and NGOs

	Funding	Regulatory Challenges	Knowledge Gaps
Growers (n=48)	72%	21%	-
Researchers (n=28)	54%	29%	46%
Municipal (n=9)	22%	22%	29%
Regulatory Agents (n=7)	71%	43%	-
Regulatory Agents (n=7)	48%	24%	24%

In addition to these open-ended questions, respondents were prompted to evaluate the importance of a list of enabling factors that were brought up during scoping interviews. Similar to Tables X and X above, results are grouped into industry, which includes growers, industry service providers, processing/distribution, and non-industry, which includes municipal officials, regulators, researchers, and NGO members. Across both groups, funding opportunities for adaptation scored highly, with an average of 4.5 for industry and 4.6 for non-industry indicating that respondents believe this is the most important enabling factor. This mirrors findings outlined in Tables X and X. Findings related to regulatory changes also align with the open-ended questions above. However, responses show that industry respondents rated more flexible lease agreements (4.5) as more important to their ability to adapt than speeding up the lease process (4.2), suggesting that adaptability and responsiveness in leasing structures may be more valuable to farmers than efficiency alone.

Also of note is the importance of affordable on-farm devices for monitoring environmental parameters, and the importance of community support for aquaculture for adaptations. Interestingly, the need for community support was pointed out by non-industry in Table 7, yet was not mentioned by industry in Table 6. Yet when prompted, industry members rated this factor as the most important factor–even above funding opportunities. Though not top of mind, clearly community support is important for the resilience of the industry.

Table 9. *Average score of importance for a list of adaptation enabling factors broken down by industry members (growers, industry service providers & processing, distribution, sales and marketing) versus all other groups. Not important (1) – very important (5)*

	Industry, Growers, Service, Providers, Processing	Non-industry, Municipal, Regulators, Researchers, NGOs	Total
Funding opportunities for adaptations	4.5	4.6	4.6
Increased community support for aquaculture	4.6	4	4.3
More flexible leases	4.5	4.1	4.3
Affordable on-farm devices for monitoring	4.3	4.2	4.2
Grant writing assistance	4.2	4.1	4.1
More opportunities for knowledge exchange (farmers)	4.1	4.1	4.1
Faster lease process	4.2	3.8	4
Development of industry-wide resilience plan	3.8	4.1	4
Climate hub for climate resources specific to ME	3.9	4.1	4

REGULATION OF POLICY BARRIERS

Growers were also asked whether there are any specific policies or regulations that have either helped or hindered their ability to adapt to climate impacts. Among growers surveyed, most responses were related to Maine's leasing process. Aligning with responses above, growers said that the length of time it takes to secure a lease in Maine hinders farmers' ability to plan and adapt for climate change (n=11). Farmers said that they "can't make changes or get leases in a reasonable amount of time." Further, farmers pointed out that leases are inflexible, requiring an amendment for any changes in gear, and that this hinders their ability to adapt quickly (n=9). One farmer explained that they "need the flexibility to innovate our gear configurations without having to wait 9 months for [the] lease amendment process." Three farmers talked about feeling like the industry is over-regulated, with one farmer specifically saying that increasing regulations make it more difficult for small businesses to survive. Other responses included urging DMR to adopt a comprehensive plan for aquaculture development and offer more guidance to fast-changing regulations. One respondent said that the new Vibrio regulations have been helpful.

RESEARCH, DEVELOPMENT AND EDUCATION NEEDS

RESEARCH AND DEVELOPMENT NEEDS

This section summarizes stakeholder perceptions of the most important research and development topics for helping aquaculture farmers adapt to climate change. Participants rated the importance of topics such as storm-resistant gear, selective breeding, climate-resilient farm management, and site selection. These categories emerged during scoping interviews. Overall, there was strong agreement across groups, with most topics receiving average scores above 4 out of 5, indicating they were considered important to very important. Notably, storm-resistant gear, climate-resilient farm management, and selective breeding were among the highest-ranked priorities, reflecting concerns about increasing weather volatility and long-term biological resilience. Research and development on equipment that is less reliant on fossil fuels was least important compared to the other prompts, however 3.8/3.9 still indicates an average of moderately important to important. Both groups were well aligned in assigning importance, with only slight differences.

Table 10. Average score of importance for a list of research and development needs for climate adaptation broken down by industry members (growers, industry service providers & processing, distribution, sales and marketing) versus all other groups.

	Industry, Growers, Service Providers, Processing	Non-industry, Municipal, Regulators, Researchers, NGOs	Total
Storm resistant gear	4.4	4.4	4.4
Climate-resilient farm management	4.3	4.4	4.3
ME Climate impacts	4.2	4.3	4.3
Selective breeding	4.3	4.2	4.2
Climate-resilient site selection	4.1	4.3	4.2
Husbandry of emerging species	4.1	4.2	4.2
New species (market research)	4	4	4
Climate conditioning	4	4.1	4.1
Equipment that is less reliant on fossil fuels	3.8	3.9	3.9

STAKEHOLDER-SPECIFIC CONSIDERATIONS

EDUCATORS

The majority of educators surveyed were K-12 educators (68%), followed by university educators(13%) and extension agents (9%). Just over 70% of educators say that they incorporate aquaculture into their instruction, and an additional 25% would like to in the future. Among those who currently incorporate aquaculture, 53% have been doing so for less than three years (Figure X). About a quarter have been teaching students about aquaculture for 3-6 years, and another quarter for more than 7 years.

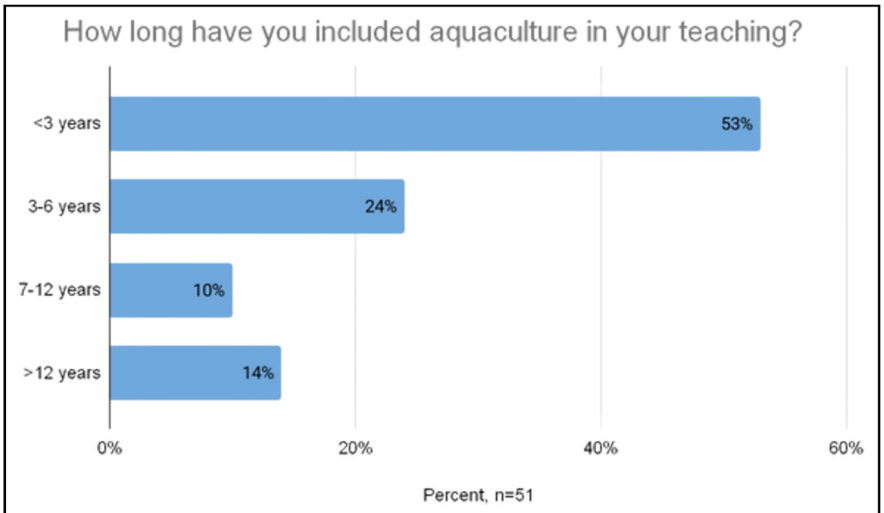


Figure 22. *How long educators have included aquaculture in their teaching*

We also asked educators whether they include aquaculture as a topic in their instruction about climate change, nearly half of which said that they do. The educators who said that they do described the way in which they incorporated aquaculture in more detail in an open-ended response. Their insights consisted of both teaching topics and teaching methods. When aquaculture was most directly integrated with climate change curriculum (n=14), it was incorporated as an adaptation or mitigation method. Most notably, downstream effects of warming waters, augmented coastal storms, and overfishing offered a stage for aquaculture's relevance, with some educators specifying ecosystem services (i.e. water filtration) as topics they connected to the industry, especially in regards to seaweed (n=11). Additional topics co-occurring with aquaculture learning included ocean biology & ecology (n=11), the wild-catch fishing & lobster industry (n=4), sustainable food systems (n=5), and general marine ecosystem services (n=7).

We have a seaweed tank from the Boothbay Sea and Science Center, which we monitor daily, recording pH, temperature, salinity, and other observations. [A staff member] from the Darling Marine Center will come and discuss seaweed and the warming of the Damariscotta River. We will participate in the Gulf of Maine Research Institute's LabVenture research project in a few weeks.

When specified, classroom-discussion was the most frequently noted mode of teaching, with experiential- and project-based learning also being mentioned. Educational resources and organizations mentioned by name included the Boothbay Sea & Science Center, Darling Marine Center & associated faculty, Gulf of Maine Research Institute, Maine Aquaculture Innovation Center, and World Wildlife Fund.

When asked what would make it easier for educators to incorporate aquaculture into their instruction related to climate change, respondents primarily discussed teaching resources. In order to better instruct their students, 52% described the need for more or better access to educator-specific resources. This included established lesson/curriculum plans (with one mention to the Next Generation Science Standards), increased time or instruction-plan flexibility, additional funding, and details of what barriers exist to accessing pre-existing resources.

An inexpensive hands-on curriculum for 6th grade. My budget for materials is seriously limited, so I do not have funds to purchase a lot. Also, most of the lesson plans I find online are geared towards younger or older students. For example: I enjoyed the cooking workshops at the conference last year (delicious!), but our FCS kitchen is only available at certain times. So I would have to work with other teachers to change schedules so we could have access, and I would have to pay out-of-pocket for ingredients.

Early childhood education, primary, secondary, and postsecondary educators all spoke about requiring specialized, multimedia materials for their students based on their age and stage of learning. Aside from representing the most commonly-expressed student-specific need (n=11), it also underpins all other resource requests. Respondents also advocated for access to aquaculture experts, as well as field-trips & hands-on activities.

About three quarters of educators also expressed interest in professional development (PD) opportunities related to incorporating aquaculture into their instruction. When given a

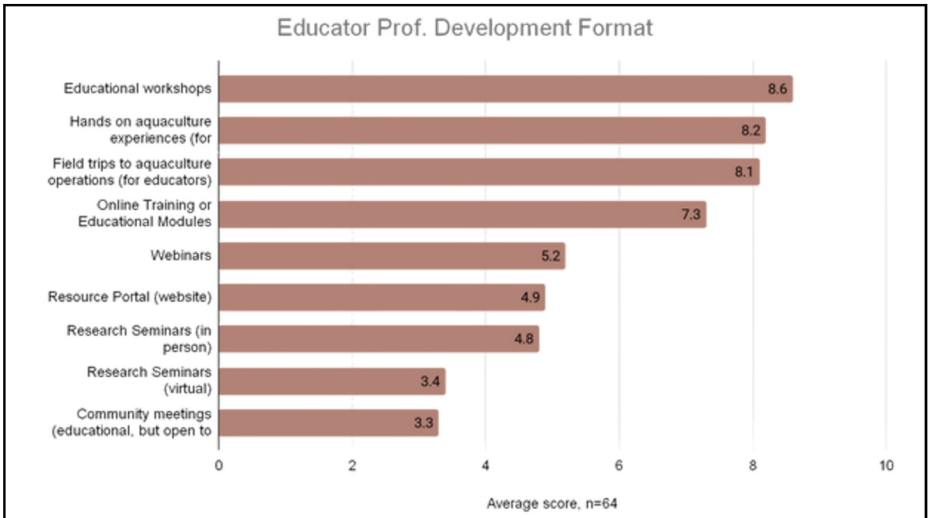


Figure 22. *Professional Development Opportunity Format*

list of various PD delivery formats, educational workshops, hands- on aquaculture experiences, and field trips to aquaculture operations for educators ranked as most useful, demonstrating the importance of in-person, experience-based opportunities for educators.

MUNICIPALITIES

We asked a subset of questions to respondents who selected either Maine municipal government or committee member, Wabanaki Nations government member, or member of the Community Resilience Partnership program as their affiliation. We were interested in what climate-related information was most useful in planning and managing aquaculture operations in their communities, and whether aquaculture was a regular part of their planning discussions.

In total, there were 14 respondents in this subsample. For information useful in planning and managing aquaculture, respondents discussed both environmental and economic data. Environmental information included studies showing any potential interactions with local wild species, information on sea level rise, and better weather forecasting. Two respondents specified the need for accessible, localized data available to the public including water temperature, rainfall, salinity, pH, and water quality data. One also requested data related to the rate of climate impacts for preparedness planning. Economic data that respondents said would be useful includes information related to real earning potential across species for small-scale farmers in rural areas.

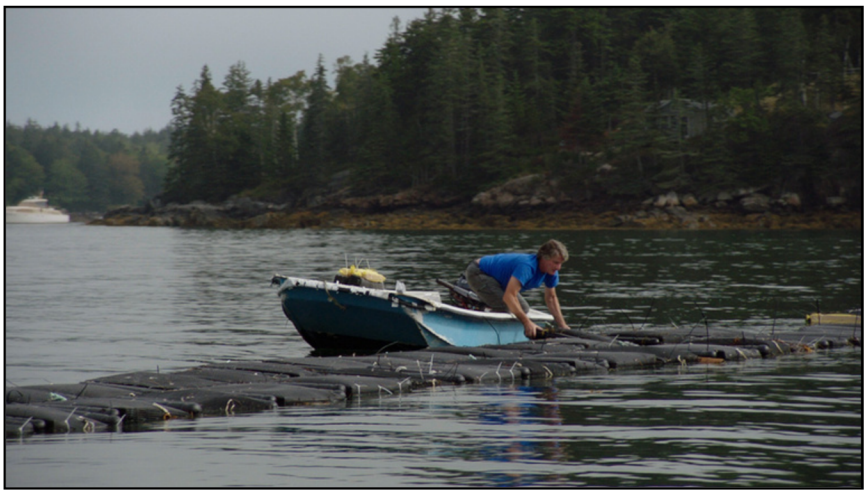
To gauge whether municipalities are having discussions about aquaculture in their resilience planning, we asked a series of related questions to the sample subset. When asked how often aquaculture is part of planning discussions in their community, 80% of municipal representatives said "sometimes", 10% said it is "most of the time", and an additional 10% said that it is "never" part of planning discussions. We then asked a similar question related to climate resilience. Similarly, the majority of respondents said that climate resilience is "sometimes" part of planning discussions (60%), with an additional 20% saying that it is part of discussions "most of the time." Ten percent said that climate resilience is "always" part of the discussion, and another 10% said that climate resilience is "never" discussed as in planning discussions. Lastly, we asked municipal representatives how often aquaculture is part of discussions related to climate resilience in their community. Thirty-percent of respondents said "never," 50% said "sometimes," 10% said "about half of the time" and 10% said "most of the time."

While these results are encouraging–as the majority of this subsample said that aquaculture is part of their planning discussions both independently and as part of climate resilience planning–these results are likely not representative. The subsample of municipal and Wabanaki representatives was small (n=14). Additionally, the individuals included in the initial survey sample list have some degree of involvement with or interest in aquaculture, so we would expect a higher level of inclusion of aquaculture in discussions than municipalities state-wide. We would also expect some differences in the incorporation of aquaculture in planning based on location–with coastal communities having more opportunities than inland communities. More research is needed to gain a better understanding of the degree to which communities are including aquaculture in their resilience planning.

Lastly, we asked members of this subsample whether they were interested in educational opportunities related to incorporating aquaculture into their community's resilience planning. Seventy-percent of respondents said "yes" or "maybe." Among those respondents, topics of interest specifically mentioned were how communities can support aquaculture in a way that benefits the community and localized planning assistance that incorporates place-based research. For example, one respondent said they are interested in finding out what "types of aquaculture [are] viable in my area of responsibility and impacts on other fisheries and navigation." Preferred format for these educational opportunities were community meetings, farmer-led workshops, and in-person research seminars.

RESEARCHERS & STUDENTS

To gain a better understanding of the research landscape related to aquaculture and climate change, we asked respondents who identified as a researcher or student whether they had done or are currently doing any research related to climate impacts on aquaculture. Out of 39 respondents, just over 50% said "no," 15% said "no, but I plan to," and 33% said "yes." Research topics included the development of resilient shellfish stocks through selective breeding (n=3), the effects of climate impacts on the growth, reproduction and health of aquatic organisms (n = 2), economic feasibility analysis for income diversification (n = 1), the use of DNA and RNA tools to improve shellfish and finfish farming (n = 1), building climate resilience through nursery methods and farm design for shellfish (n = 1), reducing the reliance on fossil fuels for powering land based aquaculture (n = 1), social-ecological systems and responses to climate change (n = 1), and shellfish restoration as a climate resiliency strategy (n = 1).



CONCLUSION

Maine's aquaculture industry faces critical climate-driven challenges, from rising ocean temperatures and extreme weather events to shifting regulatory landscapes and socio-economic pressures. This assessment, informed by stakeholder input through surveys and interviews, reveals the challenges facing Maine's aquaculture sectors and highlights pathways toward resilience and sustainable adaptation.

A clear consensus emerges among stakeholders recognizing anthropogenic climate change and expressing significant concern about its implications for Maine's aquaculture industry. Growers from all subsectors are experiencing tangible impacts, notably increased biofouling, warming waters, reduced ice coverage, intensified storm events, and economic pressures from rising energy costs. While these environmental changes often negatively affect operations through increased labor demands, infrastructure damage, and fluctuating yields, they also present unique opportunities, such as extended growing seasons and potential market shifts toward climate-resilient species.

Adaptation is widely regarded as an imperative rather than an option, however substantial barriers remain pervasive. High financial costs of implementing adaptation measures, protracted regulatory processes, and inflexible lease agreements impede the rate and effectiveness of response strategies. Stakeholders explicitly call for targeted financial assistance, particularly grants and incentives, coupled with regulatory reform to expedite leasing and permitting processes, enabling more responsive management adjustments.

The industry's self-reliance and ingenuity is apparent with the majority of aquaculture growers independently developing and implementing adaptation strategies through trial and error and peer collaboration. However, the industry clearly expresses the need for expanded educational resources, increased peer-to-peer knowledge exchange opportunities, and stronger connections with research institutions and extension services. There is demand for precise, localized, and predictive environmental data (temperature forecasts, disease risks, biofouling patterns, and storm predictions) growers consider essential for informed decision-making and proactive adaptation planning.

From a research and development perspective, stakeholders prioritize innovation in storm-resilient infrastructure, improved methodologies for resilient farm management and site selection, and selective breeding programs. To advance these areas, respondents emphasize the need for increased funding for applied research, policies that incentivize sustainable practices, and affordable on-farm environmental monitoring.

Building climate resilience within Maine's aquaculture sector demands coordinated action and cross-sector collaboration among growers, industry service providers, educators, researchers, governmental agencies, and local communities. Future efforts should explicitly address the challenges identified, leveraging the collective strengths of Maine's academic and research institutions, ingenuity of local farmers, and proactive state-level policy frameworks.

This report establishes a critical baseline from which stakeholders can advance strategic planning, targeted investments, and policy alignment. Maine is uniquely positioned not only to enhance the resilience and sustainability of its own aquaculture industry but also to serve as a national and international model for climate-adaptive aquaculture practices in the face of global environmental change.