Climate Change Risk and Opportunity Assessment for the Seafood Industry

Contents

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Key Terms

- **Climate hazard:** A potentially damaging event or phenomenon caused by climate factors (e.g., rising global temperatures), that could consequently result in major impacts to the province's seafood sector, such as environmental degradation, infrastructure damage, or social and economic disruptions.
- **Risk**: The chance that a hazard will cause harm. Risk is a function of the likelihood of a hazard occurring and the severity of its consequences.
- **Likelihood**: The probability that a climate hazard scenario will occur.
- **Consequence**: A measure of the severity of impacts from a climate hazard scenario.

Introduction

Climate change presents a unique set of challenges and some opportunities for Prince Edward Island's (PEI) seafood industry. The Province of PEI has already taken steps to understand and prepare for climate change (see textbox for recent actions).

Government commitments and reports commissioned in recent years have paved the way for this seafood focused climate change risk assessment. This report builds on the findings of the 2021 province-wide Climate Change Risk Assessment, which included high level discussion of how the seafood industry could be affected by climate change. This assessment also partially fulfills Action 13 in the 2022 Building Resilience: Climate Adaptation Plan, which commits the province to working with industry partners to identify priority risks to the seafood industry.

The seafood climate change risk and opportunity assessment explores potential impacts of climate change on PEI's aquaculture, commercial fishing, and processing sectors.[1] This assessment identifies potential risks and opportunities of key species and infrastructure assets (Table 1) to eight climate change hazards (Table 2). The PEI Department of Fisheries, Tourism, Sport and Culture (DFTSC) selected the focus species and infrastructure assets, emphasizing those that most significantly contribute to the province's economy. A sensitivity analysis was completed to help determine the most pertinent climate hazards per sector to analyze further in this assessment.

To ground truth the findings of the risk and opportunity assessment and build buy-in across the industry, the DFTSC also held a series of in-person workshops with industry representatives in August 2023. The purpose of these workshops was to vet and discuss high priority risks facing each sector and begin to identify potential adaptation options to address priority risks.

Timeline of Key Climate Actions

- 2018: Taking Action: A Climate Change Action Plan for PEI, 2018-2023, includes a commitment to taking proactive measures to reduce PEI's vulnerability to climate change as well as taking advantage of new opportunities.
- 2019: Former Department of Fisheries and Communities Mandate Letter, outlines department priorities, including developing research and knowledge to better understand and promote sustainable fisheries industries.
- 2021: Former Department of Fisheries and Communities Strategic Plan 2021-2024, outlines the department's action items to support a sustainable and growing fishing industry.
- 2022: Building Resilience: Climate Adaptation Plan, includes an action to identify and respond to priority climate risks to the farming, fishing, and tourism sectors.
- 2023: Department of Fisheries, Tourism, Sport, and Culture Mandate Letter, outlines department priorities, including using evidence-based tools to consider the impacts of climate change in the decision-making process.

[1] This assessment evaluates risks to seafood production, infrastructure, and operations on PEI. It does not, for example, evaluate risks to the shipping of seafood products after the product has left the island. Recognizing that climate impacts to neighboring provinces may also affect PEI's seafood industry, the DFTSC will consider opportunities for collaboration with neighboring provinces to adapt to priority risks.

The risk and opportunity assessment results and discussions with industry representatives will inform adaptation planning and decision-making at the DFTSC. The DFTSC is committed to working with industry partners to establish programs and initiatives that will help ensure resilient and sustainable growth of the PEI seafood industry in the face of climate change. Industry partners will be key to the design and successful implementation of any new programs and initiatives.

Table 1. Focus species or infrastructure assets per sector

Aquaculture Sector	Commercial Fishing Sector	Processing Sector
1. Mussels 2. Oysters 3. Rainbow Trout 4. Atlantic Salmon	1. Lobster 2. Snow Crab 3. Atlantic Bluefin Tuna 4. Atlantic Mackerel 5. Atlantic Herring 6. Rock Crab 7. Soft Shell Clams	1. Processing Facilities 2. Storage Facilities 3. Buying Stations 4. Inbound/Outbound Transportation

Table 2. Climate hazard scenarios

Hazard		Aquaculture	Commercial Fishing	Processing
Oceanic/ riverine warming		X	X	
Heat wave	**Marine**	X	X	
	Atmospheric	X		X
Heavy precipitation and flooding		X		X
Post-tropical storm		X	X	X
Acidification		X	X	
Hypoxia			X	
Coastal erosion				X
Ice storm/ freezing rain				X

Summary of Findings

Table 3, Table 4, and Table 5 provide a summary of risk ratings across all sectors, species (aquaculture and commercial fishing), and assets (processing). All four aquaculture species received a High risk rating for post-tropical storms and mussels additionally face High risk from oceanic/riverine warming and marine heat waves by 2050. Atlantic salmon and rainbow trout may also face moderate risk to atmospheric heat waves, especially if heat waves threaten the power and energy infrastructure. Heavy precipitation and flooding also pose a moderate risk to Atlantic salmon and rainbow trout. Priority risks for the commercial fishing sector are more varied across species by 2050, including High risk ratings for post-tropical storms (lobster), marine heat waves (Atlantic herring, soft shell clams), and oceanic/riverine warming (snow crab). Atlantic bluefin tuna, Atlantic mackerel, and rock crab did not receive any High risk ratings.

Adaptation considerations for high priority risks facing key aquaculture and commercial fishing species might focus on reducing infrastructure vulnerabilities from post-tropical storms, modifying practices to the extent possible to reduce losses from warming temperatures, and taking actions to minimize significant disruptions to livelihoods.

Unsurprisingly, post-tropical storms emerge as the highest risk by 2050 for processing sector assets, including processing and storage facilities and inbound/outbound transportation. These risks are driven by the potential for significant damage to critical infrastructure and the possibility of an extended power outage. Risk to facilities from atmospheric heat waves are also driven by power outage concerns, which can lead to significant losses of live and refrigerated products.

Adaptation considerations for the processing sector might focus on measures to increase the resilience and redundancy of critical infrastructure, such as ensuring adequate backup power supplies at key facilities.

Aquaculture Sector: Summary of findings

Table 3. Aquaculture sector climate risk assessment results

Hazard	Current Likelihood	2050 Likelihood	Production/ Output	Infrastructure	Livelihood	Current Risk	Future Risk
Mussels							
Oceanic/Riverine Warming	3	5	3	2	4	**Medium (9.0)**	**High (15.0)**
Post-Tropical Storm	4	4	3	4	4	**High (14.7)**	**High (14.7)**
Heat Wave (Marine)	4	5	3	2	3	**Medium (10.7)**	**High (13.3)**
Heavy Precipitation and Flooding	3	4	3	2	2	**Medium (7.0)**	**Medium (9.3)**
Acidification	2	3	3	1	2	**Low (4.0)**	**Low (6.0)**
Oysters							
Post-Tropical Storm	4	4	3	4	4	**High (14.7)**	**High (14.7)**
Heavy Precipitation and Flooding	3	4	3	2	3	**Medium (8.0)**	**Medium (10.7)**
Oceanic/Riverine Warming	1	2	3	2	4	**Low (3.0)**	**Low (6.0)**
Heat Wave (Marine)	1	2	3	2	3	**Low (2.7)**	**Low (5.3)**
Acidification	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Rainbow Trout							
Post-Tropical Storm	4	4	4	4	4	**High (16.0)**	**High (16.0)**
Heat Wave (Atmospheric)	3	5	3	3	1	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	2	3	2	**Medium (7.0)**	**Medium (9.3)**
Atlantic Salmon							
Post-Tropical Storm	4	4	4	4	4	**High (16.0)**	**High (16.0)**
Heat Wave (Atmospheric)	3	5	3	3	1	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	2	3	2	**Medium (7.0)**	**Medium (9.3)**

Commercial Fishing Sector: Summary of findings

Table 4. Commercial fishing sector climate risk assessment results

Hazard	Current Likelihood	2050 Likelihood	Production / Output	Infrastructure	Livelihood	Current Risk	Future Risk
Lobster							
Post-Tropical Storm	4	4	3	4	3	**High (13.3)**	**High (13.3)**
Acidification	5	5	3	1	3	**Medium (11.7)**	**Medium (11.7)**
Hypoxia	3	4	3	1	3	**Medium (7.0)**	**Medium (9.3)**
Oceanic/Riverine Warming	1	2	4	2	4	**Low (3.3)**	**Low (6.7)**
Heat Wave (Marine)	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Snow Crab							
Oceanic/Riverine Warming	3	5	3	2	3	**Medium (8.0)**	**High (13.3)**
Heat Wave (Marine)	3	4	4	2	3	**Medium (9.0)**	**Medium (12.0)**
Post-Tropical Storm	4	4	1	4	2	**Medium (9.3)**	**Medium (9.3)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Hypoxia	3	4	1	1	1	**Low (3.0)**	**Low (4.0)**
Atlantic Bluefin Tuna							
Post-Tropical Storm	4	4	2	3	3	**Medium (10.7)**	**Medium (10.7)**
Hypoxia	3	4	3	1	2	**Low (6.0)**	**Medium (8.0)**
Acidification	2	3	2	1	1	**Low (2.7)**	**Low (4.0)**
Oceanic/Riverine Warming	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Heat Wave (Marine)	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Atlantic Mackerel							
Heat Wave (Marine)	2	4	4	2	3	**Low (6.0)**	**Medium (12.0)**
Post-Tropical Storm	4	4	2	3	2	**Medium (9.3)**	**Medium (9.3)**
Oceanic/Riverine Warming	2	4	3	2	2	**Low (4.7)**	**Medium (9.3)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Hypoxia	3	4	1	1	1	**Low (3.0)**	**Low (4.0)**

Hazard	Current Likelihood	2050 Likelihood	Production / Output	Infrastructure	Livelihood	Current Risk	Future Risk
Atlantic Herring							
Heat Wave (Marine)	3	5	4	2	3	**Medium (9.0)**	**High (15.0)**
Post-Tropical Storm	4	4	2	3	2	**Medium (9.3)**	**Medium (9.3)**
Oceanic/Riverine Warming	2	4	3	2	2	**Low (4.7)**	**Medium (9.3)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Hypoxia	3	4	1	1	1	**Low (3.0)**	**Low (4.0)**
Rock Crab							
Post-Tropical Storm	4	4	2	3	3	**Medium (10.7)**	**Medium (10.7)**
Oceanic/Riverine Warming	1	3	4	2	3	**Low (3.0)**	**Medium (9.0)**
Hypoxia	3	4	3	1	2	**Low (6.0)**	**Medium (8.0)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Heat Wave (Marine)	1	2	3	2	2	**Low (2.3)**	**Low (4.7)**
Soft Shell Clams							
Heat Wave (Marine)	4	5	4	1	3	**Medium (10.7)**	**High (13.3)**
Oceanic/Riverine Warming	4	5	3	1	2	**Medium (8.0)**	**Medium (10.0)**
Post-Tropical Storm	4	4	3	2	2	**Medium (9.3)**	**Medium (9.3)**
Acidification	3	4	4	1	2	**Medium (7.0)**	**Medium (9.3)**
Hypoxia	3	4	3	1	2	**Low (6.0)**	**Medium (8.0)**

Processing Sector: Summary of findings

Table 5. Processing sector climate risk assessment results

Hazard	Current Likelihood	2050 Likelihood	Production/ Output	Infrastructure	Livelihood	Current Risk	Future Risk
Processing Facilities							
Post-Tropical Storm	4	4	3	4	3	**High (13.3)**	**High (13.3)**
Heat Wave (Atmospheric)	3	5	3	2	2	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	3	3	2	**Medium (8.0)**	**Medium (10.7)**
Coastal Erosion	4	5	1	3	1	**Low (6.7)**	**Medium (8.3)**
Ice Storm/Freezing Rain	4	3	2	2	2	**Medium (8.0)**	**Low (6.0)**
Storage Facilities							
Post-Tropical Storm	4	4	3	4	3	**High (13.3)**	**High (13.3)**
Heat Wave (Atmospheric)	3	5	3	2	2	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	2	3	2	**Medium (7.0)**	**Medium (9.3)**
Coastal Erosion	4	5	1	3	1	**Low (6.7)**	**Medium (8.3)**
Ice Storm/Freezing Rain	4	3	2	2	2	**Medium (8.0)**	**Low (6.0)**
Buying Stations							
Post-Tropical Storm	4	4	3	3	2	**Medium (10.7)**	**Medium (10.7)**
Heat Wave (Atmospheric)	3	5	3	2	1	**Low (6.0)**	**Medium (10.0)**
Heavy Precipitation and Flooding	3	4	2	2	2	**Low (6.0)**	**Medium (8.0)**
Coastal Erosion	4	5	1	2	1	**Low (5.3)**	**Low (6.7)**
Ice Storm/Freezing Rain	4	3	1	1	1	**Low (4.0)**	**Low (3.0)**
Inbound/Outbound Transportation							
Post-Tropical Storm	4	4	4	4	2	**High (13.3)**	**High (13.3)**
Coastal Erosion	4	5	1	3	1	**Low (6.7)**	**Medium (8.3)**
Heat Wave (Atmospheric)	3	5	2	2	1	**Low (5.0)**	**Medium (8.3)**
Heavy Precipitation and Flooding	3	4	2	3	1	**Low (6.0)**	**Medium (8.0)**
Ice Storm/Freezing Rain	4	3	2	2	1	**Low (6.7)**	**Low (5.0)**

Methodology Overview

Figure 1 provides an overview of the six-step process for this assessment. ICF completed this analysis in close collaboration with the DFTSC and assessment findings were further vetted with key industry representatives during sector-specific workshops in August 2023. Appendix A provides additional details on each step of the climate risk and opportunity assessment methodology.

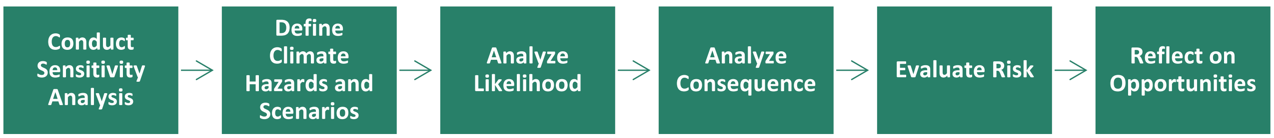

Figure 1. Climate risk and opportunity assessment process diagram.

The climate risk and opportunity assessment focused on 15 species and infrastructure assets that are critical to the aquaculture, commercial fishing, and seafood processing sectors of the PEI seafood industry (Table 6).

Table 6. Focus species or infrastructure assets per sector

Aquaculture Sector	Commercial Fishing Sector	Processing Sector
1. Mussels 2. Oysters 3. Rainbow Trout 4. Atlantic Salmon	1. Lobster 2. Snow Crab 3. Atlantic Bluefin Tuna 4. Atlantic Mackerel 5. Atlantic Herring 6. Rock Crab 7. Soft Shell Clams	1. Processing Facilities 2. Storage Facilities 3. Buying Stations 4. Inbound/Outbound Transportation

To define the scope of the climate risk and opportunity assessment, ICF first conducted a **climate sensitivity analysis** to identify key climate sensitivities and critical thresholds at which species and assets begin to experience significant impacts. ICF then selected and **defined specific climate hazard scenarios** (Table 7) to further analyze in this assessment. Each scenario represents one possible permutation of that hazard and is used to illustrate the types of consequences associated with the hazard.

Table 7. Climate hazard scenarios

Hazard	Scenario	Focus per Sector		
		Aquaculture	Commercial Fishing	Processing
Oceanic/ riverine warming	Average water temperature rises above a species-specific threshold for adults that results in reduced growth, reduced recruitment, or some other indicated non-lethal limit threshold.	X	X	
Marine heat wave	More frequent occurrence of water temperatures above a species-specific lethal limit for adults for mature specimens (if available).	X	X	

Hazard	Scenario	Focus per Sector		
		Aquaculture	Commercial Fishing	Processing
Atmospheric heat wave	Three consecutive days with temperatures above 29°C.	X		X
Heavy precipitation and flooding	100mm of rain in 24 hours.	X		X
Post-tropical storm	Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022.	X	X	X
Acidification	Acidification in the Gulf of St. Lawrence reaches a species-specific threshold (if available).	X	X	
Hypoxia	More frequent hypoxic conditions.		X	
Coastal erosion	Acceleration of the historic rate of erosion (28 cm/year).			X
Ice storm/ freezing rain	Multi-day severe ice storm/freezing rain event in winter.			X

To assess risk, ICF rated the **likelihood** of each hazard scenario occurring (scale of rare (1) to almost certain (5)), and the **consequences** of that scenario on production/output, infrastructure, and livelihoods (scale of insignificant (1) to significant (4)). Risk is a function of likelihood and consequence so these ratings were combined to calculate risk for present day and 2050 using the risk rating matrix (Table 8) and score-to-rating rubric (Table 9).

Table 8. Climate risk rating matrix

	Consequence			
Likelihood	**Insignificant**	**Minimal**	**Moderate**	**Significant**
Almost Certain	Low	Medium	High	High
Likely	Low	Medium	Medium	High
Possible	Low	Low	Medium	Medium
Unlikely	Low	Low	Low	Medium
Rare*	Low	Low	Low	Low

*Scenarios that received a “rare” likelihood rating for both the current and future time period were not evaluated further and received a Negligible overall risk rating.

Table 9. Risk rating rubric

Risk Score	Risk Rating
No score*	Negligible
1-6	Low
7-12	Medium
13-20	High

*Scenarios that received a “rare (1)” likelihood rating for both the current and future time period were not evaluated further and received a Negligible overall risk rating.

See Appendix A for additional details on each step of the climate risk and opportunity assessment methodology, including the likelihood and consequence rating scales.

Climate Risks and Opportunities by Seafood Sector

The following sections detail climate risks and opportunities across all three sectors, aquaculture, commercial fishing, and processing. Each likelihood, consequence, and risk score is accompanied by a brief description of the knowledge base gathered through literature, workshops, and professional judgment.

Aquaculture Sector

This assessment evaluated risks to the aquaculture sector from five key climate hazards. Focus climate hazards were selected based on a sensitivity analysis of mussels, oysters, rainbow trout, and Atlantic salmon. For additional details on the sensitivity and risk analyses, see Appendix A: Climate Risk and Opportunity Assessment Methodology. Risk ratings are based on the following scenario events:

- **Oceanic/Riverine warming:** Average water temperature rises above a species-specific threshold for adults that results in reduced growth, reduced recruitment, or some other indicated non-lethal limit threshold
- **Heat wave:**
    - **Marine:** More frequent occurrence of temperatures above a species-specific lethal limit for adults for mature specimens (if available)
    - **Atmospheric:** Three consecutive days with temperatures above 29°C
- **Heavy precipitation and flooding:** 100mm of rain in 24 hours
- **Post-tropical storm:** Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022
- **Acidification:** Acidification in the Gulf of St. Lawrence reaches a species-specific threshold (if available)

As shown in Table 10, post-tropical storms pose a High risk across the four aquaculture species. Mussels additionally are at High risk to oceanic/riverine warming and marine heat waves. Risks from post-tropical storms are driven by the potential for critical infrastructure damage, which could subsequently affect production and livelihoods. Oceanic/riverine warming and marine heatwaves can lead to mortality events, reducing production and affecting livelihoods for mussel growers.

Potential Opportunities

Although climate change poses considerable risks to the aquaculture industry on PEI, changes in certain hazards may create potential opportunities for some aquaculture species. For example, warmer springs and falls may benefit the mussel aquaculture industry by allowing for earlier seeding in the spring and earlier harvesting.[2] Earlier springs and later falls may also extend the growing season for mussels and oysters. Oysters could experience increased growth rates as warming temperatures result in less time below the lower end of the optimal temperature range (although this may result in increased labour to ensure oyster quality).[3]

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[2] Isabel Fuentes-Santos et al., "Modeling the Impact of Climate Change on Mussel Aquaculture in a Coastal Upwelling System: A Critical Assessment," *Science of The Total Environment* 775 (June 25, 2021): 145020, https://doi.org/10.1016/j.scitotenv.2021.145020.

[3] Guenette, "Chapter 4. A Review of the Physiological Susceptibility of Commercial Species of Fish and Crustaceans of the Northwest Atlantic to Changes in Water Temperature, Dissolved Oxygen, PH and Salinity."

Mussel and oyster feeding and overall health could be positively or negatively affected by changes in coastal erosion and subsequent changes to the composition of coastal ecosystems.[4] An example of a positive benefit of coastal erosion happened in 2010, when a breach occurred near the centre of Tracadie Bay. This created a second outlet, resulting in improved circulation of water in the bay which benefited mussel and oyster farmers.[5]

[4] Prince Edward Island, “Prince Edward Island (PEI) Climate Change Risk Assessment.”
[5] Prince Edward Island, “Prince Edward Island (PEI) Climate Change Risk Assessment.”

Table 10. Aquaculture sector climate risk assessment results

Hazard	Current Likelihood	2050 Likelihood	Production/ Output	Infrastructure	Livelihood	Current Risk	Future Risk
Mussels							
Oceanic/Riverine Warming	3	5	3	2	4	**Medium (9.0)**	**High (15.0)**
Post-Tropical Storm	4	4	3	4	4	**High (14.7)**	**High (14.7)**
Heat Wave (Marine)	4	5	3	2	3	**Medium (10.7)**	**High (13.3)**
Heavy Precipitation and Flooding	3	4	3	2	2	**Medium (7.0)**	**Medium (9.3)**
Acidification	2	3	3	1	2	**Low (4.0)**	**Low (6.0)**
Oysters							
Post-Tropical Storm	4	4	3	4	4	**High (14.7)**	**High (14.7)**
Heavy Precipitation and Flooding	3	4	3	2	3	**Medium (8.0)**	**Medium (10.7)**
Oceanic/Riverine Warming	1	2	3	2	4	**Low (3.0)**	**Low (6.0)**
Heat Wave (Marine)	1	2	3	2	3	**Low (2.7)**	**Low (5.3)**
Acidification	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Rainbow Trout							
Post-Tropical Storm	4	4	4	4	4	**High (16.0)**	**High (16.0)**
Heat Wave (Atmospheric)	3	5	3	3	1	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	2	3	2	**Medium (7.0)**	**Medium (9.3)**
Atlantic Salmon							
Post-Tropical Storm	4	4	4	4	4	**High (16.0)**	**High (16.0)**
Heat Wave (Atmospheric)	3	5	3	3	1	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	2	3	2	**Medium (7.0)**	**Medium (9.3)**

Mussels (blue mussel, *Mytilus edulis*)

Figure 2. PEI mussel aquaculture. Source: PEI Department of Fisheries, Tourism, Sport, and Culture, 2016.

The mussel (*Mytilus edulis*) is a medium-sized marine bivalve mollusc predominantly found in the cool waters of the northern Atlantic Ocean. The mussel aquaculture industry on PEI is a vibrant and integral part of the region's aquaculture sector, providing a significant source of income and employment opportunities, supporting the equivalent of hundreds of full-time jobs. Aquaculture processes for the mussel begin with the collection of spat, the juvenile stage of the mussel, which naturally attach themselves to substrates. These collected spat are then placed in mesh socks and suspended in water from longline systems. Over a period of approximately 1 to 2 years, the spat grow and mature into harvestable mussels, ready to be collected and processed for market. Mussels do most of their growing in the spring and fall and harvesting can occur year-round.

The products derived from these mussels are diverse, including live mussels, frozen in-shell mussels, vacuum-packed mussels, pasteurized mussels, high-oxygen pack mussels, and other value-added products. These offerings cater to a wide range of consumer preferences and have helped the industry build a strong market presence. In 2021, the PEI mussel aquaculture industry recorded a harvest weight of 37.5 million pounds, representing a market value of $30 million. This significant yield underscores the importance of the sector to the local economy. The industry is supported by 323 aquaculture leases spanning a total acreage of 11,233.[6] The widespread adoption of mussel farming and its substantial economic impact attest to the success of the mussel aquaculture industry on PEI.

Figure 3 summarizes climate risks to the PEI mussel aquaculture industry. Oceanic/riverine warming, marine heat waves, and post-tropical storms received High risk ratings. The oceanic/riverine warming and marine heat wave ratings are driven by the potential for a moderate reduction in yield and subsequent disruptions to livelihoods. The post-tropical storm rating is driven by the potential for significant damage to critical equipment and infrastructure and impacts to livelihoods.

[6] PEI Department of Fisheries, Tourism, Sport and Culture. “2021 Fishery Statistics.” February 2, 2023. https://www.princeedwardisland.ca/en/publication/2021-fishery-statistics.

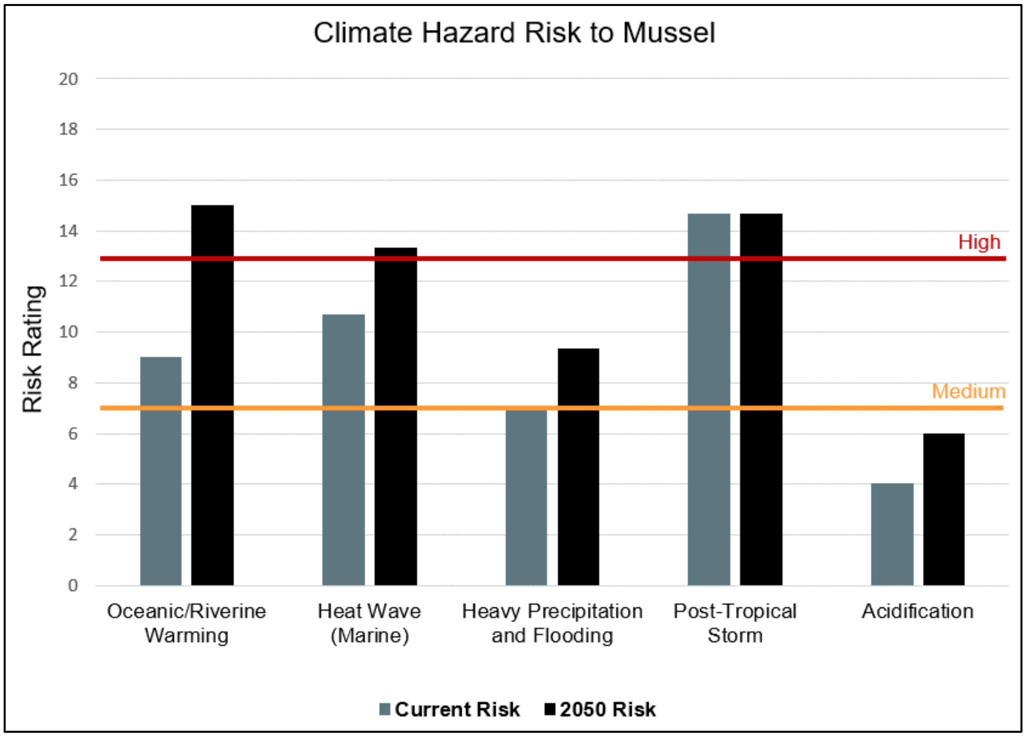

Figure 3. Summary of current and future climate hazard risk to mussel aquaculture.

1. Oceanic/Riverine Warming

Scenario: Average sea surface temperature rises above 22°C
Impact to Species: Reduction in growth rates

Oceanic/riverine warming on PEI currently represents a **Medium** risk to PEI's mussel aquaculture industry. This risk increases to **High** by mid-century (Table 11). Livelihoods could be most significantly affected by this scenario.

Warming sea temperatures may also lead to some potential **opportunities** for mussels on PEI. It is likely that increased growth rates could be achieved as warming temperatures result in less time below the lower end of the optimal growth rate (10°C). Further, while mussels tolerate temperatures as low as -1.7°C, warming temperatures could reduce the occurrence of extreme cold events that can cause mussel mortality.

Table 11. Mussels risk summary for oceanic/riverine warming

Ocean/Riverine Warming: Mussels							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	3	2	4	3	**Medium (9.0)**	**High (15.0)**

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The mussel ratings are relative to the critical sea surface temperature threshold of 22°C.

Current: (Rating: 3 – Possible)
Recorded July-August summer at coastal sites around PEI range from 11-27°C and average 21°C.

Future: (Rating: 5 – Almost Certain)
Under a high emissions scenario, July-August temperatures at coastal sites could range from 15-31°C and average 25°C.

Consequences

Oceanic/riverine warming poses overall moderate consequences to PEI's mussel aquaculture industry with impacts on production, infrastructure, and livelihoods. This hazard can lead to lower productivity for mussel growers, thereby affecting their income and livelihoods. The ramifications of increased water temperatures on mussels could be irreversible without sufficient adaptation.

Production/Output (Rating: 3 – Moderate)
Increases in temperature could result in a noticeable reduction in productivity and outputs as mussels may spend less time within optimal growing temperatures during the summer, especially during particularly warm summers. Rating considerations included:

- Mussels are moderately sensitive to heat. Temperatures above 22°C can result in reductions in growth and temperatures of 27°C–28°C are potentially lethal for all life stages.[7] There is scientific and local anecdotal evidence that mussels can acclimate to higher temperatures. Given this possibility, it is reasonable to assume the species could be able to acclimate to a gradual increase in warmer temperatures over a long period of time.[8] The use of genomics to introduce higher temperature tolerant strains of the mussel may also reduce climate change impacts of oceanic warming.
- Earlier melting of sea ice may result in earlier spring blooms of phytoplankton, potentially causing a mismatch for zooplankton, which feed upon phytoplankton. This relationship may affect mussels, which rely on plankton as a food source.[9]
- Higher winter temperatures may result in less thick sea ice cover, preventing deployment of equipment and machinery necessary for winter mussel harvesting.[10]
- Warmer temperatures may lead to more favourable conditions for pests and diseases such as the clubbed tunicate, which could experience longer spawning seasons. Warmer temperatures may also increase the range of other invasive species not currently present in PEI that may affect mussel mortality and overall productivity.[11,12]

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[7] "Mytilus edulis, blue mussel," McGill University, n.d., http://www.geog.mcgill.ca/climatechange/ReportsMap/musselIRpt.pdf.
[8] Laurent Seuront et al., "Decreased Thermal Tolerance under Recurrent Heat Stress Conditions Explains Summer Mass Mortality of the Blue Mussel Mytilus Edulis," *Scientific Reports* 9, no. 1 (November 25, 2019): 17498, https://doi.org/10.1038/s41598-019-53580-w.
[9] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report" (University of Prince Edward Island, 2017), https://projects.upei.ca/climate/files/2018/10/PEI-Climate-Change-Adaptation-Recommendations-Report_medres.pdf.
[10] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[11] Prince Edward Island, "Aquatic Invasive Species," February 8, 2016, https://www.princeedwardisland.ca/en/information/fisheries-and-communities/aquatic-invasive-species.
[12] "UNH Researchers Find Warmer Oceans Could Increase Invasive 'Sea Squirts,'" UNH Today, February 6, 2018, https://www.unh.edu/unhtoday/news/release/2018/02/06/unh-researchers-find-warmer-oceans-could-increase-invasive-sea-squirts.

- Although closures due to biotoxins are typically rare, warming waters may lead to an increased occurrence of biotoxin closures. As of August, two biotoxin closures have occurred in the 2023 calendar year.[13]

Infrastructure (Rating: 2 – Minimal)

Damage to infrastructure due to increased temperatures is unlikely to be severe and most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 4 – Significant)

If temperatures are consistently above the temperature threshold for mussels, the mussel aquaculture industry could experience severe disruption to livelihoods resulting in significant loss of income or employment that may be long-lasting or even permanent. Rating considerations included:

- Mussels are PEI's largest aquaculture export, worth approximately $30 million in 2021, and the industry supports the equivalent of hundreds of full-time jobs.[14, 15, 16] If warmer future conditions result in less productive mussel growth, the mussel aquaculture industry on PEI may decline and could support fewer employment opportunities.
- Mussel farming is an important part of the local culture and heritage on PEI. If warmer temperatures resulted in the decline or disappearance of this industry, it could have significant impacts on the community's identity and way of life.
- If impacts on the mussel aquaculture industry are severe, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

2. Heat Wave (Marine)

Scenario: More frequent occurrence of sea surface temperatures above 27°C
Impact to Species: Lethal limit

Marine heat waves on PEI currently represent a **Medium** risk to PEI's mussel aquaculture industry. This risk increases to **High** by mid-century (Table 12).

[13] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[14] Department of Fisheries and Communities. "Economic Contributions of the Seafood Sector in Prince Edward Island," 2021. https://www.princeedwardisland.ca/sites/default/files/publications/pei_final_seafood_sector_economic_contribution_report2.pdf.
[15] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[16] Gulf Region Department of Fisheries and Oceans. "An Economic Analysis of the Mussel Industry in Prince Edward Island," June 2006. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/328179-e.pdf.

Table 12. Mussels risk summary for marine heat wave.

Marine Heat Wave: Mussels							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	5	3	2	3	2.7	**Medium (10.7)**	**High (13.3)**

Likelihood

Appendix B Heat Wave (Marine) provides additional details on likelihood rating assumptions. The mussel ratings are relative to the critical sea surface temperature threshold of 27°C.

Current: (Rating: 4 – Likely)

Summer marine heat waves at coastal sites have reached 27-28°C.

Future: (Rating: 5 – Almost Certain)

Under a high emissions scenario, a summer marine heat wave in coastal waters could reach 31-32°C by 2050.

Consequences

More frequent marine heat waves pose moderate consequences to PEI's mussel aquaculture industry with impacts to production and livelihoods. Marine heat waves can cause mussel mortality events, reducing mussel production and affecting livelihoods of those who depend on the mussel aquaculture industry.

Production/Output (Rating: 3 – Moderate)

More frequent marine heat waves could result in a noticeable reduction in productivity and outputs. Rating considerations included:

- Sea surface temperatures of 27°C–28°C can be dangerous and potentially lethal for all life stages. Notably, mussels are often grown in shallow water that can respond quickly to changes in sea surface temperature.[17]
- Heat events in combination with handling and transport to processing centres can cause added stress to mussels and may affect product quality. Due to the combination of these stresses, even temperatures below 27°C may result in adverse impacts.[18]
- Larger mussels are less able to withstand short hot periods than smaller specimens, which suggests marine heat waves could affect mussel meat yields.[19]
- Marine heat events can contribute to harmful algal blooms, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvesting areas if conditions become dangerous from a human health perspective. These events are monitored through the Canadian Shellfish Sanitation Program (CSSP).[20] If necessitated by the CSSP, shellfish harvesting areas are closed for a minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses.

[17] "Mytilus edulis, blue mussel," McGill University, n.d., http://www.geog.mcgill.ca/climatechange/ReportsMap/musselRpt.pdf.
[18] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[19] "Mytilus edulis, blue mussel," McGill University, n.d., http://www.geog.mcgill.ca/climatechange/ReportsMap/musselRpt.pdf.
[20] Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546

  - Although closures due to biotoxins are typically rare, marine heat waves may lead to an increased occurrence of biotoxin closures. As of August, two biotoxin closures have occurred in the 2023 calendar year.[21]

Infrastructure (Rating: 2 – Minimal)

Damage to infrastructure due to increased sea surface temperatures is unlikely to be severe and most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher sea surface temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 3 – Moderate)

Disruption to livelihoods from an increase in frequency in marine heat wave events that affect mussel growth or survival could cause moderate reductions in income for those that depend on mussels on PEI for their livelihoods. Rating considerations included:

- Mussels are PEI's largest aquaculture export, worth approximately $30 million in 2021, and the industry supports the equivalent of hundreds of full-time jobs.[22, 23, 24]
- Marine heat waves are short-term events, and while a single marine heat wave event of moderate intensity may not be an intense enough event to have significant impact on livelihoods of those who depend on the mussel aquaculture industry, increased frequency of marine heat waves (i.e., one or more marine heat waves each year) could result in noticeable disruption to those who depend on the mussel aquaculture industry for their livelihood.
- If increased frequency of marine heat wave causes a decline in mussel productivity, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

3. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI currently represent a **Medium** risk to PEI's mussel aquaculture industry. This risk increases but remains **Medium** into mid-century (Table 13).

[21] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[22] Department of Fisheries and Communities. "Economic Contributions of the Seafood Sector in Prince Edward Island."
[23] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[24] Gulf Region Department of Fisheries and Oceans. "An Economic Analysis of the Mussel Industry in Prince Edward Island."

Table 13. Mussels risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Mussels							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	3	2	2	2.3	**Medium (7.0)**	**Medium (9.3)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)

This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)

Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

Consequences

Heavy precipitation and flooding events pose minimal to moderate consequences to PEI's mussel aquaculture industry with most impacts occurring to production and output. This hazard could result in a noticeable reduction in yield. Heavy precipitation events can cause excess nutrient-rich or contaminated runoff and harmful algal blooms which may necessitate multi-day or -week closures for human health safety. Effects would likely be short-term and would not have significant impacts to the livelihoods of those who depend on the mussel aquaculture industry.

Production/Output (Rating: 3 – Moderate)

These events could lead to a noticeable reduction in productivity and outputs that lasts days to weeks, especially if runoff from these events contributes to a change in water classification resulting in shellfish harvesting closures. Rating considerations included:

- Nutrient-rich or contaminated runoff (among other factors) can contribute to harmful algal blooms or contaminate water in shellfish harvesting areas, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvesting areas if conditions become dangerous from a human health perspective. If necessitated by the CSSP, shellfish harvesting areas are closed for a minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses.[25, 26]
- Runoff may result in more favourable growing conditions for some unwanted species that could reduce the ability of mussels to grow optimally (i.e., sea lettuce).[27]
- Mussels prefer slightly lower than ocean-level salinity (25-30 parts per thousand (ppt) but can tolerate a wide range of salinity (0-40 ppt, for short periods). Mussels have the ability to close their shells to avoid very low salinity waters that may occur after heavy

[25] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment," July 27, 2021, https://www.princeedwardisland.ca/sites/default/files/publications/pei_ccra_2021.pdf.
[26] Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546.
[27] Jillian Trainor, "Sea Lettuce Growing Concern for Island Shellfish Fishermen," peicanada.com, July 19, 2017, https://www.peicanada.com/news/sea-lettuce-growing-concern-for-island-shellfish-fishermen/article_61bbe052-6be2-11e7-8b6b-b777e7c2761f.html.

precipitation events so would likely avoid serious impacts from reduced salinity after events.[28]

- Intense precipitation events may result in the inability for aquaculture workers to conduct operations, although since this scenario is fairly short in duration (24 hours), productivity is unlikely to be significantly affected. If back-to-back heavy precipitation events occur, shellfish harvesting areas may remain closed longer, yielding more significant consequences.

Infrastructure (Rating: 2 – Minimal)

Severe precipitation events could flood boat ramps and potentially damage equipment and equipment warehouses. However, most equipment is likely to be easily replaceable or recoverable.

Livelihoods (Rating: 2 – Minimal)

While the mussel aquaculture industry is relatively large on PEI, the short-term nature of heavy precipitation events and their potential effects is unlikely to yield significant or long-term consequences to livelihoods.

4. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Heavy precipitation and flooding events on PEI currently represent a **High** risk to PEI's mussel aquaculture industry. This risk remains **High** by mid-century (Table 14). Infrastructure and livelihoods could be most significantly affected by this scenario.

Table 14. Mussels risk summary for post-tropical storm

Post-Tropical Storm: Mussels							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	3	4	4	3.7	**High (14.7)**	**High (14.7)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

Post-tropical storms pose overall significant consequences to PEI's mussel aquaculture industry, with potentially far-reaching impacts on production, infrastructure, and livelihoods. This hazard can cause crop losses, considerable damage to critical harvesting equipment, and

[28] Shackell et al., Climate Change Impacts, Vulnerabilities and Opportunities Analysis of the Marine Atlantic Basin.

potential reductions in employment opportunities. The ramifications of an intense post-tropical storm could linger for months and, should mussel spat be lost, the effects could span into subsequent years.

Production/Output (Rating: 3 – Moderate)

The quantity and quality of mussels harvested could experience a noticeable reduction in productivity and outputs that lasts weeks to months to even years. Rating considerations included:

- Post-tropical storms can directly cause damage to mussel aquaculture lines, buoys, and anchors through intense wave action (e.g., snapped lines and tangled gear).
- Coastal flooding can restrict access to harbours and aquaculture farm sites, affecting operations.
- Nutrient-rich or contaminated runoff (among other factors) from post-tropical storms can contribute to harmful algal blooms or contaminate water in shellfish harvesting areas, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvesting areas if conditions become dangerous from a human health perspective. If necessitated by the CSSP, shellfish harvesting areas are closed for a minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses.
- It is unlikely that a post-tropical storm would disrupt harvesting for an entire season, although this is possible under the most severe storm events or if mussel spat is severely impacted, which can affect future seasons' productivity.
    - Post-Tropical Storm Fiona led to substantial mussel seed losses for several farmers. The ramifications of this loss will become most evident two years after the storm, coinciding with when the lost seed would have matured and ready for markets. While this affected a number of farmers, seed loss was not universal, with only certain leases being impacted.[29]

Infrastructure (Rating: 4 – Significant)

Post-tropical storms can cause significant and/or widespread damage or failure to infrastructure. Repairs or replacements may be costly and could take months to years from severe events. Rating considerations included:

- Post-Tropical Storm Fiona resulted in destroyed or lost aquaculture equipment (e.g., floats, long lines, socks).
- Post-Tropical Storm Fiona demolished breakwaters protecting harbours and ripped floating wharves from mooring systems.
    - Harbours significantly affected by Fiona will take years to return to full operational capacity.[30]
- Post-Tropical Storm Fiona damaged vessels moored in harbours as well tractor trailers.

[29] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

[30] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

- Post-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to aquaculture sites.

Post-Tropical Storm Fiona and Prince Edward Aqua Farms

Prince Edward Aqua Farms Inc., a leading mussel aquaculture operation in PEI, faced significant challenges from Post-Tropical Storm Fiona. Although Prince Edward Aqua Farms Inc. was able to sink all mussel lines before Fiona hit, lines were stripped of mussel socks and tangled to the point that much of the equipment could not be reused. In Malpeque Bay the deep turbulent waters and tide spun spat collector ties one way and then the other way when the tide changed, knotting and tangling the lines. In other operating areas, the intensity of the storm's waves dislodged lines from their anchors, which then became tangled.

All seed was lost in Malpeque Bay from the event and as a result, Prince Edward Aqua Farms Inc. had to trim their sales in 2023 and likely in 2024 to account for lost product from the storm. The severity of impacts to mussel leases across PEI was dependent on location and storm conditions (landfall location, wind direction and speed, etc.). Each post-tropical storm is different, making it difficult for mussel farmers to plan and strategize for these events.

Figure 4. Buoys for mussel longlines at Prince Edward Aquafarms.

Livelihoods (Rating: 4 – Significant)

Significant loss of export markets and income as well as loss of employment opportunities tied to mussel maintenance and harvesting could significantly affect livelihoods. Impacts could last months to years, especially if critical infrastructure (e.g., vessels, buoys) or mussel spat lines or socks are damaged. Rating considerations included:

- Mussels are PEI's largest aquaculture export, worth approximately $30 million in 2021, and the industry supports the equivalent of hundreds of full-time jobs.[31, 32, 33]
- Post-Tropical Storm Fiona is preliminarily estimated to have caused $75 million in damages to shellfish farms (including mussels *and* oysters), which includes lost gear, lost time, as well as the loss of mussel and oyster market-ready products and spat for future crops.[34] Further, there is no reasonably affordable commercial aquaculture insurance available nor is there insurance programs (i.e., Business Risk Management) that covers loss of marine crops so workers directly tied to mussel maintenance and harvesting may have no immediate recourse if a storm causes damages that preclude aquaculture operations.

[31] Department of Fisheries and Communities. "Economic Contributions of the Seafood Sector in Prince Edward Island."
[32] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[33] Gulf Region Department of Fisheries and Oceans. "An Economic Analysis of the Mussel Industry in Prince Edward Island."
[34] Dean-Simmons, Barb. "Mussels Are Getting to Market but Storm Losses for P.E.I. Growers at Least $75 Million." Saltwire. Accessed June 19, 2023. https://www.saltwire.com/atlantic-canada/business/mussels-are-getting-to-market-but-storm-losses-for-pei-growers-at-least-75-million-100799622/.

5. Acidification

Scenario: Acidification approaches 7.6 pH
Impact to Species: Reduced growth for larvae and reduced hatching

Acidification on PEI currently represents a **Low** risk to PEI's mussel aquaculture industry. This risk increases slightly but remains **Low** by mid-century (Table 15).

Table 15. Mussels risk summary for acidification

Acidification: Mussels							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	3	3	1	2	2	**Low (4.0)**	**Low (6.0)**

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions. The mussel ratings are relative to the critical pH threshold of 7.6 units.

Current: (Rating: 2 – Unlikely)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units, and decreasing at a rate of 0.04 units per decade. However, limestone around PEI may buffer acidity effects in PEI's nearshore coastal areas.

Future: (Rating: 3 – Possible)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050. However, limestone around PEI may buffer acidity effects in PEI's nearshore coastal areas.

Consequences

Acidification poses minimal consequences to PEI's mussel aquaculture industry. This hazard can affect production/output if more acidic conditions reduce the growth and hatch rate of mussel larvae; however, under the scenario of 7.6 pH impacts are not expected for more mature life stages.

Production/Output (Rating: 3 – Moderate)

The mussel aquaculture industry is heavily dependent on wild mussel seed and spat for grow-out aquaculture operations. Acidification could result in a noticeable reduction in productivity and outputs primarily due to the potential for mussel larvae to experience reduced growth and hatching, limiting the supply of wild mussel seed and spat for grow-out. However, limestone around PEI may buffer acidity effects in PEI's nearshore coastal areas. Rating considerations included:

- Mussel larvae may experience reduced size, shell thickness/growth, and hatching rate, at lower pHs relative to higher pHs.[35]
- Mature mussels are unlikely to experience reduced growth until pH levels of 7.1.[36]

[35] F. Gazeau et al., "Effect of Ocean Acidification on the Early Life Stages of the Blue Mussel *Mytilus Edulis*," *Biogeosciences* 7, no. 7 (July 1, 2010): 2051–60, https://doi.org/10.5194/bg-7-2051-2010.
[36] John Arthur Berge et al., "Effects of Increased Sea Water Concentrations of CO2 on Growth of the Bivalve Mytilus Edulis L," *Chemosphere* 62, no. 4 (January 2006): 681–87, https://doi.org/10.1016/j.chemosphere.2005.04.111.

- More intense acidification may weaken mussels' ability to attach to hard surfaces, which could increase risk of their dislodgment from aquaculture gear.
- Impacts to food quality for mussels may be possible if ocean chemistry changes, although this would likely occur under more acidic conditions than this scenario.[37]

Infrastructure (Rating: 1 – Insignificant)

Damage to infrastructure due to acidification is unlikely.

Livelihoods (Rating: 2 – Minimal)

Changes to mussel larvae growth and hatching success may have consequences to the livelihoods of mussel farmers in subsequent seasons. However, this scenario is unlikely to have more than minimal consequences since mortality events are not anticipated and more mature specimens are likely to be unaffected.

Oysters (eastern oyster, *Crassostrea virginica*)

Figure 5. Oyster aquaculture. Source: Government of PEI 2016.

The oyster (*Crassostrea virginica*) is a medium-sized marine bivalve mollusc found in waters along eastern North America, from the Gulf of St. Lawrence to the Gulf of Mexico. The oyster industry on PEI is composed of both cultured oysters through aquaculture practices as well as a commercial wild oyster fishery. The oyster industry provides a significant source of income and employment opportunities, supporting the equivalent of hundreds of full-time jobs. Aquaculture processes for oysters include both bottom and off-bottom culture. Oysters raised in bottom culture are grown on the sea floor and collected using rakes at low tide. Oysters raised in off-bottom culture are grown in bags or cages. Harvesting can occur year-round. PEI's commercial wild oyster fishery is a licensed fishery with a spring (May 1 to July 15) and fall (September 15 to November 30) season.

Live traditional and cocktail oysters are both sold on PEI. In 2021, the PEI oyster industry (including both aquaculture and commercially fished oysters) recorded a harvest weight of 13.4 million pounds, representing a market value of over $21 million. This significant yield underscores the sector's importance to the local economy. The oyster aquaculture industry is supported by 788 oyster and clam aquaculture leases for bottom culture, spanning a total acreage of 5,318. The industry is also supported by 357 oyster aquaculture leases for off-

[37] Leigh Michael Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia" (Center for Marine Applied Research (CMAR), 2021).

bottom culture, spanning a total acreage of 2,706.[38] The widespread adoption of oyster farming and its substantial economic impact attest to the success of the oyster industry on PEI.

Figure 6 summarizes the predominant climate risks to the oyster aquaculture industry. Post-tropical storms have the highest risk rating and can lead to direct crop losses, considerable damage to critical harvesting equipment, and potential reductions in employment opportunities. The ramifications of an intense post-tropical storm could linger for months or years.

Wild Oysters

Although this assessment is focused on risks and opportunities to the oyster aquaculture industry, many of the same findings also apply to commercially harvested wild oysters, with a few notable differences. These differences stem from the use of different equipment and harvesting methods. Wild oysters are harvested from oyster beds on the sea floor using oyster tongs. Reflections on wild oysters are noted in textboxes throughout this section.

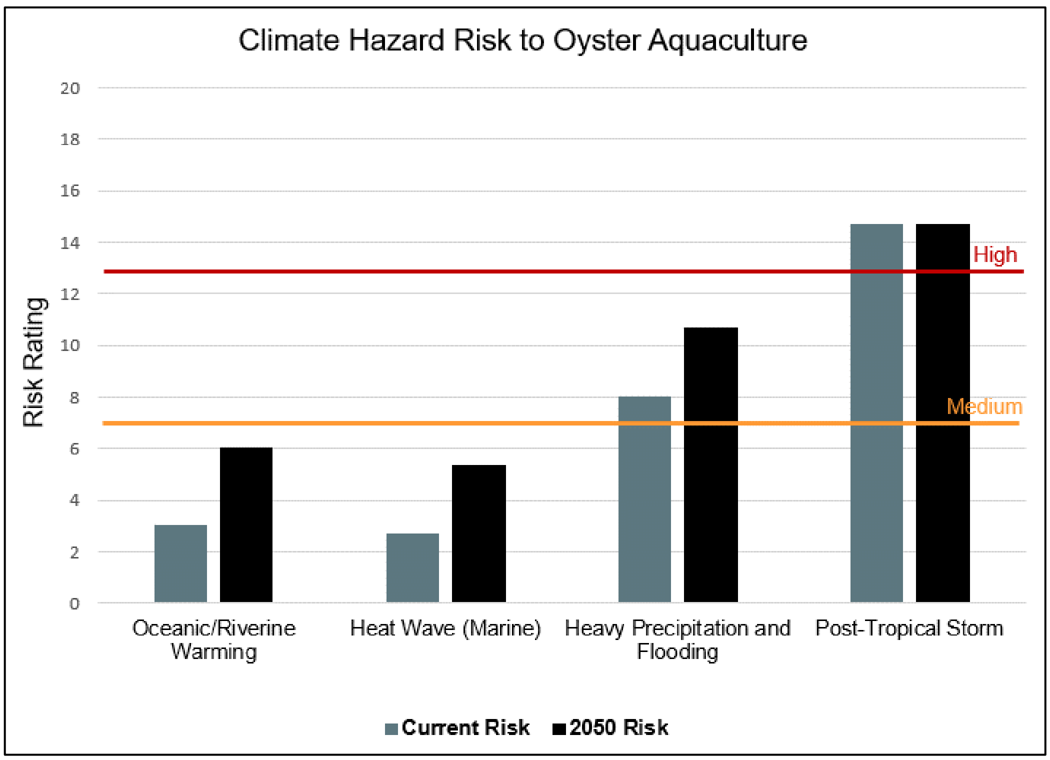

Figure 6. Summary of current and future climate hazard risk to oyster aquaculture.

1. Oceanic/Riverine Warming

Scenario: Average sea surface temperature rises above 32°C
Impact to Species: Reduction in growth rates and physiological complications

Oceanic/riverine warming on PEI currently represents a **Low** risk to PEI's oyster aquaculture industry. This risk increases but remains **Low** into mid-century (Table 16).

Warming sea temperatures may also lead to some potential **opportunities** for oyster cultivation on PEI. As sea surface temperatures rise, the oyster season will

[38] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

likely extend, commencing earlier in the spring and concluding later in the fall. These warmer conditions will accelerate oyster growth by driving an increase in nutrient availability and metabolic rates. As a result, oyster growers may be able to bring harvests to market more rapidly.

Table 16. Oysters risk summary for oceanic/riverine warming

Oceanic/Riverine Warming: Oysters							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
1	2	3	2	4	3	**Low (3.0)**	**Low (6.0)**

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The oyster ratings are relative to the critical sea surface temperature threshold of 32°C.

Current: (Rating: 1 – Rare)

Recorded July-August summer at coastal sites around PEI range from 11-27°C and average 21°C.

Future: (Rating: 2 – Unlikely)

Under a high emissions scenario, July-August temperatures at coastal sites could range from 15-31°C and average 25°C.

Consequences

Oceanic/riverine warming poses overall moderate consequences to PEI's oyster aquaculture industry with impacts on production, infrastructure, and livelihoods. This hazard can lead to lower productivity for oyster growers, affecting their income and livelihoods. The ramifications of increased water temperatures on oysters could be irreversible without sufficient adaptation. While oysters are not expected to experience physiological impacts from temperatures below 32°C, these temperatures may burden the oyster aquaculture industry may still experience challenges at temperatures less than 32°C due to increased incidence of disease and invasive species, toxic algae blooms, and greater biofouling on oyster cages.

Production/Output (Rating: 3 – Moderate)

Increases in temperature could result in a noticeable reduction in productivity and outputs as oysters may have less time within optimal growing temperatures during the summer, especially during particularly warm summers. Increases in pests and diseases, such as *Vibrio* bacterial pathogens and may also occur. Rating considerations included:

- Eastern oysters can survive temperatures up to 36°C for adults, however, temperatures higher than 32°C negatively impact their growth and physiology.

Wild Oysters

Wild oysters may be more susceptible to pests and predators, including invasive species, as a result of oceanic warming (e.g., boring sponge, green crabs) since these oysters are generally found in the littoral and sublittoral zones until harvested.

- Earlier melting of sea ice may result in earlier spring blooms of phytoplankton, potentially causing a mismatch for zooplankton, which feed upon phytoplankton. This relationship may affect cultured oysters, which rely on plankton as a food source.[39]
- Rising temperatures may increase cultured oyster growth rates, which can result in reduced quality (i.e., a greater proportion of standard versus choice oysters).[40]
- Oysters that are already stressed from high temperatures may be more susceptible to pests and diseases. Warmer temperatures may also lead to more favourable conditions for pests and diseases (e.g., the clubbed tunicate, which could experience longer spawning seasons) and increase the range of other invasive species not currently present in PEI that may affect oyster mortality.[41,42]
    - Increased sea temperatures may also increase the likelihood of *Vibrio* bacterial pathogens present in oysters, which can result in rare but dangerous infection for humans. *Vibrio* pathogens prefer warmer water temperatures.[43]
    - Other diseases may lead to mortality in oyster populations.[44,45]

Infrastructure (Rating: 2 – Minimal)

Damage to infrastructure due to increased temperatures is unlikely to be severe and most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces, particularly for off-bottom oyster aquaculture equipment and gear. Warmer ocean temperatures may heighten growth rates for some organisms, potentially leading to greater biofouling. This could increase the weight and drag on equipment, and make equipment more difficult to clean and maintain. Similar to mussel socks, oyster aquaculture gear tends to sink as they become heavier with biofouling, leading to strained gear, lines, winches, and suboptimal growing conditions.[46]

Wild Oysters

Wild oyster harvesting requires minimal infrastructure. Biofouling on equipment is not a concern as equipment is not left in the water for extended periods of time.

Livelihoods (Rating: 4 – Significant)

If consistent temperatures above the temperature threshold for oysters occur the oyster aquaculture industry could experience severe disruption to livelihoods resulting in significant loss of income or employment that may be long-lasting or even permanent. Rating considerations included:

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[39] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report" (University of Prince Edward Island, 2017), https://projects.upei.ca/climate/files/2018/10/PEI-Climate-Change-Adaptation-Recommendations-Report_medres.pdf.

[40] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results.* August 2023.

[41] Prince Edward Island, "Aquatic Invasive Species," February 8, 2016, https://www.princeedwardisland.ca/en/information/fisheries-and-communities/aquatic-invasive-species.

[42] "UNH Researchers Find Warmer Oceans Could Increase Invasive 'Sea Squirts,'" UNH Today, February 6, 2018, https://www.unh.edu/unhtoday/news/release/2018/02/06/unh-researchers-find-warmer-oceans-could-increase-invasive-sea-squirts.

[43] Archer et al. "Climate warming and increasing Vibrio vulnificus infections in North America." Scientific Reports. March, 2023. https://www.nature.com/articles/s41598-023-28247-2

[44] USDA, "Potential Introduction Pathways of Ostreid Herpesvirus-1 (OsHV-1) in the United States," 2020, https://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/downloads/potential-intro-pathways-oshv-1.pdf

[45] Renault et al. "Ostreid Herpesvirus 1 Infection among Pacific Oyster (*Crassostrea gigas*) Spat: Relevance of Water Temperature to Virus Replication and Circulation Prior to the Onset of Mortality." Applied Environmental Microbiology. September, 2014. https://doi.org/10.1128%2FAEM.00484-14

[46] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

- Oysters are PEI's second largest bivalve shellfish export, with Island exports worth approximately $21 million in 2021 and the industry supporting the equivalent of hundreds of full-time jobs.[47, 48]
- Oyster aquaculture is an important part of the local culture and heritage on PEI. If warmer temperatures lead to the decline or disappearance of the oyster aquaculture industry, it could significantly impact the community's identity and way of life.
- If increased heat impacts on the oyster industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures above 36°C
Impact to Species: Lethal limit

Marine heat waves on PEI currently represent a **Low** risk to PEI's oyster aquaculture industry. This risk increases but remains **Low** into mid-century (Table 17).

Table 17. Oysters risk summary for marine heat wave

Marine Heat Wave: Oyster							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
1	2	3	2	3	2.7	**Low (2.7)**	**Low (5.3)**

Likelihood

Appendix B Heat Wave (Marine) provides additional details on likelihood rating assumptions. The oyster ratings are relative to the critical sea surface temperature threshold of 36°C.

Current: (Rating: 1 – Rare)
Summer marine heat waves at coastal sites have reached 27-28°C.

Future: (Rating: 2 – Unlikely)
Under a high emissions scenario, a summer marine heat wave in coastal waters could reach 31-32°C by 2050.

Consequences

More frequent marine heat waves pose minimal to moderate consequences to PEI's oyster aquaculture industry with impacts to production and livelihoods. This hazard could result in a noticeable reduction in productivity and outputs as marine heat waves can lead to oyster mortality events, reducing oyster production and affecting livelihoods of those who depend on oyster aquaculture.

Production/Output (Rating: 3 – Moderate)
Increase in marine heat wave frequency could result in a noticeable reduction in productivity and outputs as marine heat waves can lead to oyster mortality events,

Wild Oysters

Since wild oysters remain submerged until harvested, they may be more susceptible to predators and aquatic invasive species.

[47] Department of Fisheries and Communities. "Economic Contributions of the Seafood Sector in Prince Edward Island."
[48] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

reducing oyster production. Impacts can also occur during air drying and due to algal blooms. Rating considerations included:

- Sea surface temperatures of 36°C can be dangerous and potentially lethal for oysters at all life stages. Notably, oysters are often grown in shallow water that can respond quickly to changes in temperature.[49]
- Farmers with off-bottom cages that use the practice of 24-hr flipping to air dry fouling could expose oysters to high atmospheric temperatures that typically accompany marine heat wave events. PEI farmers have experienced high mortalities from this scenario in the past.
- Oysters are sometimes transported on boats and to processing facilities in open boxes exposed to the sun. This can further stress the oysters and potentially lead to mortality.[50]
- Marine heat events can contribute to harmful algal blooms, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvesting areas if conditions become dangerous from a human health perspective. These events are monitored through the CSSP.[51] If necessitated by the CSSP, shellfish harvesting areas are closed for a minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses.

Infrastructure (Rating: 2 – Minimal)

Damage to infrastructure due to increased sea surface temperatures is unlikely to be severe and most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher sea surface temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces, particularly for off-bottom oyster aquaculture. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain. Similar to mussel socks, oyster aquaculture gear tend to sink as they become heavier with biofouling, leading to strained gear, lines, winches, and suboptimal growing conditions.[52]

Wild Oysters

Wild oyster harvesting requires minimal infrastructure. Biofouling on equipment is not a concern as equipment is not left in the water for extended periods of time.

Livelihoods (Rating: 3 – Moderate)

Disruption to livelihoods from an increase in frequency in marine heat wave events that affect oyster growth or survival could cause moderate reductions in income for those that depend on the oyster aquaculture industry on PEI for their livelihoods. Rating considerations included:

[49] Cassostrea," McGill University, n.d., http://www.geog.mcgill.ca/climatechange/ReportsMap/Crassostrea%204D.pdf.
[50] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[51] Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546
[52] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

- Oysters are PEI's second largest bivalve shellfish export, with Island exports worth approximately $21 million in 2021 and the industry supporting the equivalent of hundreds of full-time jobs.[53, 54]
- Marine heat waves are short-term events, and while a single marine heat wave event of moderate intensity may not be an intense enough event to have significant impact on livelihoods of those who depend on oyster aquaculture, increased frequency of marine heat waves (i.e., one or more marine heat waves each year) could result in noticeable disruption to those who depend on oyster aquaculture for their livelihood.
- If increased heat impacts on the oyster aquaculture industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

3. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI currently represent a **Medium** risk to PEI's oyster aquaculture industry. This risk increases but remains **Medium** into mid-century (Table 18).

Table 18. Oysters risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Oysters							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	3	2	3	2.7	**Medium (8.0)**	**Medium (10.7)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)

This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)

Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

Consequences

Heavy precipitation and flooding events pose moderate consequences to PEI's oyster aquaculture industry. These events may reduce salinity that leads to oyster mortality events and disrupted spat production, thereby affecting livelihoods. This hazard could result in a noticeable reduction in yield as heavy precipitation events can lead to excess nutrient-rich and contaminated runoff and harmful algal blooms which may necessitate multi-day or -week closures. The ramifications of an intense precipitation and flooding event could last for weeks and, should oyster spat incur damage or destruction, a lesser degree of consequences could span into subsequent years.

[53] Department of Fisheries and Communities. "Economic Contributions of the Seafood Sector in Prince Edward Island."
[54] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Production/Output (Rating: 3 – Moderate)

Heavy precipitation events can cause noticeable reduction in productivity and outputs that lasts weeks to months, or even until subsequent seasons if spawning or spat is disrupted. Rating considerations included:

Wild Oysters

Tidal forces on the south shore of PEI are typically more pronounced than on the north side with fluctuations reaching approximately 9 feet. This may affect the spring and fall fishing seasons for wild oysters and the suitability of fishing areas.

- Changes in water quality and salinity may occur, stressing oyster farms and natural populations; low salinity can lead to mortality events as well as inhibit feeding, growth, and spawning.[55]
    - Sudden drops in salinity following precipitation events may also leave oysters more vulnerable to pathogens such as *Vibrio* which can lead to mortality events.[56]
- Nutrient-rich or contaminated runoff (among other factors) can contribute to harmful algal blooms or contaminate water in shellfish harvesting areas, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvesting areas if conditions become dangerous from a human health perspective. These events are monitored through the CSSP.[57] If necessitated by the CSSP, shellfish harvesting areas are closed for a minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses.[58, 59]
- Runoff may result in more favourable growing conditions for some unwanted species that could reduce the ability of oysters to grow optimally (i.e., sea lettuce).[60]
- Intense precipitation events may result in the inability for aquaculture workers to conduct operations, although since this scenario is fairly short in duration (24 hours), productivity is unlikely to be significantly affected.

Infrastructure (Rating: 2 – Minimal)

Severe precipitation events can lead to minimal disruption to infrastructure, such as the flooding of boat ramps, and damaged or destroyed culture equipment. However, most equipment is likely to be easily replaceable or recoverable.

Livelihoods (Rating: 3 – Moderate)

The oyster aquaculture industry is relatively large on PEI, and there is potential for heavy precipitation events to result in changes to production and output that yield moderate disruption to livelihoods, some of which may extend beyond a single season. Rating considerations included:

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[55] Guenette, S. "Chapter 4. A Review of the Physiological Susceptibility of Commercial Species of Fish and Crustaceans of the Northwest Atlantic to Changes in Water Temperature, Dissolved Oxygen, PH and Salinity," in *Climate Change Impacts, Vulnerabilities, and Analysis of the Marine Atlantic Basin*, 2013, 83–168.

[56] Li X, Yang B, Shi C, Wang H, Yu R, Li Q, Liu S. Synergistic Interaction of Low Salinity Stress With Vibrio Infection Causes Mass Mortalities in the Oyster by Inducing Host Microflora Imbalance and Immune Dysregulation. Front Immunol. 2022 May 19 doi: 10.3389/fimmu.2022.859975

[57] Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546

[58] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment," July 27, 2021, https://www.princeedwardisland.ca/sites/default/files/publications/pei_ccra_2021.pdf.

[59] Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546

[60] Jillian Trainor, "Sea Lettuce Growing Concern for Island Shellfish Fishermen," peicanada.com, July 19, 2017, https://www.peicanada.com/news/sea-lettuce-growing-concern-for-island-shellfish-fishermen/article_61bbe052-6be2-11e7-8b6b-b777e7c2761f.html.

- Oysters are PEI's second largest bivalve shellfish export, with Island exports worth approximately $21 million in 2021 and the industry supporting the equivalent of hundreds of full-time jobs.[61, 62]
- Heavy precipitation events could contribute to short-term closure events that reduce productivity of the oyster aquaculture industry in a single season and longer-term mortality events that have the potential to significantly reduce yield in a single season and even affect subsequent seasons through spat and/or spawning disturbance. These consequences have the potential to effect income and employment opportunities for those that rely on the oyster aquaculture industry.

4. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **High** risk to PEI's oyster aquaculture industry for both the current period and mid-century (Table 19). Infrastructure and livelihoods could be most significantly affected by this scenario.

Table 19. Oysters risk summary for post-tropical storm

Post-Tropical Storm: Oysters							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	3	4	4	3.7	**High (14.7)**	**High (14.7)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

Post-tropical storms pose significant consequences to PEI's oyster aquaculture industry, with potentially far-reaching impacts on production, infrastructure, and livelihoods. This hazard can lead to direct oyster crop losses, considerable damage to critical harvesting equipment, and potential reductions in employment opportunities. The ramifications of an intense post-tropical storm could linger for months or years and, should oyster spat incur damage or destruction, the effects could span into even subsequent years.

[61] Department of Fisheries and Communities. "Economic Contributions of the Seafood Sector in Prince Edward Island."
[62] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Production/Output (Rating: 3 – Significant)

The quantity and quality of aquaculture oysters harvested could experience a noticeable reduction in productivity and outputs that lasts weeks to months and even years. Rating considerations included:

- Post-tropical storms can directly cause damage to aquaculture oysters through intense wave action.
  - Sinking oyster cages ahead of storms can act as a preventive measure, positioning the oysters deeper in the water column where wave action is less intense. However, sunk cages still face risks, especially in areas with strong underlying currents or where sediment displacement can occur. Floating cages are more exposed and thus generally incur more damage during severe storm events.[63]
- Flooding, storm surge, and high winds as a result of post-tropical storms can cause erosion and runoff, which may result in heavy silt formation in rivers/estuaries, smothering oysters cages and bags on bottom leases in rivers/estuaries.
- Post-tropical storms can temporarily restrict access to harbours and aquaculture farm sites, affecting ability to harvest.
- Nutrient-rich and contaminated runoff (among other factors) associated with post-tropical storms can contribute to harmful algal blooms or contaminate water in shellfish harvesting areas, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvesting areas if conditions become dangerous from a human health perspective. If necessitated by the CSSP, shellfish harvesting areas are closed for a minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses.[64, 65]
- It is unlikely that a post-tropical storm would disrupt harvesting for an entire season, although this is possible under the most severe storm events (i.e., severe impacts to market-ready and near market-ready crops) or if oyster spat is severely impacted, which can affect future seasons productivity.
- The severity of storm impacts on oyster aquaculture leases is likely to vary considerably across PEI, influenced by factors like location of storm landfall, wave action, water depth, gear type, farming method, and seasonal timing. While certain preventive measures might be in place, events like Post-Tropical Storm Fiona demonstrate that

Wild Oysters

Post-tropical storms will move silt and change the dynamics of the sea floor, which can have positive or negative impacts on wild oyster beds and production. For example, Post-Tropical Storm Fiona cleared the silt off some beds, buried other beds in excess silt, and created new oyster habitat in areas like Stanley Bridge where a small channel was morphed into a wide flay oyster bed.

[63] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[64] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment," July 27, 2021, https://www.princeedwardisland.ca/sites/default/files/publications/pei_ccra_2021.pdf.
[65] Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546.

some areas, especially those near shifting sand dunes or in shallower waters, can experience more profound consequences than others.[66]

Infrastructure (Rating: 4 – Significant)

Significant, and/or widespread damage to infrastructure can occur from post-tropical storms. Repairs or replacements may be costly and could take months to years from severe events. Rating considerations included:

Wild Oysters

Wild oyster fishing requires much less equipment that oyster aquaculture. Infrastructure impacts will be less severe for the wild oyster industry.

- Post-Tropical Storm Fiona resulted in destroyed or lost aquaculture equipment (e.g., floats, cages, rope).
- Post-Tropical Storm Fiona demolished breakwaters protecting harbours and ripped floating wharves from mooring systems.
    - Harbours most affected by Fiona will take years to return to full operational capacity.[67]
- Post-Tropical Storm Fiona damaged vessels moored in harbours as well as tractor trailers.
- Post-tropical storms can temporarily inundate or damage coastal roadways and bridges, restricting access to aquaculture sites.

Post-Tropical Storm Fiona and Raspberry Point Oysters

Raspberry Point Oysters Company, a leading oyster aquaculture operation in PEI, faced significant challenges from Post-Tropical Storm Fiona. The storm led to the destruction and loss of 5,000-6,000 oyster cages essential for cultivation. Cages are typically submerged prior to significant storm events. But due to limited diver capacity and warning time ahead of the storm, not all cages were able to be submerged, leaving many vulnerable to intense wave action and damage. Since Fiona, Raspberry Point Oysters has been experimenting with more resilient cage materials and lines to better withstand future severe storm events. To improve facility resilience, they are elevating low-lying buildings and electrical equipment, ensuring there is sufficient backup power, and installing solar panels.

Figure 7. Oyster cages damaged by Post-Tropical Storm Fiona at Raspberry Point Oysters.

Livelihoods (Rating: 4 – Significant)

Severe disruption to livelihoods could occur with significant loss of income or employment lasting months to years, especially if critical infrastructure (e.g., vessels, buoys, cages/bags) or oyster crops and/or spat are damaged. Rating considerations included:

[66] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[67] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

- Oysters are PEI's second largest bivalve shellfish export, with Island exports worth approximately $21 million in 2021 and the industry supporting the equivalent of hundreds of full-time jobs.[68, 69]
- Post-Tropical Storm Fiona is preliminarily estimated to have caused $75 million in damage to the seafood industry on PEI, with the bulk of damage/loss to the aquaculture and processing sectors.[70] For mussel and oyster shellfish farms, loses included gear, time, mussel and oyster market-ready products, and spat for future crops.[71] Further, there is no reasonably affordable commercial aquaculture insurance available nor is there insurance programs (i.e., Business Risk Management) that covers loss of marine crops so workers directly tied to oyster aquaculture maintenance and harvesting may have no immediate recourse if a storm causes damages that preclude aquaculture operations.

Post-Tropical Storm Fiona and Savage Harbour Wharf

Post-Tropical Storm Fiona caused significant damage to seafood operations and facilities across PEI, including at Savage Harbour Wharf. Offices at the harbour were inundated by a foot of water and erosion stakes were washed away by the storm. Simpson Aquaculture saw 2000 oyster bags end up at the Creek Road bridge in French Village. Over 100 of these bags went above the bridge as it washed out during the storm. One lobster boat was swamped during the storm, and a new tractor purchased by Simpson Aquaculture just two months prior to the storm for $60,000 experienced significant flood damage. The oyster farm at the harbour was also affected, with an estimated 10% of spat collectors lost in Pownal Bay. Simpson Aquaculture did not have any insurance coverage on the oyster farm.

5. Acidification

Scenario: Acidification approaches 7.1 pH
Impact to Species: Decreased physiological function, growth rates, and reproductive consequences

This scenario is **almost certain not to occur** by mid-century (likelihood rating: 1). For details, see Acidification. As a result, ICF did not evaluate the consequences of this scenario and the overall risk to PEI's oyster aquaculture industry is **Negligible**.

Oysters have demonstrated positive responses when exposed to pH levels ranging from 7.5 to 7.9, indicating their ability to tolerate moderate acidification. Specifically, oysters examined at these pH levels have been found to exhibit positive effects on both adult reproductive development and larval survival.[72,73]

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[68] Department of Fisheries and Communities. "Economic Contributions of the Seafood Sector in Prince Edward Island."
[69] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[70] The estimated $75 million in damage/loss from Post-Tropical Storm Fiona does not account for damages to harbours and wharves under federal jurisdiction. Therefore, the overall estimate to the seafood industry on PEI is likely much greater than $75 million.
[71] Dean-Simmons, Barb. "Mussels Are Getting to Market but Storm Losses for P.E.I. Growers at Least $75 Million." Saltwire. Accessed June 19, 2023. https://www.saltwire.com/atlantic-canada/business/mussels-are-getting-to-market-but-storm-losses-for-pei-growers-at-least-75-million-100799622/.
[72] Jeff C Clements et al., "CO2-Induced Low PH in an Eastern Oyster (Crassostrea Virginica) Hatchery Positively Affects Reproductive Development and Larval Survival but Negatively Affects Larval Shape and Size, with No Intergenerational Linkages:," *ICES Journal of Marine Science* 78, no. 1 (February 1, 2021): 349–59, https://doi.org/10.1093/icesjms/fsaa089.
[73] Boulais, M., Chenevert, K.J., Demey, A.T. et al. Oyster reproduction is compromised by acidification experienced seasonally in coastal regions. Sci Rep 7, 13276 (2017). https://doi.org/10.1038/s41598-017-13480-3

Rainbow Trout (*Oncorhynchus mykiss*)

The rainbow trout (*Oncorhynchus mykiss*) is a native trout species of western North America that prefers cool lakes, ponds, and streams. Rainbow trout are not grown to market size on PEI. Rather, they are cultured for grow-out in other provinces. On PEI, rainbow trout are grown in land-based tanks through the early life stages. Most operations are on recirculation systems, which allow for high-density farming in indoor tanks. Culturing can occur year-round. In 2021, the PEI cultured finfish industry, which includes rainbow trout, Atlantic salmon, and Atlantic halibut, had a market value of $4.2 million.[74]

Figure 8. Rainbow trout fingerlings in land-based aquaculture tank. Source: PEI Government 2016.

Figure 9 summarizes climate risks to rainbow trout. Post-tropical storms have the highest risk rating and most severe consequences of any hazard. These events can cause significant damage to critical infrastructure and potential product losses, especially if a power outage occurs.

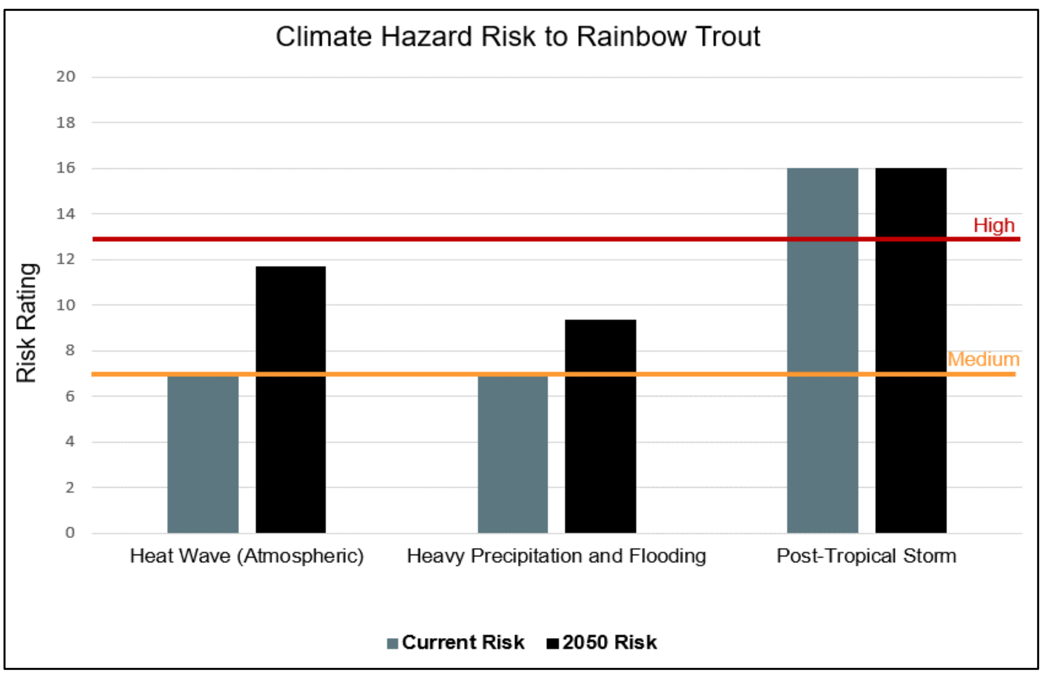

Figure 9. Summary of current and future climate hazard risk to rainbow trout.

[74] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics.

1. Oceanic/Riverine Warming

Atmospheric/oceanic/riverine warming is **not applicable** to land-based, finfish aquaculture. Rainbow trout are raised in land-based facilities with a controlled environment.

2. Heat Wave (Atmospheric)

Scenario: Three consecutive days with temperatures above 29°C
Impact to species: Stress and potentially lethal

Increased frequency of heat waves on PEI is currently a **Medium** risk to PEI's rainbow trout aquaculture industry. This risk increases but remains **Medium** into mid-century (Table 20).

Table 20. Rainbow trout risk summary for atmospheric heat wave

Atmospheric Heat Wave: Rainbow Trout							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	3	3	1	2.3	**Medium (7.0)**	**Medium (11.7)**

Likelihood

Appendix B Heat Wave (Atmospheric) provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Historically, this scenario has occurred 0.05 times per year on average.

Future: (Rating: 5 – Almost Certain)
Future projections indicate this scenario will occur 2.1 times per year on average.

Consequences

Heat waves are a concern for aquaculture facility operations, particularly if stress on the energy system caused a power outage and limited the ability of staff to maintain optimal operating conditions (e.g., water temperature, oxygen levels). A heat wave could also increase cooling demand and costs for the facility. Any disruptions would likely be temporary.

Production/Output (Rating: 3 – Moderate)
Although rainbow trout are raised in a controlled environment, there may be a noticeable reduction in productivity and outputs if the heat wave causes a power outage at the facilities due to stress on the energy system. Lack of power for an extended period of time could lead to widespread stress or mortality, leading to a notable reduction in output. Rating considerations included:

- If power is not restored for an extended period of time or if the facility does not have sufficient backup power sources, facilities may not be able to maintain optimal controlled conditions (e.g., temperature, oxygen), leading to stress and mortality.
- Some facilities have backup power sources on site, so a widespread disruption or loss of production may not be as severe.

- Prolonged warm temperatures cause stress and potential mortality for rainbow trout when temperatures rise above 23.9°C.[75,76]

Infrastructure (Rating: 3 – Moderate)

While a 3-day heat wave is not expected to cause any physical damage to infrastructure or equipment, a heat wave-induced power outage will limit the functionality of equipment and cause disruptions for up to a few days. Rating considerations included:

- If power is not restored for an extended period of time or if the facility does not have sufficient backup power sources, the facility may not be able to function for the duration of the power outage.
- Some facilities have backup power sources and may only experience minimal disruption.
- A heat wave will increase cooling demand and cost at facilities.

Livelihoods (Rating: 1 – Insignificant)

The 3-day heat wave may cause temporary disruptions at facilities, but not a loss of income or employment. Rating considerations included:

- The heat wave would only cause disruptions to operations if a power outage occurred.
- If a power outage did occur for up to or longer than 3 days, it may actually increase staffing needs at facilities to help maintain the tanks and prevent product losses.
- Heat waves may pose health risks, such as heat stress, to workers during a power outage.

3. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI are currently a **Medium** risk to PEI's rainbow trout aquaculture industry. This risk increases but remains **Medium** into mid-century (Table 21).

Table 21. Rainbow trout risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Rainbow Trout							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	2	3	2	2.3	**Medium (7.0)**	**Medium (9.3)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)

This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)

Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

75 N. Feindel et al., "Chapter 6. Climate Change and Marine Aquaculture in Atlantic Canada and Quebec."
76 Mugwanya et al., "Anthropogenic Temperature Fluctuations and Their Effect on Aquaculture."

Consequences

The primary concern from heavy precipitation and flooding is damage to infrastructure that is critical to land-based aquaculture operations. However, damage from a non-coastal heavy precipitation event will likely be isolated to select facilities in flood-prone areas rather than widespread, thus minimizing the impact on production or livelihoods.

Production/Output (Rating: 2 – Minimal)

Heavy precipitation and flooding are not expected to directly impact production, though impacts to the facilities may temporarily disrupt operations and productivity/output. Rating considerations included:

- Rainbow trout are raised in a controlled environment in groundwater-fed tanks. Thus, heavy precipitation and flooding would have minimal impact on trout and water quality within the tanks.
- If flood damage led to a power outage and the facility does not have sufficient backup power, the fish may begin to experience stress. However, power outages would likely be limited to a few facilities and emergency power supplies (e.g., generators) could be directed to select facilities. Some facilities have backup power sources on site.

Infrastructure (Rating: 3 – Moderate)

Heavy precipitation and flooding can cause damage to electrical equipment, structures, and other key infrastructure at facilities that could take days to months to repair, depending on the severity. Rating considerations included:

- Land-based aquaculture operations are heavily reliant on electrical equipment and other key infrastructure.
- If flood damage led to a power outage at a facility without sufficient backup power, operations may be disrupted. However, power outages would likely be limited to a few facilities and emergency power supplies (e.g., generators) could be directed to select facilities. Some facilities have backup power sources on site.

Livelihoods (Rating: 2 – Minimal)

Facilities that require more significant repairs may need to limit or close operations for weeks to months, temporarily reducing income and employment at those locations. However, that scenario is not expected to be widespread, and employees may be able to work at other facilities. Rating considerations included:

- Land-based aquaculture operations are heavily reliant on functional electrical equipment and other key infrastructure. Damage to key infrastructure could stall operations.
- Assumption that only a limited number of facilities would experience significant damage from a non-coastal heavy precipitation event.

4. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **High** risk to PEI's rainbow trout aquaculture industry for both the current period and mid-century (Table 22).

Production/output, infrastructure, and livelihoods could all be significantly affected by this scenario.

Table 22. Rainbow trout risk summary for post-tropical storm

Post-Tropical Storm: Rainbow Trout							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	4	4	4	4	**High (16.0)**	**High (16.0)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

High winds, storm surge, and heavy rain from post-tropical storms will have significant and widespread consequences to rainbow trout aquaculture. This hazard can cause product losses (especially if a power outage occurs), significant damage to critical infrastructure, and have long-lasting impacts on livelihoods.

Production/Output (Rating: 4 – Significant)

Post-Tropical Storm Fiona caused a multi-day, island-wide power outage that put all aquaculture facilities at risk of power loss and subsequent fish mortality. Total or significant losses are feasible from post-tropical storms if water quality conditions cannot be maintained. There may be a significant disruption or complete loss of production that lasts months or even years. Rating considerations included:

- If power is not restored for an extended period of time or if the facility does not have sufficient backup power sources, facilities may not be able to maintain optimal controlled conditions (e.g., temperature, oxygen), leading to stress and mortality.
- Post-tropical storms can cause island-wide power outages and damage, making it difficult to restore power quickly or mobilize emergency equipment (e.g., generators) once the storm has begun. Although the province prioritized delivering power to land-based aquaculture facilities to minimize losses during Post-Tropical Storm Fiona, significant losses could occur from future events if facilities are not prepared or if emergency services are delayed.

Infrastructure (Rating: 4 – Significant)

Post-tropical storms can cause significant widespread damage to or failure of aquaculture infrastructure across the island. Repairs or replacements may be costly and could take months to years from severe events. Rating considerations included:

- Post-Tropical Storm Fiona damaged some facilities and caused widespread power outages.
- Post-tropical storms can temporarily inundate or damage coastal roadways and bridges restricting access to aquaculture sites.
- Post-tropical storms can also impact wellboats that move smolts from PEI to grow-out operations in neighbouring provinces.

Livelihoods (Rating: 4 – Significant)

If a post-tropical storm causes significant product loss and severe damage to critical infrastructure, livelihoods may be impacted for months to years while the industry recovers. A severe disruption to livelihoods could result in a significant loss of income or employment. Finfish aquaculture (rainbow trout, Atlantic salmon, Atlantic halibut) are PEI's largest pelagic export valued at about $4 million in 2021.

5. Acidification

Ocean acidification is **not applicable** to land-based, finfish aquaculture. Rainbow trout are raised in a controlled environment.

Atlantic Salmon (*Salmo salar*)

The Atlantic salmon (*Salmo salar*) is a species of ray-finned fish found in the northern Atlantic Ocean and nearby rivers. They are anadromous, meaning they can live in both fresh and saltwater. Atlantic salmon are seldom grown to market size on PEI and are more likely to be cultured for grow-out in other provinces and countries. On PEI, Atlantic salmon are grown in land-based tanks through the early life stages. Most operations are on recirculation systems, which allow for high-density farming in indoor tanks. Culturing can occur year-round. In 2021, the PEI cultured finfish industry—which includes rainbow trout, Atlantic salmon, and Atlantic halibut—had a market value of $4.2 million.[77]

Figure 10. Atlantic salmon in land-based aquaculture tank. Source: PEI Government 2016.

[77] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics.

Figure 11 summarizes climate risks to Atlantic salmon. Post-tropical storms have the highest risk rating and most severe consequences of any hazard. These events can cause significant damage to critical infrastructure and potential product losses, especially if a power outage occurs.

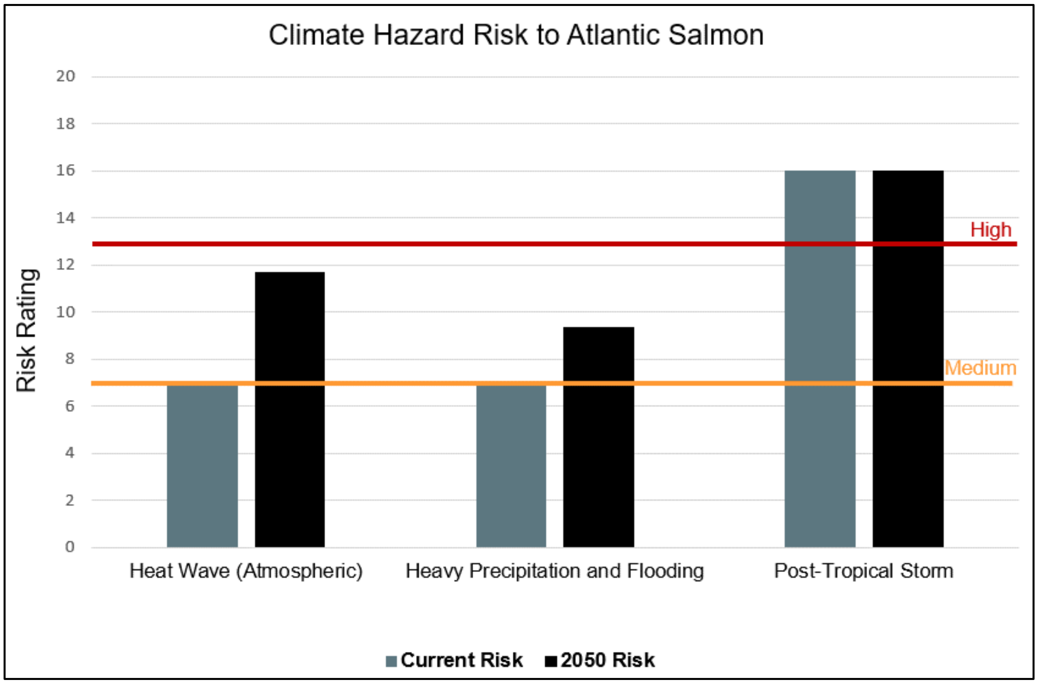

Figure 11. Summary of current and future climate hazard risk to Atlantic salmon.

1. Oceanic/Riverine Warming

Oceanic/riverine warming is **not applicable** to land-based, finfish aquaculture. Atlantic Salmon are raised in land-based facilities with a controlled environment.

2. Heat Wave (Atmospheric)

Scenario: Three consecutive days with temperatures above 29°C
Impact to species: Stress and potentially lethal

Increasingly frequent heat waves on PEI are currently a **Medium** risk to PEI's Atlantic salmon aquaculture industry. This risk increases but remains **Medium** into mid-century (Table 23).

Table 23. Atlantic salmon risk summary for atmospheric heat wave

Atmospheric Heat Wave: Atlantic Salmon							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	3	3	1	2.3	**Medium (7.0)**	**Medium (11.7)**

Likelihood

Appendix B Heat Wave (Atmospheric) provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Historically, this scenario has occurred 0.05 times per year on average.

Future: (Rating: 5 – Almost Certain)
Future projections indicate this scenario will occur 2.1 times per year on average.

Consequences

Heat waves are a concern for aquaculture facility operations, particularly if stress on the energy system caused a power outage and limited the ability of staff to maintain optimal operating conditions (e.g., water temperature, oxygen levels). A heat wave could also increase cooling demand and costs for the facility. Any disruptions would be temporary for the duration of the heat wave.

Production/Output (Rating: 3 – Moderate)
While Atlantic salmon are raised in a controlled environment, this rating assumes that the heat wave causes a power outage at the facilities due to stress on the energy system. Lack of power for an extended period of time could lead to widespread stress or mortality, resulting in a notable reduction in output/productivity. Rating considerations included:

- If power is not restored for an extended period of time or if the facility does not have sufficient backup power sources, facilities may not be able to maintain optimal controlled conditions (e.g., temperature, oxygen), leading to stress and mortality.
- Some facilities have backup power sources on site so a widespread disruption or loss of production may not be as severe.
- Atlantic salmon begin to experience thermal stress at 22-28°C. Research shows that 50% of Atlantic salmon can survive at this range for 7 days. The upper limit for Atlantic salmon is 30-33°C, which fish can only tolerate for 10 minutes.[78,79]

Infrastructure (Rating: 3 – Moderate)
While a 3-day heat wave is not expected to cause any physical damage to infrastructure or equipment, a heat wave-induced power outage will limit the functionality of equipment and cause disruptions for up to a few days. Rating considerations included:

- If power is not restored for an extended period of time or if the facility does not have sufficient backup power sources, the facility may not be able to function for the duration of the power outage.
- Some facilities have backup power sources on site and may only experience minimal disruption.
- A heat wave will increase cooling demand and cost at facilities.

Livelihoods (Rating: 1 – Insignificant)
The 3-day heat wave may cause temporary disruptions at facilities, but not a loss of income or employment. Rating considerations included:

- The heat wave would only cause disruptions to operations if a power outage occurred.
- If a power outage did occur for up to or longer than 3 days, it may actually increase staffing needs at facilities to help maintain the tanks and prevent product losses.

[78] N. Feindel et al., “Chapter 6. Climate Change and Marine Aquaculture in Atlantic Canada and Quebec.”
[79] Mugwanya et al., “Anthropogenic Temperature Fluctuations and Their Effect on Aquaculture.”

- Heat waves may also pose health risks to workers (e.g., heat stress) during a power outage.

3. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI are currently a **Medium** risk to PEI's Atlantic salmon aquaculture industry. This risk increases but remains **Medium** into mid-century (Table 24).

Table 24. Atlantic salmon risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Atlantic Salmon							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	2	3	2	2.3	**Medium (7.0)**	**Medium (9.3)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)
This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)
Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

Consequences

The primary concern from heavy precipitation and flooding is damage to key infrastructure, which are critical to land-based aquaculture operations. However, damage from a non-coastal heavy precipitation event will likely be isolated to select facilities in flood-prone areas rather than widespread, thus minimizing the impact on production or livelihoods.

Production/Output (Rating: 2 – Minimal)
Heavy precipitation and flooding are not expected to directly impact production, though impacts to the facilities may cause some temporary disruption to operations. Rating considerations included:

- Atlantic salmon are raised in a controlled environment in groundwater-fed tanks. Thus, heavy precipitation and flooding would have minimal impact on salmon and water quality within the tanks.
- If flood damage led to a power outage and the facility does not have sufficient backup power, the fish may begin to experience stress. However, power outages would likely be limited to a few facilities and emergency power supplies (e.g., generators) could be directed to select facilities. Some facilities have backup power sources on site.

Infrastructure (Rating: 3 – Moderate)
Heavy precipitation and flooding can cause partial damage or disruption to electrical equipment, structures, and other key infrastructure at land-based aquaculture facilities which could take days to months to repair, depending on the severity. Rating considerations included:

- Land-based aquaculture operations are heavily reliant on electrical equipment and other key infrastructure.
- If flood damage led to a power outage and the facility does not have sufficient backup power, operations may be disrupted. However, power outages would likely be limited to a few facilities and emergency power supplies (e.g., generators) could be directed to select facilities. Some facilities have backup power sources on site.

Livelihoods (Rating: 2 – Minimal)

Facilities that require more significant repairs may need to limit or close operations for weeks to months, temporarily reducing income and employment at those locations. However, that scenario is not expected to be widespread, and employees may be able to work at other facilities. Thus, there may be minimal disruption to livelihoods. Rating considerations included:

- Land-based aquaculture operations are heavily reliant on functional electrical equipment and other key infrastructure. Damage to key infrastructure could stall operations.
- Assumption that only a limited number of facilities would experience significant damage from a non-coastal heavy precipitation event.

4. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **High** risk to PEI's Atlantic salmon aquaculture industry both for the current period and mid-century (Table 25). Production/output, infrastructure, and livelihoods could all be significantly affected by this scenario.

Table 25. Atlantic salmon risk summary for post-tropical storm

Post-Tropical Storm: Atlantic Salmon							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	4	4	4	4	**High (16.0)**	**High (16.0)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

High winds, storm surge, and heavy rain from post-tropical storms will have significant and widespread consequences to Atlantic salmon land-based aquaculture. This hazard can cause product losses (especially if a power outage occurs), significant damage to critical infrastructure, and have long-lasting impacts on livelihoods.

Production/Output (Rating: 4 – Significant)

Post-Tropical Storm Fiona caused a multi-day, island-wide power outage that put all land-based aquaculture facilities at risk of power loss and subsequent fish mortality. Total or significant losses are feasible from post-tropical storms if water quality conditions cannot be maintained. Thus, there may be significant disruption or complete loss of production. Rating considerations included:

- If power is not restored for an extended period of time or the facility does not have sufficient backup power sources, facilities may not be able to maintain optimal controlled conditions (e.g., temperature, oxygen), leading to stress and mortality.
- Post-tropical storms can cause island-wide power outages and damage, making it difficult to restore power quickly or mobilize emergency equipment (e.g., generators) once the storm has begun. Although the province prioritized getting power to land-based aquaculture facilities to minimize losses during Post-Tropical Storm Fiona, significant losses could occur from future events if facilities are not prepared or emergency services are delayed.

Infrastructure (Rating: 4 – Significant)

Post-tropical storms can cause significant widespread damage or failure to aquaculture infrastructure across the island. Repairs or replacements may be costly and could take months to years from severe events. Rating considerations included:

- Post-Tropical Storm Fiona damaged some facilities and caused widespread power outages.
- Post-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to aquaculture sites.
- Post-tropical storms can also impact wellboats that move smolts from PEI to grow-out operations in neighbouring provinces.

Livelihoods (Rating: 4 – Significant)

If a post-tropical storm causes significant product loss and severe damage to critical infrastructure, livelihoods may be impacted for months to years while the industry recovers. A severe disruption to livelihoods could result in a significant loss of income or employment. Finfish aquaculture (rainbow trout, Atlantic salmon, Atlantic halibut) are PEI's largest pelagic export valued at about $4 million in 2021.

5. Acidification

Ocean acidification is **not applicable** to land-based, finfish aquaculture. Atlantic salmon are raised in a controlled environment.

Commercial Fishing Sector

This assessment evaluated risks to the commercial fishing sector from six key climate hazards. Focus climate hazards were selected based on a sensitivity analysis of lobster, snow crab, Atlantic bluefin tuna, Atlantic mackerel, Atlantic herring, rock crab, and soft shell clam. For additional details on the sensitivity and risk analyses, see Appendix A: Climate Risk and Opportunity Assessment Methodology. Risk ratings are based on the following scenario events:

- **Oceanic/Riverine warming:** Average sea surface temperature rises above a species-specific threshold for adults that results in reduced growth, reduced recruitment, or some other indicated non-lethal limit threshold
- **Marine heat wave:** More frequent occurrence of temperatures above a species-specific lethal limit for adults for mature specimens (if available)
- **Heavy precipitation and flooding:** 100mm of rain in 24 hours
- **Post-tropical storm:** Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022
- **Acidification:** Acidification in the Gulf of St. Lawrence reaches a species-specific threshold (if available)
- **Hypoxia:** More frequent hypoxic conditions

As shown in Table 26, the greatest risks to commercial species include post-tropical storms (Atlantic bluefin tuna, rock crab, lobster), marine heat waves (Atlantic herring, Atlantic mackerel, soft shell clams), and oceanic/riverine warming (snow crab). Post-tropical storm ratings are primarily driven by significant impacts to commercial fishing equipment and harbours. However, post-tropical storms mainly occur during the fall and thus would only affect fall fishing seasons. Risks from heat waves and oceanic/riverine warming are primarily driven by significant declines in production/output and could affect all fishing seasons.

Potential Opportunities

Although climate change poses considerable risks to the commercial fishing industry on PEI, changes in certain hazards may create potential opportunities for some commercial species. For example, ocean warming may have some benefits for lobster populations, including increased abundance of certain food sources, potential migration of lobster populations northward, and decreased abundance of certain predators.[80] Additionally, an earlier arrival of spring temperatures could lead to an increase in lobster populations, providing benefits to the industry by mid-century. In recent years, lobster abundance in Atlantic Canada and PEI has increased due to earlier, warmer temperatures.[81]

The snow crab industry on PEI may also benefit from earlier and warmer spring, which could extend fishing seasons on the front end by causing earlier ice melt on harbours and fishing grounds. Snow crab reproduction may also increase due to warming sea temperatures. Female crabs typically reproduce just once every two years in waters colder than 1°C but reproduce

[80] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[81] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."

annually in temperatures above 1.8°C. A small increase in temperature could therefore lead to a two-fold increase in reproductive output in some areas.[82]

Warmer temperatures may also affect sea ice. Although PEI does not typically rely on sea ice for access to fishing grounds, earlier ice melt due to warmer temperatures in the spring could potentially lengthen the fishing season. Additionally, hazards like coastal erosion can cause shifts in access points for the commercial fishing industry at large. These may be positive or negative.

[82] Timothy P. Foyle, Ronald K. O'Dor, and Robert W. Elner, "Energetically Defining the Thermal Limits of the Snow Crab," *Journal of Experimental Biology* 145, no. 1 (September 1, 1989): 371–93, https://doi.org/10.1242/jeb.145.1.371.

Table 26. Commercial fishing sector climate risk assessment results

Hazard	Current Likelihood	2050 Likelihood	Production / Output	Infrastructure	Livelihood	Current Risk	Future Risk
Lobster							
Post-Tropical Storm	4	4	3	4	3	**High (13.3)**	**High (13.3)**
Acidification	5	5	3	1	3	**Medium (11.7)**	**Medium (11.7)**
Hypoxia	3	4	3	1	3	**Medium (7.0)**	**Medium (9.3)**
Oceanic/Riverine Warming	1	2	4	2	4	**Low (3.3)**	**Low (6.7)**
Heat Wave (Marine)	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Snow Crab							
Oceanic/Riverine Warming	3	5	3	2	3	**Medium (8.0)**	**High (13.3)**
Heat Wave (Marine)	3	4	4	2	3	**Medium (9.0)**	**Medium (12.0)**
Post-Tropical Storm	4	4	1	4	2	**Medium (9.3)**	**Medium (9.3)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Hypoxia	3	4	1	1	1	**Low (3.0)**	**Low (4.0)**
Atlantic Bluefin Tuna							
Post-Tropical Storm	4	4	2	3	3	**Medium (10.7)**	**Medium (10.7)**
Hypoxia	3	4	3	1	2	**Low (6.0)**	**Medium (8.0)**
Acidification	2	3	2	1	1	**Low (2.7)**	**Low (4.0)**
Oceanic/Riverine Warming	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Heat Wave (Marine)	1	1	N/A	N/A	N/A	**Negligible**	**Negligible**
Atlantic Mackerel							
Heat Wave (Marine)	2	4	4	2	3	**Low (6.0)**	**Medium (12.0)**
Post-Tropical Storm	4	4	2	3	2	**Medium (9.3)**	**Medium (9.3)**
Oceanic/Riverine Warming	2	4	3	2	2	**Low (4.7)**	**Medium (9.3)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Hypoxia	3	4	1	1	1	**Low (3.0)**	**Low (4.0)**
Atlantic Herring							
Heat Wave (Marine)	3	5	4	2	3	**Medium (9.0)**	**High (15.0)**
Post-Tropical Storm	4	4	2	3	2	**Medium (9.3)**	**Medium (9.3)**

Hazard	Current Likelihood	2050 Likelihood	Production / Output	Infrastructure	Livelihood	Current Risk	Future Risk
Oceanic/Riverine Warming	2	4	3	2	2	**Low (4.7)**	**Medium (9.3)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Hypoxia	3	4	1	1	1	**Low (3.0)**	**Low (4.0)**
Rock Crab							
Post-Tropical Storm	4	4	2	3	3	**Medium (10.7)**	**Medium (10.7)**
Oceanic/Riverine Warming	1	3	4	2	3	**Low (3.0)**	**Medium (9.0)**
Hypoxia	3	4	3	1	2	**Low (6.0)**	**Medium (8.0)**
Acidification	2	3	2	1	2	**Low (3.3)**	**Low (5.0)**
Heat Wave (Marine)	1	2	3	2	2	**Low (2.3)**	**Low (4.7)**
Soft Shell Clams							
Heat Wave (Marine)	4	5	4	1	3	**Medium (10.7)**	**High (13.3)**
Oceanic/Riverine Warming	4	5	3	1	2	**Medium (8.0)**	**Medium (10.0)**
Post-Tropical Storm	4	4	3	2	2	**Medium (9.3)**	**Medium (9.3)**
Acidification	3	4	4	1	2	**Medium (7.0)**	**Medium (9.3)**
Hypoxia	3	4	3	1	2	**Low (6.0)**	**Medium (8.0)**

Lobster (*Homarus americanus*)

The lobster (*Homarus americanus*) is a marine crustacean found on the Atlantic Coast of North America. The lobster fishing industry is PEI's largest commercial fishery, providing a significant source of income and employment opportunities, supporting the equivalent of over a thousand full-time jobs. The main fishing season in PEI is from May to June, when 72-80% of the harvest is caught. Fishing also happens from early August to early October. Lobster harvest around PEI is divided based on the length of the carapace, or the body of the lobster. Smaller lobster with a carapace length that is greater than the minimum legal size and less than 81 mm are referred to as canners, as they were historically sent to canneries or processing plants. Larger lobster with a carapace length of 81 mm or greater are referred to as markets, as they were historically sold on the live market for use in restaurants or grocery stores.

Figure 12. Lobster fisher with traps. Source: Tourism PEI 2023.

The products derived from lobster are diverse, including live, fresh/cooked, and frozen whole lobster, as well as lobster meat, tails, and bodies. Vacuum-packed, canned, and paste lobster products are also derived, in addition to other value-added products. These offerings cater to a wide range of consumer preferences and have helped the industry build a strong market presence. Lobster are PEI's most valuable fishery. In 2021, the PEI lobster fishing industry recorded a harvest weight of over 47 million pounds, representing a market value of almost $371 million. This significant yield underscores the importance of the sector to the local economy. The industry is supported by 1,219 licensed lobster harvesters.[83] The widespread adoption of lobster fishing and its substantial economic impact attest to the success of the lobster industry on PEI.

Figure 13 summarizes climate risks to lobster. Post-tropical storms have the highest risk rating of all climate hazards and can lead to lobster mortality and loss or damage of fishing equipment. These impacts may have significant effects on the livelihoods of lobster harvesters on PEI. Post-tropical storms primarily occur in the fall and can greatly impact lobster fishing equipment and infrastructure during the fall season. However, the effects of these storms on lobster populations unfold over time, influencing both the fall and subsequent fishing seasons in the spring. While oceanic/riverine warming also received significant consequence ratings for impacts to production and livelihoods, the likelihood of temperatures crossing the critical threshold for lobster by 2050 is low, therefore lowering the overall risk.

[83] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

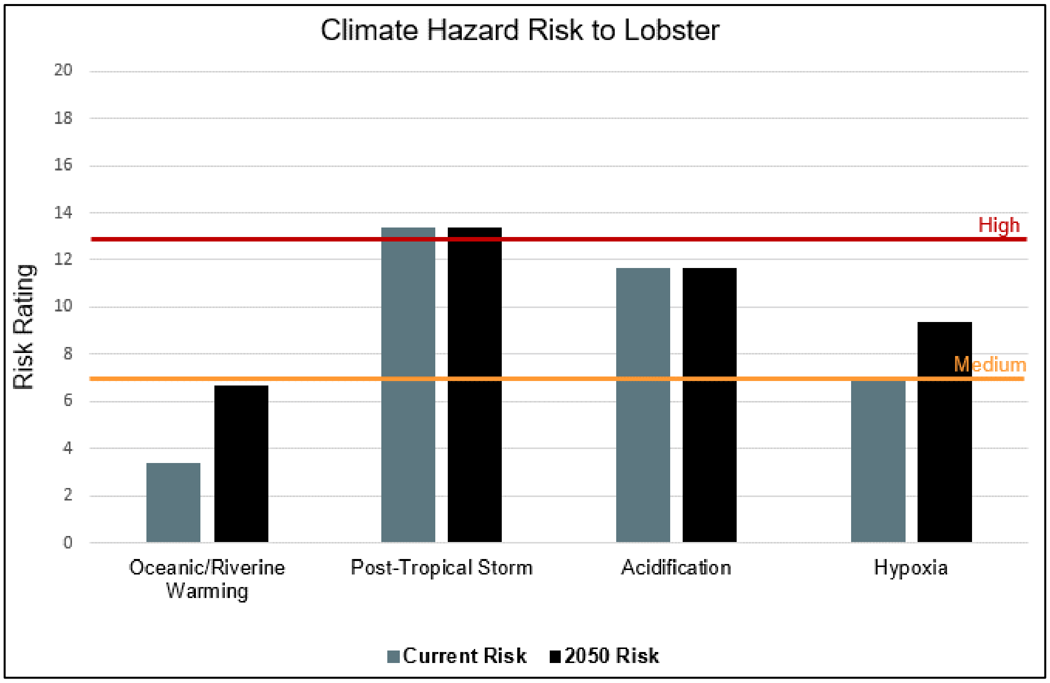

Figure 13. Summary of current and future climate hazard risk to lobster.

1. Oceanic/Riverine Warming

Scenario: Average sea surface temperature rises above 25°C
Impact to species: Slower development, hindered moult, disrupted/irregular heartbeat

Oceanic/riverine warming on PEI currently represents a **Low** risk to PEI's lobster industry. This risk increases but remains **Low** by mid-century (Table 27). Production/output and livelihoods could be most significantly affected by this scenario.

Warming sea temperatures may also lead to some potential **opportunities** for the lobster industry on PEI. Ocean warming can have some benefits to lobster populations, including increased abundance of certain food sources, potential migration of lobster populations northward, and decreased abundance of certain predators.[84,85] An earlier arrival of spring temperatures could lead to a temporary increase in lobster population, providing benefits to the industry by mid-century.[86]

Table 27. Lobster risk summary for oceanic/riverine warming

Oceanic/Riverine: Lobster							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
1	2	4	2	4	3.3	**Low (3.3)**	**Low (6.7)**

[84] Blair J. W. Greenan et al., "Climate Change Vulnerability of American Lobster Fishing Communities in Atlantic Canada," Frontiers in Marine Science 6 (2019), https://www.frontiersin.org/articles/10.3389/fmars.2019.00579.
[85] DRAFT Stantec, "Lobster Habitat Climate Change Risk Assessment" (DRAFT 2023).
[86] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The lobster ratings are relative to the critical sea surface temperature threshold of 25°C.

Current: (Rating: 1 – Rare)
In the Gulf of St. Lawrence, average summer sea surface temperatures currently range from 16°C to 19°C.

Future: (Rating: 2 – Unlikely)
Under a high emissions scenario, average summer sea surface temperatures are projected to range from 20°C to 23°C by 2050.

Consequences

Oceanic/riverine warming can lead to lower productivity for lobster harvesters, as high temperatures can adversely affect lobster development, survival, and fecundity. Increasing temperatures could also lead to lobster migration away from the warming waters, affecting available populations and industry outputs. Meanwhile, these changes could have significant effects on livelihoods of those in the lobster industry, which is the most valuable industry on PEI.

Production/Output (Rating: 4 – Significant)
Increases in temperature could result in a noticeable reduction in productivity and outputs as lobster may spend less time within optimal temperatures, especially during particularly warm summers. Rating considerations included:

- Lobster are vulnerable to high temperatures. Temperatures above 25°C can have adverse effects on lobster function, such as slower development, hindered moult, and disrupted or irregular heartbeat. Temperatures of 33.4°C and above can be dangerous and even lethal for all life stages.[87,88]
    - The risk of higher temperatures is the greatest for lobster in their early life stages, as they are unable to swim well enough to other areas to avoid high sea surface temperatures. Warmer temperatures can affect the growth of lobster larvae, such as through slower respiration rates.[89]
    - Lobster in warmer waters tend to reach maturity at smaller sizes and younger ages, increasing the potential of reduced fecundity.[90]
    - If possible, lobster will move to colder waters if the optimal temperature conditions are surpassed.
    - Lobster may moult earlier in the season due to warming temperatures, which could require a shift in harvesting periods. Further, an earlier moult makes lobster more susceptible to shell disease due to a longer period of exposure.[91,92,93]

[87] DRAFT Stantec, "Lobster Habitat Climate Change Risk Assessment" (DRAFT 2023).
[88] Brady K. Quinn, "Threshold Temperatures for Performance and Survival of American Lobster Larvae: A Review of Current Knowledge and Implications to Modeling Impacts of Climate Change," *Fisheries Research* 186 (February 1, 2017): 383–96, https://doi.org/10.1016/j.fishres.2016.09.022.
[89] Brady K. Quinn, "Threshold Temperatures for Performance and Survival of American Lobster Larvae: A Review of Current Knowledge and Implications to Modeling Impacts of Climate Change."
[90] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[91] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[92] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[93] Maya L. Groner et al., "Rising Temperatures, Molting Phenology, and Epizootic Shell Disease in the American Lobster," *The American Naturalist* 192, no. 5 (November 2018): E163–77, https://doi.org/10.1086/699478.

        - In PEI, lobster fishing is paused in July to avoid disrupting spawning and moulting periods. However, with rising temperatures, spawning and moulting periods may shift earlier, leading to potential for harvesting sensitive lobster.[94] For example, earlier spawning time would result in more overlap between the fishing season and the presence of female lobster carrying eggs, which are more sensitive to warmer temperatures.
    - There may be temperature-driven declines in herring and mackerel abundance that result in bait shortages for the lobster fishery.[95]
- Warmer temperatures under climate change may introduce or increase the prevalence of some predators of lobster, such as the black bass.[96]
- Lobster are more susceptible to epizootic shell diseases at temperatures above 10^{o}C. Severe cases of shell disease can cause blindness and moulting issues.[97,98,99,100]
- High humidity and high heat conditions can cause lobster to die or become limp during transport to a processing facility.[101]
- Earlier melting of sea ice may result in earlier spring blooms of phytoplankton, potentially causing a mismatch for zooplankton, which feed upon phytoplankton. This relationship could have ripple effects up the food chain, potentially affecting lobster, which feed on species that rely on plankton.[102,103]
- An absence of sea ice may lead to colder open waters due to wind chill effects during winter. Sea ice traditionally insulates and stabilizes the water, providing warmer conditions beneficial for the lobster fishery. Reduced sea ice also results in choppier and more turbulent waters, posing challenges for lobster and potentially leading to a later opening date for the spring lobster fishing season.[104]

Infrastructure (Rating: 2 – Minimal)

Damage to infrastructure due to increased temperatures is unlikely to be severe and most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms such as plants and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

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[94] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[95] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[96] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[97] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[98] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[99] Maya L. Groner et al., "Rising Temperatures, Molting Phenology, and Epizootic Shell Disease in the American Lobster," *The American Naturalist* 192, no. 5 (November 2018): E163–77, https://doi.org/10.1086/699478.
[100] Blair J. W. Greenan et al., "Climate Change Vulnerability of American Lobster Fishing Communities in Atlantic Canada," *Frontiers in Marine Science* 6 (2019), https://www.frontiersin.org/articles/10.3389/fmars.2019.00579.
[101] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[102] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report."
[103] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[104] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Livelihoods (Rating: 4 – Significant)

The lobster industry is PEI's most valuable industry. If temperatures consistently surpass the optimal threshold for lobster, the industry could become less profitable, leading to a siginificant disruption in livelihoods and loss of income. Rating considerations included:

- Lobster are PEI's most valuable fishery, with a value of about $370,882,000 in 2021, with the industry holding about 1,219 licensed lobster harvesters.[105] If warmer future conditions result in less productive lobster growth, the lobster industry in PEI may decline and could support fewer employment opportunities.
- Changes in sea ice can impact the timing of lobster operations.
- Lobster fishing is an essential part of the local culture and heritage in PEI. If warmer temperatures resulted in the decline or disappearance of this industry, it could have significant impacts on the community's identity and way of life.
- If the impacts of increased temperatures on the lobster industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures above 33.4°C
Impact to species: Lethal

This scenario is **almost certain not to occur** by mid-century (likelihood rating: 1). For details, see Heat Wave (Marine). As a result, ICF did not evaluate the consequences of this scenario and the overall risk to PEI's lobster industry is **Negligible**.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **High** risk to PEI's lobster industry for the current period and mid-century (Table 28). Infrastructure could be most significantly affected by this scenario.

Table 28. Lobster risk summary for post-tropical storm

Post-Tropical Storm: Lobster							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	3	4	3	3.3	**High (13.3)**	**High (13.3)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

[105] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Future: (Rating: 4 – Likely)
Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

Lobster populations are susceptible to storm surges and salinity levels, potentially leading to mortality which would reduce the lobster available for industry outputs. The number of fishing days in a season may also decrease, in part due to potential loss or damage of equipment. These changes in turn may have significant effects on the livelihoods of those involved in the lobster industry.

Production/Output (Rating: 3 – Moderate)
Increased frequency and/or intensity of storms could result in a noticeable reduction in productivity and outputs in the fall fishing season as lobster may see various impacts and spend less time within optimal salinity levels. Impacts to production and output in the spring fishing season are possible but are likely to be less severe. Rating considerations included:

- Increase storm frequency and intensity can adversley affect nearshore and larval stage lobster, and storm surges can result in lobster mortality.
- Lobster are sensitive to salinity, which can be affected by storms. After a heavy storm, the salinity can fall significantly to levels below the lethal threshold for adult lobster (8-14 ppt), and lobster may migrate to deeper water or even experience lethal outcomes.[106,107]
    - Even if lobster are able to survive short-term exposure to low salinity, they may experience physiological stress on growth and reproduction.[108]
    - Reduced salinity results in a rapid increase of the lobster heart rate, followed by a reduction in heart rate as the salinity continues to lower. [109]
    - Moulting lobster are especially vulnerable to low salinity.[110]
- Increased severe storm activity could decrease the number of fishing days in a season, leading to a reduced number of caught lobster.[111]

Infrastructure (Rating: 4 – Significant)
Damage to infrastructure due to increasing frequency and intensity of storms is likely to be severe and repairments or replacements of most equipment could take months or years. Rating considerations included:

- Severe storm events can result in the loss or damage of commercial fishing boats and lobster traps.[112]

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[106] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[107] Steven H. Jury et al., "Lobster Movements in Response to a Hurricane."
[108] Christopher G. Dufort et al., "Detection of Salinity by the Lobster, Homarus Americanus," Biology Bulletin 201 (December 2001): 424–34, https://www.bio.umass.edu/biology/kunkel/pub/lobster/PDFs/Dufort_etal_Lob-BiolBull2001.pdf.
[109] Christopher G. Dufort et al., "Detection of Salinity by the Lobster, Homarus Americanus."
[110] S. Koepper et al., "Spatial and Temporal Patterns in the Sex Ratio of American Lobsters (Homarus Americanus) in Southwestern Nova Scotia, Canada," Scientific Reports 11, no. 1 (December 16, 2021): 24100, https://doi.org/10.1038/s41598-021-03233-8.
[111] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[112] Lisa Jackson, " Hurricane Fiona was a 'historic, extreme event' for Atlantic Canada – and hit the seafood sector hard," Global Seafood Alliance, Septmeber 2022, https://www.globalseafood.org/advocate/hurricane-fiona-was-a-historic-extreme-event-for-atlantic-canada-and-hit-the-seafood-sector-hard/.

- Boat hauling capacity ahead of severe storm events is constrained on PEI. This limitation may result in boats remaining in the water during severe weather, increasing their vulnerability to damage.[113]
- Post-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to commercial fishing sites.

Livelihoods (Rating: 3 – Moderate)

The lobster industry is PEI's most valuable fishery, and if more frequent and/or severe storms occur, the lobster industry could be less profitable, leading to a significant disruption in livelihoods and a noticeable loss of income. Rating considerations included:

- With a value of about $370,882,000 in 2021, the lobster industry is PEI's most valuable fishery. PEI has approximately 1,219 licensed lobster harvesters.[114] If increased storm frequency and intensity result in lobster mortality, migration, and stress, the lobster industry in PEI may decline and could support fewer employment opportunities.
- Lobster fishing is an essential part of the local culture and heritage on PEI. If increasing frequency and intensity of storms resulted in the declineation or disappearance of this industry, it could have significant impacts on the community's identity and way of life.
- If the impacts of the increased frequency and intensity of the lobster industry are significant enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.
- Severe storms also have safety implications for lobster harvesters.

4. Acidification

Scenario: Acidification approaches 7.7 pH
Impact to species: Weakened shell, affected larva growth, increased lobster energy consumption

Acidification on PEI represents a **Medium** risk to PEI's lobster industry. This risk increases but remains **Medium** into mid-century (Table 29).

Table 29. Lobster risk summary for acidification

Acidification: Lobster							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
5	5	3	1	3	2.3	**Medium (11.7)**	**Medium (11.7)**

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions. The Lobster ratings are relative to the critical pH threshold of 7.7 units.

[113] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[114] PEI Department of Fisheries, Tourism, Sport, and Culture, "2021 Fishery Statistics."

Current: (Rating: 5 – Almost Certain)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units and decreasing at a rate of 0.04 units per decade.

Future: (Rating: 5 – Almost Certain)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050.

Consequences

Increased acidification could cause disruptions to production/output, as lobster are made more vulnerable and less marketable due to the weakening of their shells. In turn, the livelihoods of those involved in the industry may be affected.

Production/Output (Rating: 3 – Moderate)

Acidification could result in a noticeable reduction in productivity and outputs as lobster may see various adverse impacts. Rating considerations included:

- Lobster are sensitive to pH changes and acidification.
    - Acidification can soften and weaken the shell, making lobster more vulnerable and less marketable.[115]
    - Acidifcation can affect the growth of lobster larva, such as resulting in slower respiration rates.[116]
    - Acidification can increase a lobster's energy consumption, leading to slowed development and increased energy requirements.[117]

Infrastructure (Rating: 1 – Insignificant)

Damage to infrastructure due to acidification is unlikely.

Livelihoods (Rating: 3 – Moderate)

The lobster industry is PEI's most valuable fishery, and if impacts from acidification occur, the lobster industry could be less profitable, leading to a significant disruption in livelihoods and a noticeable loss of income. Rating considerations included:

- Lobster are PEI's most valuable fishery, with a value of about $370,882,000 in 2021. PEI has approximately 1,219 licensed lobster harvesters.[118] If increased acidification impacts result in affected lobster growth and even lobster mortality, the lobster industry in PEI may decline and could support fewer employment opportunities.
- Lobster fishing is an essential part of the local culture and heritage in PEI. If impacts of acidification resulted in the decline or disappearance of this industry, it could have significant impacts on the community's identity and way of life.
- If the impacts of increased frequency and intensity of the lobster industry are significant enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

[115] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[116] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[117] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."
[118] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

5. Hypoxia

Scenario: More frequent hypoxic conditions
Impact to species: Decreased growth, weakened shell, reduced weight gain

Hypoxia on PEI currently represents a **Medium** risk to PEI's lobster industry. This risk increases but remains **Medium** into mid-century (Table 30).

Table 30. Lobster risk summary for hypoxia

Hypoxia: Lobster							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	3	1	3	2.3	**Medium (7.0)**	**Medium (9.3)**

Likelihood

Appendix B Hypoxia provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Hypoxia is worsening in the Gulf of St. Lawrence due to many factors, including warmer upper-ocean temperatures.

Future: (Rating: 4 – Likely)
Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase, potentially causing more frequent or widespread hypoxia events.

Consequences

Increased hypoxia could cause disruptions to production/output, as lobster become more vulnerable and less marketable due to hindered lobster growth and weakened shells. In turn, livelihoods of those involved in the lobster industry may be impacted, particularly as it is the most valuable fishery on PEI.

Production/Output (Rating: 3 – Moderate)
Hypoxic conditions could result in a noticeable reduction in productivity and outputs as lobster may experience various adverse impacts. Rating considerations included:

- Hypoxic conditions can make lobster weak and lethargic and can lead to migration or mortality events.[119,120,121]
- Reduced levels of dissolved oxygen of 50-60% or below can affect lobster growth, such as reduced shell hardness and weight gain.[122]

Infrastructure (Rating: 1 – Insignificant)
Damage to infrastructure due to coastal hopixia is unlikely.

[119] Massachusetts Division of Marine Fisheries, "Southern Cape Cod Bay Experiences Lobster Mortalities Related to Low Oxygen," 2020, https://www.mass.gov/news/southern-cape-cod-bay-experiences-lobster-mortalities-related-to-low-oxygen.
[120] Sarah Paquette, "So You Want to Know: Why Is Dissolved Oxygen Important?," Maine Lobstermen's Community Alliance, October 22, 2013, https://mlcalliance.org/2013/10/22/so-you-want-to-know-why-is-dissolved-oxygen-important/.
[121] D. McLeese, "Effects of Temperature, Salinity and Oxygen on the Survival of the American Lobster," *Journal of the Fisheries Research Board of Canada* 13 (April 13, 2011): 247–72, https://doi.org/10.1139/f56-016.
[122] Robert Bayer, John Riley, and Darrell Donahue, "The Effect of Dissolved Oxygen Level on the Weight Gain and Shell Hardness of New-Shell American Lobster Homarus Americanus," *Journal of the World Aquaculture Society* 29, no. 4 (1998): 491–93, https://doi.org/10.1111/j.1749-7345.1998.tb00674.x.

Livelihoods (Rating: 3 – Moderate)

The lobster industry is PEI's most valuable industry, and if impacts from hypoxia occur, the lobster industry could be less profitable, leading to a significant disruption in livelihoods and a noticeable loss of income. Rating considerations included:

- Lobster are PEI's most valuable fishery, with a value of about $370,882,000 in 2021, with the industry holding about 1,219 licensed lobster harvesters.[123] If increased hypoxia impacts result in affected lobster growth and even lobster mortality, the lobster industry in PEI may decline and could support fewer employment opportunities.
- Lobster fishing is an essential part of the local culture and heritage in PEI. If impacts of hypoxia resulted in the decline or disappearance of this industry, it could have significant impacts on the community's identity and way of life.
- If the impacts of increased frequency and intensity of the lobster industry are significant enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

Snow Crab (*Chionoecetes opilio*)

The snow crab (*Chionoecetes opilio*) is a type of crustacean native to shelf depths in the northwest Atlantic Ocean. The fishing season for snow crab on PEI is from mid-April to late-June, or until the harvesting quota is reached. Snow crabs are harvested off the North Shore in the Gulf of St. Lawrence. There are currently 28 active snow crab licences on PEI.

Figure 14. Snow crab fishing. Source: CBC News.

The products derived from snow crabs include fresh, frozen, and whole round snow crabs, as well as sections of the snow crab. In 2021, the PEI snow crab fishing industry recorded a harvest weight of just over 5.8 million pounds, representing a market value of over $45 million.[124]

Figure 15 summarizes climate risks to snow crabs. Oceanic/riverine warming has the highest risk rating of any hazard and can lead to a significant reduction in habitat suitability for snow crabs. Reductions in snow crab yield over time can affect the income and livelihoods of snow crab harvesters. Although the overall risk rating is lower, marine heat waves also received significant consequence ratings for production impacts.

[123] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[124] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

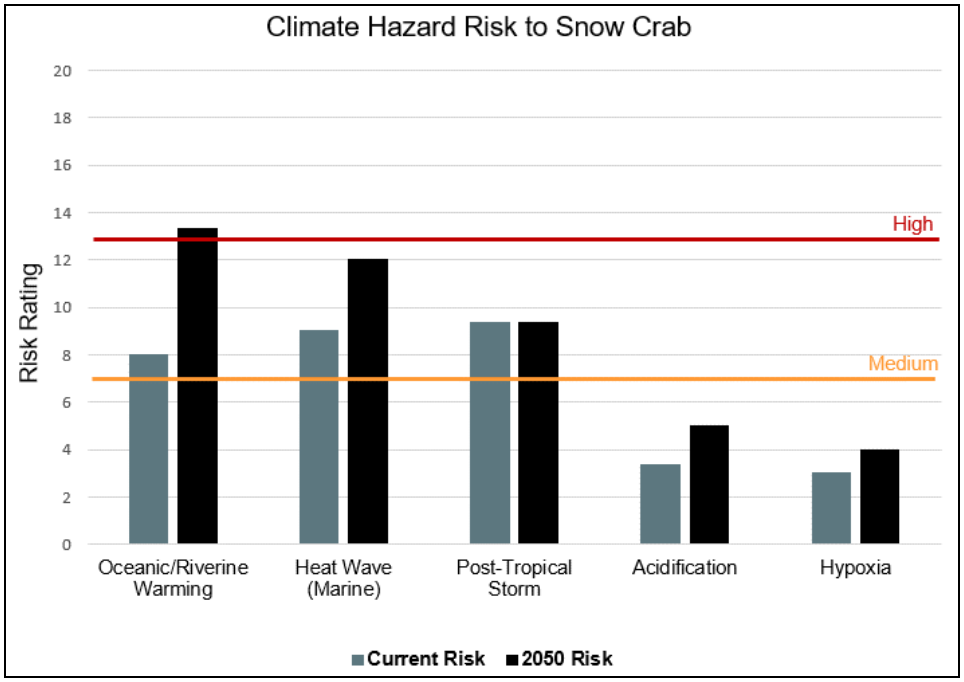

Figure 15. Summary of current and future climate hazard risk to snow crab.

1. Oceanic/Riverine Warming

Scenario: Average water temperature rises above 7°C
Species Impact: Physiological concerns

Oceanic/riverine warming on PEI currently represents a **Medium** risk to PEI's snow crab industry. This risk increases to **High** by mid-century (Table 31).

Although warming temperatures will have predominantly negative impacts on snow crabs, future conditions could prove beneficial for snow crab reproduction. Female crabs typically reproduce just once every two years in waters colder than 1°C but reproduce annually in temperatures above 1.8°C. Thus, a small increase in temperature could potentially lead to a two-fold increase in reproductive output in some areas.[125]

Table 31. Snow crab risk summary for oceanic/riverine warming

Ocean/Riverine Warming: Snow Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	3	2	3	2.7	**Medium (8.0)**	**High (13.3)**

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The snow crab ratings are relative to the critical sea surface temperature threshold of 7°C.

[125] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."

Current: (Rating: 3 – Possible)

As described in Oceanic/Riverine Warming, sea surface temperatures have been increasing around PEI at a rate of approximately 0.46°C per decade. However, snow crabs reside in deeper waters that have more stable temperatures and are therefore less likely to be affected by changes in average sea surface temperatures.[126] The layer of water in the Gulf of St. Lawrence from 150 to 540m is characterized by temperatures between 1 and >7°C. The Gulf-wide average was at a series record high in 2020, at 6.7°C, and reached a record average of 7.7°C in Cabot Strait.[127]

Future: (Rating: 5 – Almost Certain)

Under a high emissions scenario deep-water temperatures around PEI are projected to increase by about 2°C by 2050, meaning average deep-water temperatures will almost certainly exceed 7°C.[128]

Consequences

Snow crabs are especially sensitive to oceanic/riverine warming, with small changes in temperature affecting multiple aspects of snow crab physiology, including growth rate and body size. Oceanic warming may also cause a significant reduction in habitat suitability for snow crabs. Reductions in snow crab yield over time can affect the income and livelihoods of snow crab harvesters.

Production/Output (Rating: 3 – Moderate)

Increases in temperature could result in a noticeable reduction in productivity and outputs as snow crabs may spend less time within optimal growing temperatures, especially during particularly warm summers. Rating considerations included:

- Snow crabs have a narrow tolerable temperature range, making them more sensitive to warming temperatures. Many aspects of snow crab physiology (e.g., growth rate, body size, and fecundity) are sensitive to small changes in temperature.[129]
- Oceanic warming may force crabs to migrate to colder temperatures, reducing yields near PEI.
- As the Scotian Shelf waters are projected to warm over the coming century, there is a possibility that snow crab on the Scotian Shelf will experience a large reduction in habitat suitability, ocean warming, decreasing oxygen concentrations, and recruitment, which could potentially lead to their commercial extinction by the year 2070.[130]
- Earlier melting of sea ice may result in earlier spring blooms of phytoplankton, potentially causing a mismatch for zooplankton which feed upon phytoplankton. This relationship could have ripple effects up the food chain, potentially affecting snow crab, which feed on species that rely on plankton.[131]

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[126] Brown, Maggie. "How Warming Waters around P.E.I. Could Affect Snow Crab and Lobster." CBC News. Accessed June 19, 2023. https://www.cbc.ca/news/canada/prince-edward-island/pei-cbc-ocean-temperatures-rise-dfo-concerns-1.6831992.
[127] Galbraith, et al. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2020. 2021. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40980856.pdf
[128] Lavoie, et al. Projections of future physical and biogeochemical conditions in the Gulf of St. Lawrence, on the Scotian Shelf and in the Gulf of Maine. 2020. https://publications.gc.ca/collections/collection_2020/mpo-dfo/Fs97-18-334-eng.pdf
[129] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[130] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[131] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report."

- An increased prevalence of disease may occur under increasing temperatures, resulting in decreased marketability and even snow crab mortality.[132,133]

Infrastructure (Rating: 2 – Minimal)

Damage to infrastructure due to increased temperatures is unlikely to be severe and most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 3 – Moderate)

If consistent temperatures above the temperature threshold for snow crab occur, the industry could be less profitable, leading to a disruption in livelihoods and a loss of income. Rating considerations included:

- Snow crabs are PEI's second most valuable fishery, with a value of about $45,156,000 in 2021.[134] If warmer future conditions result in less productive snow crab growth, the snow crab industry in PEI may decline and could support fewer employment opportunities.
- Changes in sea ice can impact the timing of snow crab operations.
    - For example, earlier ice melt due to warmer temperatures in the spring could potentially result in an earlier start of the fishing season.
- Oceanic warming may force crabs to migrate to colder temperatures, extending trips (and costs) for commercial harvesters. If the impacts of increased temperatures on the snow crab industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures above 12°C
Impact: Lethal limit

Increasing frequency of marine heat waves on PEI currently represents a **Medium** risk to PEI's snow crab industry. This risk increases but remains **Medium** into mid-century (Table 32). Production/output could be most significantly affected by this scenario.

Table 32. Snow crab risk summary for marine heat wave

Marine Heat Wave: Snow Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	4	2	3	3	**Medium (9.0)**	**Medium (12.0)**

[132] R. Chong, "Chapter 28 – Bitter crab disease." https://www.sciencedirect.com/science/article/abs/pii/B9780323954341000280
[133] D. Chapman, "What happened to the crabs?" https://environmentamerica.org/alaska/center/articles/what-happened-to-the-crabs/#:~:text=Snow%20Crabs%20can%20be%20subject,will%20likely%20increase%20the%20prevalence
[134] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Likelihood

Appendix B Heat Wave (Marine) provides additional details on likelihood rating assumptions. The snow crab ratings are relative to the critical sea surface temperature threshold of 12°C.

Current: (Rating: 3 – Possible)

As described in Heat Wave (Marine), historical observations indicate that the frequency, intensity, and duration of marine heat wave events are increasing. The 2012 Northwest Atlantic Marine Heat wave had a duration of 132 days and a maximum intensity of 4.5°C. [135] However, snow crab reside in deeper waters, which tend to have more stable temperatures. Increases in deep-water temperatures from marine heat waves cannot be assumed to be equal to those that occur at surface levels.[136]

Current: (Rating: 4 – Likely)

Under future warming, marine heat waves will become more frequent, intense, and longer-lasting. Future temperatures will be more likely to pass the threshold and will do so more frequently.

Consequences

Marine heat waves can cause large-scale mortality events for snow crabs, leading to significant reductions in yield. In extreme cases, fisheries may be forced to close due to decreased snow crab stocks. This in turn can significantly impact the income and livelihoods of snow crab harvesters.

Production/Output (Rating: 4 – Significant)

More frequent and intense marine heat waves could result in a noticeable reduction in productivity and outputs as marine heat waves can lead to snow crab mortality events, reducing snow crab production. Rating considerations included:

- Severe marine heat waves can lead to large-scale mortality events. Temperatures greater than 12°C are lethal to snow crabs within 96 hours.[137]
- During the marine heat wave in 2012, water temperatures reached a record high on the western Scotian Shelf, which led to the near disappearance of snow crab. Bottom water temperature increased above the 7 °C metabolic thermal breakpoint. The marine heat wave also led to substantial reductions in snow crab abundance on the eastern Scotian Shelf and resulted in several years of unexpectedly low harvest.[138]
    - From 2021 to 2022, marine heat waves caused an 80% decrease in snow crab stock, forcing a fishery in Alaska to shut down.[139]

Infrastructure (Rating: 2 – Minimal)

Damage to infrastructure due to increased temperatures is unlikely to be severe and most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

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[135] See the Heat Wave (Marine) section for an explanation of the methodology used to extrapolate current and future marine heat wave temperature values.
[136] Brown, Maggie. "How Warming Waters around P.E.I. Could Affect Snow Crab and Lobster."
[137] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[138] Zisserson, Ben and Cook, Adam, "Impact of Bottom Water Temperature Change on the Southernmost Snow Crab Fishery in the Atlantic Ocean," *Fisheries Research* 195 (November 1, 2017): 12–18, https://doi.org/10.1016/j.fishres.2017.06.009.
[139] Brown, Maggie. "How Warming Waters around P.E.I. Could Affect Snow Crab and Lobster."

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 3 – Moderate)

If an increased frequency and/or severity of extreme temperatures and marine heat waves occur, the snow crab industry could be less profitable, leading to a significant disruption in livelihoods and a noticeable loss of income and employment opportunities. Rating considerations included:

- Snow crabs are PEI's second most valuable fishery, with a value of about $45,156,000 in 2021.[100] If more frequent marine heat waves result in less productive snow crab growth, the snow crab industry in PEI may decline and could support fewer employment opportunities.
- Heat wave events may cause crabs to migrate to colder temperatures, extending trips (and costs) for commercial harvesters. If the impacts of increased temperatures on the snow crab industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **Medium** risk to PEI's snow crab industry for both the current period and mid-century (Table 33). Infrastructure could be most significantly affected by this scenario.

Table 33. Snow crab risk summary for post-tropical storm

Post-Tropical Storm: Snow Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	1	4	2	2.3	**Medium (9.3)**	**Medium (9.3)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

Post-tropical storms are unlikely to occur during snow crab fishing season and therefore there are limited consequences to production, output, and livelihoods. Post-tropical storms still may cause significant damage to fishing fleets, equipment, and other critical infrastructure.

Production/Output (Rating: 1 – Insignificant)

Post-tropical storms are unlikely to occur during the snow crab fishing season (mid-April to late-June). Further, snow crabs live in very deep water that is unlikely to be significantly affected by changing water conditions due to post-tropical storms.

Infrastructure (Rating: 4 – Significant)

Significant, and/or widespread damage or failure to infrastructure can occur from post-tropical storms. Repairs or replacements may be costly and could take months to years from severe events. Rating considerations included:

- Severe events may result in loss or damage of fishing fleets and equipment (e.g., crab pots).
- Physical damages across Atlantic Canada from Post-Tropical Storm Fiona included breakwaters demolished and no longer protecting harbours, destroyed or lost fishing equipment, floating wharves ripped from mooring systems and washed away, and electrical systems destroyed by storm surge.[140]
- Boat hauling capacity ahead of severe storm events is constrained on PEI. This limitation may result in boats remaining in the water during severe weather, increasing their vulnerability to damage.[141]
- Post-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to commercial fishing sites.

Livelihoods (Rating: 2 – Minimal)

While the snow crab industry is PEI's second most valuable industry,[142] the timing of post-tropical storm season and snow crab fishing season do not align. Thus, minimal impacts to livelihoods would be expected from this hazard. Some livelihood disruptions may occur due to damaged or lost infrastructure from post-tropical storms that occur outside the fishing season.

4. Acidification

Scenario: Acidification increases

Acidification on PEI currently represents a **Low** risk to PEI's snow crab industry. This risk increases but remains **Low** by mid-century (Table 34).

Table 34. Snow crab risk summary for acidification

Acidification: Snow Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	3	2	1	2	1.7	**Low (3.3)**	**Low (5.0)**

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions.

[140] Fisheries and Oceans Canada, "Government of Canada Support to Rebuild Small Craft Harbours and Recover Lost Fishing Gear Post-Hurricane Fiona."
[141] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[142] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Current: (Rating: 2 – Unlikely)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units, and decreasing at a rate of 0.04 units per decade.

Future: (Rating: 3 – Possible)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050.

Consequences

Acidification could weaken snow crab shells, which could have some implications for production/output and livelihoods, although overall consequences are not anticipated to be significant.

Production/Output (Rating: 2 – Minimal)

Acidification could weaken snow crab shells, increasing vulnerability to predators and decreasing the quality of the product. Rating considerations included:

- Increasing acidity is likely to impact snow crab's shells, such that they grow slower and are softer, which could lead them to be more vulnerable to predation.[143, 144]
- While there are not many studies on snow crab's pH tolerance, the closely related deep-sea Tanner crab is unable to cope with acute changes in acidity.[145]

Infrastructure (Rating: 1 – Insignificant)

Damage to infrastructure due to acidification is unlikely.

Livelihoods (Rating: 2 – Minimal)

Increased acidification could cause minimal disruption to livelihoods if snow crabs are unable to cope with changes in acidity, reducing harvest or quality.

5. Hypoxia

Scenario: More frequent hypoxic conditions

Hypoxia on PEI currently represents a **Low** risk to PEI's snow crab industry. This risk increases but remains **Low** by mid-century (Table 35).

Table 35. Snow crab risk summary for hypoxia

Hypoxia: Snow Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	1	1	1	1	**Low (3.0)**	**Low (4.0)**

Likelihood

Appendix B Hypoxia provides additional details on likelihood rating assumptions.

143 Pane, Eric F. and Barry, James P. "Extracellular Acid–Base Regulation during Short-Term Hypercapnia Is Effective in a Shallow-Water Crab, but Ineffective in a Deep-Sea Crab," *Marine Ecology Progress Series* 334 (March 26, 2007): 1–9.

144 W. Christopher Long, Katherine M. Swiney, and Robert J. Foy, "Effects of High PCO_2 on Snow Crab Embryos: Ocean Acidification Does Not Affect Embryo Development or Larval Hatching," October 7, 2022, https://doi.org/10.1101/2022.10.06.511099.

145 "Alaska Shellfish Ocean Acidification and Climate Research," NOAA Fisheries, accessed May 11, 2023, https://www.fisheries.noaa.gov/alaska/science-data/alaska-shellfish-ocean-acidification-and-climate-research.

Current: (Rating: 3 – Possible)
Hypoxia is worsening in the Gulf of St. Lawrence due to many factors, including warmer upper-ocean temperatures.

Future: (Rating: 4 – Likely)
Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase, potentially causing more frequent or widespread hypoxia events.

Consequences

Hypoxia is not expected to affect PEI's snow crab industry.

Production/Output (Rating: 1 – Insignificant)
Hypoxia is typically not a limiting factor for snow crab, as the species is hypoxia tolerant. [146] Adult male snow crabs are frequently encountered in hypoxic waters. [147]

Infrastructure (Rating: 1 – Insignificant)
Hypoxia does not affect infrastructure.

Livelihoods (Rating: 1 – Insignificant)
Hypoxia is not expected to impact livelihoods.

Atlantic Bluefin Tuna (*Thunnus thynnus*)

The Atlantic bluefin tuna (*Thunnus thynnus*) is a large species of tuna native to the western Atlantic Ocean. The fishing season for Atlantic bluefin tuna on PEI is generally from July to October. However, there is some variance in the fishing season as it operates on a quota system. Commercial fisheries use rod and reel to catch tuna around PEI, and tuna in the region typically weigh between 400 and 1,000 pounds.

Figure 16. Atlantic bluefin tuna fishing. Source: The Bass Barn.

Atlantic bluefin tuna is sold fresh on PEI. In 2021, the PEI Atlantic bluefin tuna fishing industry recorded a harvest weight of 412,538 pounds, representing a market value of just over $2.8 million.[148]

Figure 17 summarizes climate risks to Atlantic bluefin tuna. Post-tropical storms pose the greatest risk to tuna due to damage or destruction of fishing gear and fishing vessels and the

[146] Guenette, "Chapter 4. A Review of the Physiological Susceptibility of Commercial Species of Fish and Crustaceans of the Northwest Atlantic to Changes in Water Temperature, Dissolved Oxygen, PH and Salinity."
[147] Guenette, "Chapter 4. A Review of the Physiological Susceptibility of Commercial Species of Fish and Crustaceans of the Northwest Atlantic to Changes in Water Temperature, Dissolved Oxygen, PH and Salinity."
[148] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

subsequent disruption to livelihoods in the months following the storm. No climate hazards received a High risk rating or a significant consequence rating.

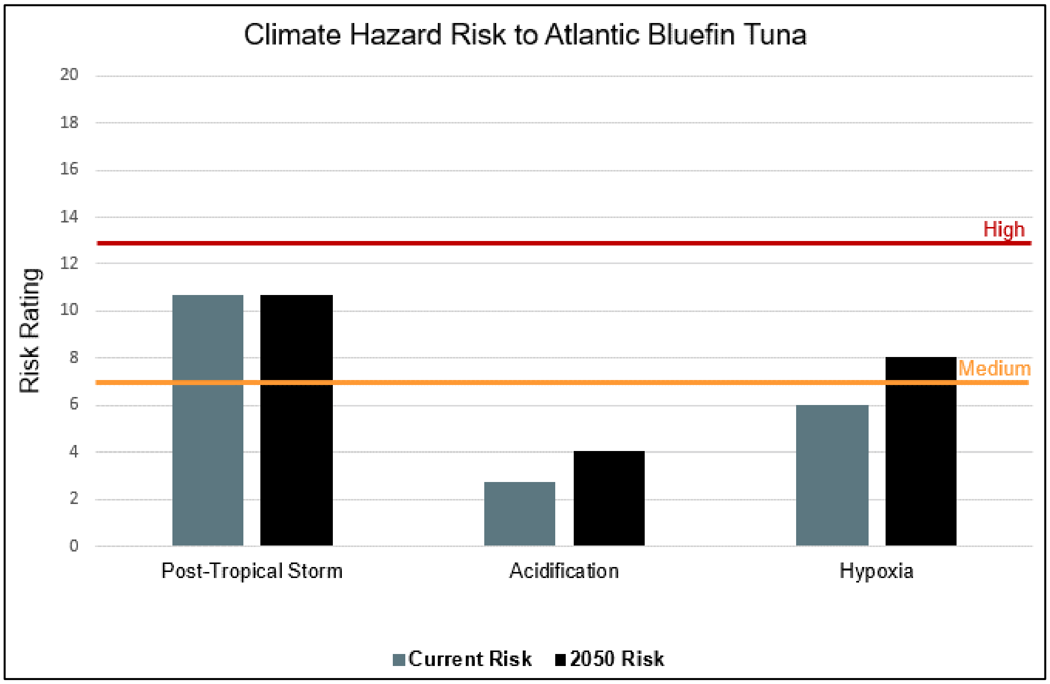

Figure 17. Summary of current and future climate hazard risk to Atlantic bluefin tuna.

1. Oceanic/Riverine Warming

Scenario: Average sea surface temperature rises above 30°C
Species Impact: Heightened vulnerability to overheating and hypoxia

This scenario is **almost certain not to occur** by mid-century (likelihood rating: 1). For details, see Oceanic/Riverine Warming. As a result, ICF did not evaluate the consequences of this scenario and the overall risk to PEI's Atlantic bluefin tuna industry is **Negligible**.

Warming oceanic temperatures may shift migration patterns of Atlantic bluefin tuna favourably for PEI. Recent harvest statistics indicate a larger proportion of the harvest is occurring in Canada, relative to the United States, suggesting tuna may be shifting their migration patterns farther northward to adjust to prey that favour the cooler waters.[149, 150]

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures above 33°C
Species Impact: Lethal limit

This scenario is **almost certain not to occur** by mid-century (likelihood rating: 1). For details, see Heat Wave (Marine). As a result, ICF did not evaluate the consequences of this scenario and the overall risk to PEI's Atlantic bluefin tuna industry is **Negligible**.

[149] Muhling et al., "Projections of Future Habitat Use by Atlantic Bluefin Tuna."
[150] "Atlantic Bluefin Tuna."

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **Medium** risk to PEI's Atlantic bluefin tuna industry for both the current period and mid-century (Table 36).

Table 36. Atlantic bluefin tuna risk summary for post-tropical storm

Post-Tropical Storm: Atlantic Bluefin Tuna							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	2	3	3	2.7	**Medium (10.7)**	**Medium (10.7)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

While post-tropical storms pose minimal direct consequences to production/output, infrastructure such as fishing gear and fishing vessels may be destroyed in intense events, which could lead to disruptions to tuna harvesters' livelihoods. The ramifications of an intense post-tropical storm could linger for months and, should fishing vessels, harbours, or wharves incur significant damage could result in harvesters not meeting their seasonal quota due to the inability to access the water.

Production/Output (Rating: 2 – Minimal)

Disruption to production/output may occur; however, unless vessels are severely damaged, disruptions are likely to be quickly resolved. Rating considerations included:

- Changes in turbulence might affect larval growth and survival. However, Atlantic bluefin tuna spawn primarily in the Gulf of Mexico between March and June, prior to most intense storms.
- Increased severe storm activity may decrease the number of fishing days in a season, leading to a reduced number of caught tuna. If vessels are damaged and unable to function, production may decrease.
- Fuel shortages may occur due to high demand and the temporary inability to transport fuel to the Island. Harvesters may not be able to obtain sufficient fuel for offshore trips, decreasing the number of fishing days in a season and potentially reducing the number of caught tuna.

Infrastructure (Rating: 3 – Moderate)

Fishing equipment, fishing vessels, harbours, and wharves may incur damage from a post-tropical storm. Disruptions may take weeks to months to fully fix and depending on the severity and type of equipment damaged, disruptions may occur for a full season and not allow some harvesters to meet their seasonal quota. Rating considerations included:

- Post-Tropical Storm Fiona resulted in destroyed or lost fishing equipment as well as demolished breakwaters that could no longer protect harbours and floating wharves ripped from mooring systems and washed away.
- Damage to fishing vessels moored in harbour may occur. If severely damaged, vessels may need to be replaced, which can take weeks to months, depending on supply chain conditions.
- Boat hauling capacity ahead of severe storm events is constrained on PEI. This limitation may result in boats remaining in the water during severe weather, increasing their vulnerability to damage.[151]
- Post-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to commercial fishing sites.

Livelihoods (Rating: 3 – Moderate)

Livelihoods may be disrupted as income or employment opportunities may be reduced for days to months. More significant impact to livelihoods could occur if fishing equipment and vessels incur significant damage. Rating considerations included:

- The Atlantic bluefin tuna fishery is relatively small, compared to other species' industries on the Island. Island exports were worth approximately $2.8 million in 2021 and with over 400,000 pounds of tuna exported.[152]
- If fishing vessels or significant amounts of fishing equipment are damaged during a post-tropical storm event, this may effectively end the tuna fishing season for afflicted tuna harvesters, which may have a significant impact on livelihoods of harvesters.

4. Acidification

Scenario: Acidification increases

Increasing acidification on PEI currently represents a **Low** risk to PEI's Atlantic bluefin tuna industry. This risk increases but remains **Low** into mid-century (Table 37).

Table 37. Atlantic bluefin tuna risk summary for acidification

Acidification: Atlantic Bluefin Tuna							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	3	2	1	1	1.3	**Low (2.7)**	**Low (4.0)**

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions.

[151] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[152] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Current: (Rating: 2 – Unlikely)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units, and decreasing at a rate of 0.04 units per decade.

Future: (Rating: 3 – Possible)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050.

Consequences

Acidification poses insignificant to minimal consequences to PEI's Atlantic bluefin tuna industry. The only potential consequence identified is acidic conditions leading to the displacement of tuna prey and thereby affecting tuna foraging patterns, potentially reducing harvest.

Production/Output (Rating: 2 – Minimal)

Acidification is unlikely to significantly affect bluefin tuna directly; however, acidification can cause negative impacts for calcifying organisms and some species of plankton which the prey of bluefin tuna and/or bluefin tuna larvae feed on. If the prey base is significantly impacted, bluefin tuna may alter their foraging and migratory patterns, which could reduce harvest near PEI.[153]

Infrastructure (Rating: 1 – Insignificant)

Acidification does not affect infrastructure related to the commercial bluefin tuna industry.

Livelihoods (Rating: 1 – Insignificant)

Harvest is unlikely to be significantly affected by acidification; tuna harvesters are unlikely to have their livelihoods affected by this hazard.

5. Hypoxia

Scenario: More frequent hypoxic conditions

Increasing frequency of hypoxia on PEI currently represents a **Low** risk to PEI's Atlantic bluefin tuna industry. This risk increases to **Medium** by mid-century (Table 38).

Table 38. Atlantic bluefin tuna risk summary for hypoxia

Hypoxia: Atlantic Bluefin Tuna							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	3	1	2	2	**Low (6.0)**	**Medium (8.0)**

Likelihood

Appendix B Hypoxia provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)

Hypoxia is worsening in the Gulf of St. Lawrence due to many factors, including warmer upper-ocean temperatures.

[153] I. Ruiz-Jarabo et al., "Survival of Atlantic Bluefin Tuna (Thunnus Thynnus) Larvae Hatched at Different Salinity and PH Conditions," *Aquaculture* 560 (November 15, 2022): 738457, https://doi.org/10.1016/j.aquaculture.2022.738457.

Future: (Rating: 4 – Likely)
Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase, potentially causing more frequent or widespread hypoxia events.

Consequences

Hypoxia poses minimal consequences to PEI's Atlantic bluefin tuna industry. The primary consequence is the potential for a decrease in harvest due to shifting tuna foraging patterns.

Production/Output (Rating: 3 – Moderate)
There may be a noticeable reduction in productivity and output. If hypoxic conditions persist throughout a full fishing season, tuna harvesters may not be able to meet their quota since tuna may alter migratory patterns to avoid hypoxic areas. Rating considerations included:

- Atlantic bluefin tuna in general are sensitive to low ambient oxygen conditions because of their high metabolic rates. The Atlantic bluefin tuna has a moderate ability to withstand lower oxygen conditions, relative to other species of tuna and billfish. As such, they may alter their foraging routes to avoid hypoxic conditions, potentially pushing them too far offshore to reasonably pursue from PEI's coast.[154] [155]
- Lower oxygen conditions may cause tuna to move to deeper, cooler waters to more easily thermoregulate under stressful conditions. This shift to deeper waters could potentially reduce harvest.[156]

Infrastructure (Rating: 1 – Insignificant)
Hypoxic conditions do not affect infrastructure.

Livelihoods (Rating: 2 – Minimal)
There may be a minimal disruption to livelihoods. Increased hypoxic conditions in traditional tuna waters near PEI may result in decreased harvest for tuna harvesters, potentially resulting in them being unable to make their seasonal quotas and losing income opportunity. If these conditions become permanent and tuna are unable to be caught offshore of PEI, this could affect culture on PEI, as tuna fishing is part of the Island's heritage.

Atlantic Mackerel (*Scomber scombrus*)

The Atlantic mackerel (*Scomber scombrus*) is a species of mackerel found in the northern Atlantic Ocean. There was no mackerel fishery on PEI in 2022 and there hasn't been one in 2023. However, if regulations allow for a season, Atlantic mackerel are typically fished from June to December. Atlantic mackerel are primarily fished by PEI inshore harvesters using gill nets or handlines and the

Figure 18. Atlantic mackerel. Source: CBC News.

[154] Shirley Leung et al., "Section 8.2 The Significance of Ocean Deoxygenation for Open Ocean Tunas and Billfishes," in *Ocean Deoxygenation: Everyone's Problem* (International Union for the Conservation of Nature (IUCN), 2019), 277–308, https://portals.iucn.org/library/sites/library/files/documents/08.2%20DEOX.pdf.
[155] Dell'Apa et al., "Potential Medium-Term Impacts of Climate Change on Tuna and Billfish in the Gulf of Mexico."
[156] Muhling et al., "Projections of Future Habitat Use by Atlantic Bluefin Tuna."

majority of mackerel are used as bait for the pot fisheries.

The products derived from Atlantic mackerel include mackerel fillets, fresh and frozen mackerel, as well as smoked and salted mackerel. In 2021, the PEI Atlantic mackerel fishing industry recorded a harvest weight of over 2.6 million pounds, representing a market value of over $3.2 million. The industry is supported by 1,256 licensed mackerel harvesters.[157]

Figure 19 summarizes climate risks to Atlantic mackerel. Marine heat waves pose the greatest risk and may cause significant reductions in productivity and outputs due to thermal stress or lethality.

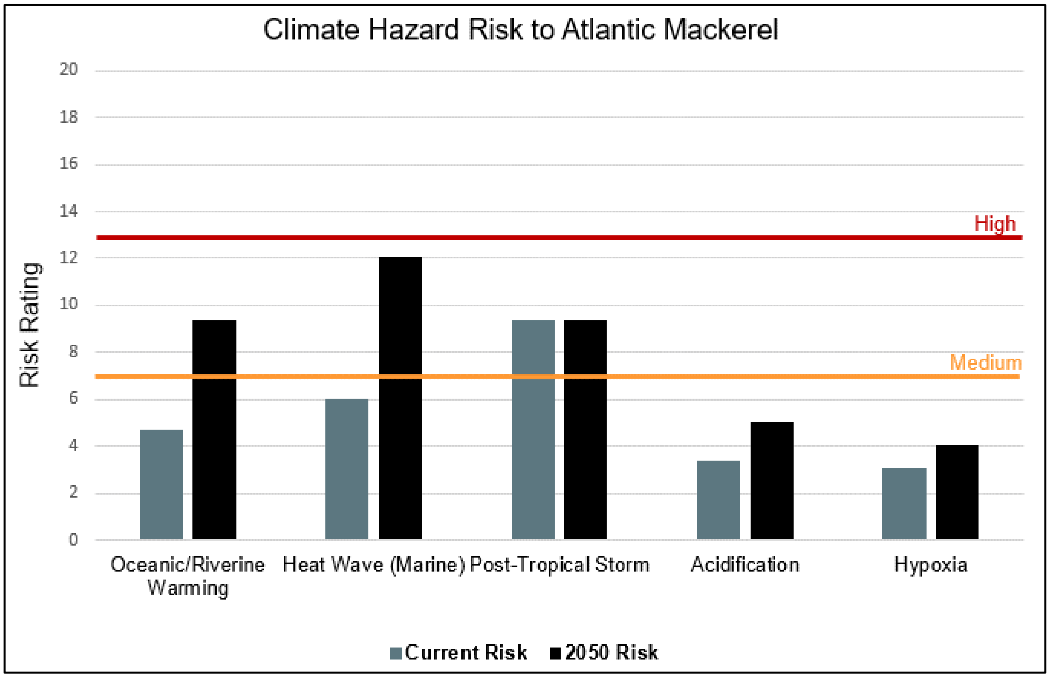

Figure 19. Summary of current and future climate hazard risk to Atlantic mackerel.

1. Oceanic/Riverine Warming

Scenario: Average sea surface temperature rises above 22°C
Species Impact: Larval thermal lethal max

Oceanic/riverine warming on PEI currently represents a **Low** risk to PEI's Atlantic mackerel industry. This risk increases to **Medium** by mid-century (Table 39).

Table 39. Atlantic mackerel risk summary for oceanic/riverine warming

Oceanic/Riverine Warming: Atlantic Mackerel							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	4	3	2	2	2.3	**Low (4.7)**	**Medium (9.3)**

[157] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The Atlantic mackerel ratings are relative to the critical sea surface temperature threshold of 22°C.

Current: (Rating: 2 – Unlikely)
In the Gulf of St. Lawrence, average summer sea surface temperatures currently range from 16°C to 19°C.

Future: (Rating: 4 – Likely)
Under a high emissions scenario, average summer sea surface temperatures are projected to range from 20°C to 23°C by 2050.

Consequences

Oceanic/riverine warming can lead to lower productivity for mackerel harvesters, as mackerel egg and larvae are especially sensitive to increases in temperature. Any changes in the distribution of Atlantic mackerel and/or survivability will likely affect the livelihoods of those involved in the mackerel industry. The lobster industry, which uses Atlantic mackerel as bait, may be impacted as well.

Production/Output (Rating: 3 – Moderate)
Increases in temperature could result in a noticeable reduction in productivity and outputs as Atlantic Mackerel may spend less time within optimal temperatures, especially during particularly warm summers. Rating considerations included:

- Atlantic mackerel are sensitive to changes in temperature, preferring temperatures between 7–16°C for adults and 8–13°C for larvae.[158,159,160]
    - Thermal stresses on larvae are the most significant issue with warming ocean temperatures above 22°C. Whereas adult mackerel could migrate away from the warm waters, larvae are at risk of lethal consequences. Although this may not be an immediate issue, it is an indicator that Atlantic mackerel may migrate away to a cooler location.
    - Changing temperatures can affect the timing and location of spawning, as they ocur near surface waters of at least 7°C (optimal: 9–14°C).[161,162]
    - Mackerel egg and larvae are especially sensitive to temperature changes, with the potential for increased mortality as temperatures increase.[163]
- Earlier melting of sea ice may result in earlier spring blooms of phytoplankton, potentially causing cause a mismatch for zooplankton, which feed upon phytoplankton. This

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[158] Anne L. Studholme, "Essential fish habitat source document. Atlantic mackerel, Scomber scombrus, life history and habitat characteristics," National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum NMFS-NE-141, 1999.
[159] W. J. Overholtz, J. A. Hare, and C. M. Keith, "Impacts of Interannual Environmental Forcing and Climate Change on the Distribution of Atlantic Mackerel on the U.S. Northeast Continental Shelf," *Marine and Coastal Fisheries* 3, no. 1 (January 1, 2011): 219–32, https://doi.org/10.1080/19425120.2011.578485.
[160] Robin Boyd et al., "Potential Consequences of Climate and Management Scenarios for the Northeast Atlantic Mackerel Fishery," *Frontiers in Marine Science* 7 (2020), https://www.frontiersin.org/articles/10.3389/fmars.2020.00639.
[161] Fisheries and Oceans Canada, "2022 Atlantic Mackerel Integrated Fisheries Management Plan (IFMP)," December 20, 2022, https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/mackerel-atl-maquereau/mac-atl-maq-2022-eng.html.
[162] Antoine Bruge et al., "Thermal Niche Tracking and Future Distribution of Atlantic Mackerel Spawning in Response to Ocean Warming," *Frontiers in Marine Science* 3 (2016), https://www.frontiersin.org/articles/10.3389/fmars.2016.00086.
[163] Fisheries and Oceans Canada, "2022 Atlantic Mackerel Integrated Fisheries Management Plan (IFMP)," December 20, 2022, https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/mackerel-atl-maquereau/mac-atl-maq-2022-eng.html.

relationship could have ripple effects up the food chain, potentially affecting mackerel, which feed on species that rely on plankton.[164,165]

  - Shifting distribution and abundance of mackerel prey impact mackerel distribution and migration patterns. Delayed migration may cause a temporal mismatch with the spring lobster fishing season, causing challenges for lobster fisherman's procurement of mackerel bait.

Infrastructure (Rating: 2 – Minimal)

There may be minimal disruption to infrastructure due to increased temperatures. Most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 2 – Minimal)

If consistent temperatures above the temperature threshold for Atlantic mackerel occur, the industry could be less profitable, leading to a disruption in livelihoods and a noticeable loss of income. However, the Atlantic mackerel fishery is a relatively small industry on PEI. Rating considerations included:

- The Atlantic mackerel fishery had a value of $3,241,000 in 2021, with a count of 1,256 licensed mackerel fisheries.[166]
- Atlantic mackerel is a source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery. If warmer future conditions result in less productive Atlantic mackerel growth, the mackerel industry in PEI may decline and could affect the lobster industry (e.g., other bait that is more expensive may need to be purchased).[167]
- If the impacts of increased temperatures on the Atlantic mackerel industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.
- Atmospheric extreme heat and heat waves can also pose safety risks for those involved in the industry.

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures above 28.5°C
Impact: Lethal limit

Increasing frequency of marine heat waves on PEI currently represents a **Low** risk to PEI's Atlantic mackerel industry. This risk increases to **Medium** by mid-century (Table 40). Production/output could be most significantly affected by this scenario.

[164] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report."
[165] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[166] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[167] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."

Table 40. Atlantic mackerel risk summary for marine heat wave

Marine Heat Wave: Atlantic Mackerel							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	4	4	2	3	3	**Low (6.0)**	**Medium (12.0)**

Likelihood

Appendix B Heat Wave (Marine) provides additional details on likelihood rating assumptions. The Atlantic mackerel ratings are relative to the critical sea surface temperature threshold of 28.5°C.

Current: (Rating: 2 – Unlikely)
Summer marine heat waves can range from 20.5°C to 23.5°C.

Future: (Rating: 4 – Likely)
Under a high emissions scenario, a summer marine heat wave could range from 24.5°C to 27.5°C by 2050.

Consequences

Marine heat waves could result in a noticeable reduction in productivity and outputs due to thermal stress or lethal outcomes for Atlantic mackerel. Any changes in the distribution of Atlantic mackerel and/or survivability will likely affect the livelihoods of those involved in the mackerel industry, in addition to the lobster industry, which has used Atlantic mackerel as bait.

Production/Output (Rating: 4 – Significant)
Extreme heat and marine heat waves could result in a significant reduction in productivity and outputs as Atlantic mackerel may spend less time within optimal temperatures and closer to lethal or dangerous temperatures. Rating considerations included:

- Atlantic mackerel are sensitive to extreme heat, with detrimental or lethal effects seen at 28.5°C for adults and 22°C for larval mackerel.[168]
    - Sustained exposure to high temperatures can induce thermal stress and potentially affect the feeding and reproductive habits of Atlantic Mackerel.[169]
    - Marine heat waves can result in the migration of Atlantic Mackerel, as populations move to cooler water to avoid the direct impacts of such events.[170]

Infrastructure (Rating: 2 – Minimal)
There may be minimal damage/disruption to infrastructure due to increased temperatures. Most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading

[168] Anne L. Studholme, “Essential fish habitat source document. Atlantic mackerel, Scomber scombrus, life history and habitat characteristics,” National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum NMFS-NE-141, 1999.
[169] Anne L. Studholme, “Essential fish habitat source document. Atlantic mackerel, Scomber scombrus, life history and habitat characteristics.”
[170] W. J. Overholtz, J. A. Hare, and C. M. Keith, “Impacts of Interannual Environmental Forcing and Climate Change on the Distribution of Atlantic Mackerel on the U.S. Northeast Continental Shelf,” *Marine and Coastal Fisheries* 3, no. 1 (January 1, 2011): 219–32, https://doi.org/10.1080/19425120.2011.578485.

to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 3 – Moderate)

If more days of extreme heat and/or marine heat waves occur, the industry could be less profitable, leading to a disruption in livelihoods and a noticeable loss of income and employment opportunities. However, the Atlantic mackerel fishery is a relatively small industry on PEI. Rating considerations included:

- The Atlantic mackerel fishery had a value of $3,241,000 in 2021, with a count of 1,256 licensed mackerel fisheries.[171]
- Atlantic Mackerel is a source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery, with a value of $370,882,000 in 2021.[172] If extreme heat and marine heat waves result in adverse impacts on Atlantic Mackerel populations, the mackerel industry in PEI may decline and also affect the lobster industry (e.g., other bait that is more expensive may need to be purchased). This change could support fewer employment opportunities.[173]
- Atmospheric extreme heat and marine heat waves can also pose safety risks for those involved in the industry.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represents a **Medium** risk to PEI's Atlantic mackerel industry for the current period and mid-century (Table 41).

Table 41. Atlantic mackerel risk summary for post-tropical storm

Post-Tropical Storm: Atlantic Mackerel							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	2	3	2	2.3	**Medium (9.3)**	**Medium (9.3)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

[171] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[172] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[173] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."

Consequences

Post-tropical storms pose consequences to PEI's Atlantic mackerel industry, primarily due to infrastructural damage to fishing fleets and equipment.

Production/Output (Rating: 2 – Minimal)

Minimal disruption to the Atlantic mackerel industry could occur as a result of more frequent and/or intense storms. Rating considerations included:

- Storms, and resulting impacts such as damaged equipment, may impede harvesters from accessing mackerel stocks.
- Severe storms also have safety implications for Atlantic mackerel harvesters, resulting hindered access to fisheries and less fish caught.

Infrastructure (Rating: 3 – Moderate)

Damage to infrastructure due to increasing frequency and intensity of storms is likely to be severe and repairments/replacements of most equipment could take weeks to months. Rating considerations included:

- Severe storm events can result in the loss or damage of fishing fleets and equipment.
- Boat hauling capacity ahead of severe storm events is constrained on PEI. This limitation may result in boats remaining in the water during severe weather, increasing their vulnerability to damage.[174]
- Post-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to commercial fishing sites.

Livelihoods (Rating: 2 – Minimal)

If more frequent and/or severe storms occur, the Atlantic mackerel industry could be less profitable, leading to a disruption to livelihoods and a loss of income and employment opportunities. However, the Atlantic mackerel fishery is a relatively small industry on PEI. Rating considerations included:

- The Atlantic mackerel fishery had a value of $3,241,000 in 2021, with a count of 1,256 licensed mackerel fisheries.[175]
- Atlantic mackerel is a source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery. If more frequent and severe storms occur, there may be less productive Atlantic mackerel growth, potentially resulting in a decline of the mackerel industry in PEI. This change could affect the lobster industry (e.g., other bait that is more expensive may need to be purchased), as well as support fewer employment opportunities.
- Storms can also have significant safety implications for those involved in the Atlantic mackerel industry.

[174] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[175] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

4. Acidification

Scenario: Acidification increases

Acidification on PEI currently represents a **Low** risk to PEI's Atlantic mackerel industry. This risk increases but remains **Low** by mid-century (Table 42).

Table 42. Atlantic mackerel risk summary for acidification

Acidification: Atlantic Mackerel							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	3	2	1	2	1.7	**Low (3.3)**	**Low (5.0)**

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions.

Current: (Rating: 2 – Unlikely)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units, and decreasing at a rate of 0.04 units per decade.

Future: (Rating: 3 – Possible)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050.

Consequences

Although acidification is unlikely to affect Atlantic mackerel directly, acidification could adversely affect prey, which could have ripple effects on Atlantic mackerel.

Production/Output (Rating: 2 – Minimal)

Although acidification is unlikely to affect Atlantic mackerel directly, it can cause adverse impacts for some species of plankton that mackerel feed on. Significant impacts to mackerel prey abundance could affect mackerel populations.

Infrastructure (Rating: 1 – Insignificant)

Damage to infrastructure due to acidification is unlikely.

Livelihoods (Rating: 2 – Minimal)

If acidification results in a loss of mackerel prey abundance, the Atlantic mackerel industry could become less profitable, leading to a minimal disruption to livelihoods and loss of income and employment opportunities. However, the Atlantic mackerel fishery is a relatively small industry on PEI. Rating considerations included:

- The Atlantic mackerel fishery had a value of $3,241,000 in 2021, with a count of 1,256 licensed mackerel fisheries.[176]
- Atlantic mackerel is a source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery. If the mackerel population changes due to acidification impacts on its prey, there may be less productive Atlantic Mackerel growth, potentially

[176] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

resulting in a decline of the mackerel industry and changes to the lobster industry in PEI (e.g., other bait that is more expensive may need to be purchased).

5. Hypoxia

Scenario: More frequent hypoxic conditions

Increasing frequency of hypoxia on PEI represents a **Low** risk to PEI's Atlantic mackerel industry for the current period and mid-century (Table 43).

Table 43. Atlantic mackerel risk summary for hypoxia

Hypoxia: Atlantic Mackerel							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	1	1	1	1	**Low (3.0)**	**Low (4.0)**

Likelihood

Appendix B Hypoxia provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Hypoxia is worsening in the Gulf of St. Lawrence due to many factors, including warmer upper-ocean temperatures.

Future: (Rating: 4 – Likely)
Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase, potentially causing more frequent or widespread hypoxia events.

Consequences

Hypoxia is not expected to affect PEI's Atlantic mackerel industry.

Production/Output (Rating: 1 – Insignificant)
Hypoxia is typically not a limiting factor for Atlantic mackerel, as it is a pelagic, schooling species. Atlantic mackerel are likely to move to more oxygen dense areas, if available. However, large-scale-hypoxic events could result in die-offs.

Infrastructure (Rating: 1 – Insignificant)
Hypoxia does not affect infrastructure.

Livelihoods (Rating: 1 – Insignificant)
Hypoxia is not expected to impact livelihoods.

Atlantic Herring (*Clupea harengus*)

The Atlantic herring (*Clupea harengus*) is a species of slab-sided northern fish that can be found in the North Atlantic. The fishing season for Atlantic herring on PEI is from May to October.

The products derived from the Atlantic herring are diverse, including fresh, frozen, smoked, and pickled herring, as well as solomon gundy and herring roe. Herring can also be used as lobster bait on PEI. In 2021, the PEI Atlantic herring fishing industry recorded a harvest weight of over

4.7 million pounds, representing a market value of approximately $1.5 million. There are 869 herring harvesters on PEI.[177]

Figure 20. Atlantic herring catch. Source: [Pew Charitable Trusts](#).

Figure 21 summarizes climate risks to Atlantic herring. Marine heat waves have the highest risk rating and most severe consequences. This risk is driven by the potential for a significant reduction in productivity and outputs due to thermal stress or even lethal outcomes for Atlantic herring.

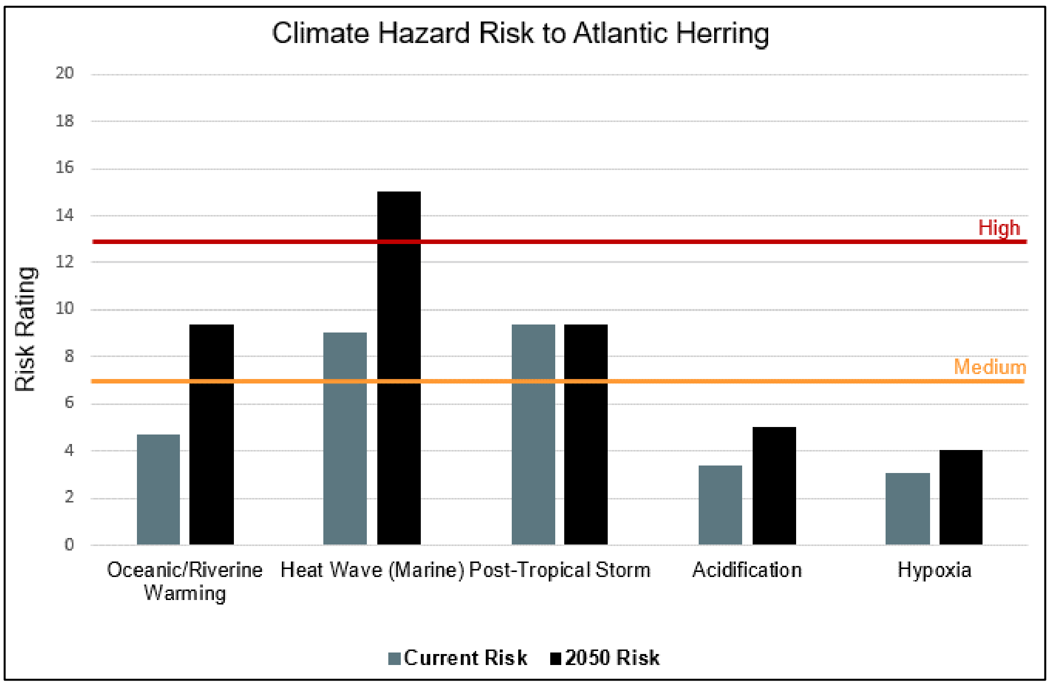

Figure 21. Summary of current and future climate hazard risk to Atlantic herring.

1. Oceanic/Riverine Warming

Scenario: Average sea surface temperature rises above 22.5°C
Species Impact: Larval thermal lethal max

Oceanic/riverine warming on PEI currently represents a **Low** risk to PEI's Atlantic herring industry. This risk increases to **Medium** by mid-century (Table 44).

[177] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Table 44. Atlantic herring risk summary for oceanic/riverine warming

Oceanic/Riverine Warming: Atlantic Herring							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	4	3	2	2	2.3	**Low (4.7)**	**Medium (9.3)**

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The Atlantic herring ratings are relative to the critical sea surface temperature threshold of 22.5°C.

Current: (Rating: 2 – Unlikely)

In the Gulf of St. Lawrence, average summer sea surface temperatures currently range from 16°C to 19°C.

Future: (Rating: 4 – Likely)

Under a high emissions scenario, average summer sea surface temperatures are projected to range from 20°C to 23°C by 2050.

Consequences

Oceanic/riverine warming could affect herring larvae which are especially vulnerable to increases in temperature and are at risk to lethal outcomes. Any changes to productivity due to this hazard can affect the livelihoods of those in the Atlantic herring industry. It may also impact those in the lobster industry, which uses herring as bait.

Production/Output (Rating: 3 – Moderate)

Increases in temperature could result in a noticeable reduction in productivity and outputs as Atlantic herring may spend less time within optimal temperatures, especially during particularly warm summers. Rating considerations included:

- Atlantic herring are sensitive to changes in temperature, preferring a temperature range of 5–19°C for adults and 8–16°C for larvae.[178,179,180]
    - Thermal stresses on larvae are the most significant issue at a warming of ocean temperatures above 22.5°C.[181] Whereas adult herring could migrate away from the warm waters, larvae are at risk of lethal consequences. Although this may not be an immediate issue, it is an indicator that Atlantic herring may migrate away to a cooler location.
    - Warmer temperatures could impact spawning, such as by decreasing larvae survivability and decreasing prey availability.[182,183]

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[178] Marta Moyano et al., "Linking individual physiological indicators to the productivity of fish populations: A case study of Atlantic herring," *Ecological Indicators* 113 (2022): 106146, https://literatur.thuenen.de/digbib_extern/dn062349.pdf
[179] "Atlantic herring, Clupea harengus," McGill University, n.d., http://www.geog.mcgill.ca/climatechange/ReportsMap/Clupea%20harengus.pdf.
[180] Bridie J M Allan et al., "Increasing Temperature and Prey Availability Affect the Growth and Swimming Kinematics of Atlantic Herring (Clupea Harengus) Larvae," *Journal of Plankton Research* 44, no. 3 (May 1, 2022): 401–13, https://doi.org/10.1093/plankt/fbac014.
[181] Marta Moyano et al., "Linking individual physiological indicators to the productivity of fish populations: A case study of Atlantic herring," *Ecological Indicators* 113 (2022): 106146, https://literatur.thuenen.de/digbib_extern/dn062349.pdf
[182] Michael Sswat et al., "Growth Performance and Survival of Larval Atlantic Herring, under the Combined Effects of Elevated Temperatures and CO2," *PLoS ONE* 13, no. 1 (January 25, 2018): e0191947, https://doi.org/10.1371/journal.pone.0191947.
[183] Elettra Leo et al., "Impact of Ocean Acidification and Warming on the Bioenergetics of Developing Eggs of Atlantic Herring Clupea Harengus," *Conservation Physiology* 6, no. 1 (January 1, 2018): coy050, https://doi.org/10.1093/conphys/coy050.

- Earlier melting of sea ice may result in earlier spring blooms of phytoplankton, potentially causing cause a mismatch for zooplankton, which feed upon phytoplankton. This relationship could have ripple effects up the food chain, potentially affecting herring, which feed on species that rely on plankton.[184,185]
    - Shifting distribution and abundance of herring prey (e.g., plankton for herring larvae) in part affect the distribution and migration patterns of herring. This delayed migration may cause a temporal mismatch with the spring lobster fishing season, causing challenges for lobster fisherman's procurement of herring bait.[186]

Infrastructure (Rating: 2 – Minimal)

There may be minimal damage/disruption to infrastructure due to increased temperatures. Most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 2 – Minimal)

If consistent temperatures above the temperature threshold for Atlantic herring occur, the industry could be less profitable, leading to a disruption in livelihoods and a loss of income and employment opportunities. However, the Atlantic herring fishery is a relatively small industry on PEI. Rating considerations included:

- The Atlantic herring fishery had a value of $1,536,000 in 2021, with a count of 869 licensed herring harvesters.[187]
- Atlantic herring is a major source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery. If warmer future conditions result in less productive Atlantic herring growth, the herring industry in PEI may decline and affect the lobster industry (e.g., other bait may need to be purchased).
- If the impacts of increased temperatures on the Atlantic herring industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures of at least 25.5°C
Impact: 3°C warmer than larval thermal max

Increasing frequency of marine heat waves on PEI currently represents a **Medium** risk to PEI's Atlantic herring industry. This risk increases to **High** by mid-century (Table 45). Production/output could be most significantly affected by this scenario.

[184] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report."
[185] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[186] Fisheries and Oceans Canada, "Canada's Oceans Now 2020," 2020, https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40939236.pdf.
[187] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Table 45. Atlantic herring risk summary for marine heat wave

Marine Heat Wave: Atlantic Herring							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	4	2	3	3	**Medium (9.0)**	**High (15.0)**

Likelihood

Appendix B Heat Wave (Marine) provides additional details on likelihood rating assumptions. The Atlantic herring ratings are relative to the critical sea surface temperature threshold of 25.5°C.

Current: (Rating: 3 – Possible)
Summer marine heat waves can range from 20.5°C to 23.5°C.

Future: (Rating: 5 – Almost Certain)
Under a high emissions scenario, a summer marine heat wave could range from 24.5°C to 27.5°C by 2050.

Consequences

Marine heat waves could result in a noticeable reduction in productivity and outputs due to thermal stress or even lethal outcomes for Atlantic herring, thereby affecting livelihoods and income.

Production/Output (Rating: 4 – Significant)
Extreme heat and marine heat waves could result in a significant reduction in productivity and outputs as Atlantic herring may spend less time within optimal temperatures and closer to lethal or dangerous temperatures. Rating considerations included:

- Atlantic herring are sensitive to extreme heat, with temperatures of 25.5°C or above being dangerous and even lethal.[188]
    - Sustained exposure to high temperatures can induce thermal stress and potentially affect the feeding and reproductive habits of Atlantic herring.[189]
    - Marine heat waves can result in the migration of Atlantic herring, as populations move to cooler water to avoid the direct impacts of such events.

Infrastructure (Rating: 2 – Minimal)
There may be minimal damage/disruption to infrastructure due to increased temperatures. Most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on equipment and cause equipment to be more difficult to clean and maintain.

[188] Marta Moyano et al., “Linking individual physiological indicators to the productivity of fish populations: A case study of Atlantic herring,” *Ecological Indicators* 113 (2022): 106146, https://literatur.thuenen.de/digbib_extern/dn062349.pdf.
[189] Marta Moyano et al., “Linking individual physiological indicators to the productivity of fish populations: A case study of Atlantic herring.”

Livelihoods (Rating: 3 – Moderate)

If increasing extreme heat and or marine heat waves occur, the industry could be less profitable, leading to a disruption in livelihoods and a loss of income and employment opportunities. However, the Atlantic herring fishery is a relatively small industry on PEI. Rating considerations included:

- The Atlantic herring fishery had a value of $1,536,000 in 2021, with a count of 869 licensed herring harvesters.[190]
- Atlantic herring is a source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery. If extreme heat and/or marine heat waves result in less productive Atlantic herring growth, the herring industry in PEI may decline and affect the lobster industry (e.g., other bait that may need to be purchased). This change could support fewer employment opportunities.
- If the impacts of extreme heat and/or marine heat waves on the Atlantic herring industry are severe enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.
- Atmospheric extreme heat and marine heat waves can also pose safety risks for those involved in the industry.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI currently represents a **Medium** risk to PEI's Atlantic herring industry for both the current period and mid-century (Table 46).

Table 46. Atlantic herring risk summary for post-tropical storm

Post-Tropical Storm: Atlantic Herring							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	2	3	2	2.3	**Medium (9.3)**	**Medium (9.3)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

Post-tropical storms could affect PEI's Atlantic herring industry, with potentially far-reaching impacts on infrastructure such as fishing fleets and equipment. Herring fecundity is especially at risk to storm events, resulting in a risk of production/output reduction.

[190] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Production/Output (Rating: 2 – Minimal)

Minimal disruption to the Atlantic herring industry could occur as a result of more frequent and/or intense storms. Rating considerations included:

- Storms, and resulting impacts such as damaged equipment, may impede harvesters from accessing herring stocks.
- Storm events may impact herring egg survival and recruitment.[191]
- Severe storms also have safety implications for Atlantic herring harvesters, reducing the number of fishing days.

Infrastructure (Rating: 3 – Moderate)

Damage to infrastructure due to increasing frequency and intensity of storms is likely to be severe and repairments or replacements of most equipment could take weeks to months. Rating considerations included:

- Severe storm events can result in the loss or damage of fishing fleets and equipment.
- Boat hauling capacity ahead of severe storm events is constrained on PEI. This limitation may result in boats remaining in the water during severe weather, increasing their vulnerability to damage.[192]
- Post-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to commercial fishing sites.

Livelihoods (Rating: 2 – Minimal)

If more frequent and/or severe storms occur, the Atlantic herring industry could be less profitable, leading to a disruption to livelihoods and a loss of income and employment opportunities. Rating considerations included:

- The Atlantic herring fishery had a value of $1,536,000 in 2021, with a count of 869 licensed herring harvesters.[193]
- Atlantic herring is a source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery. If extreme heat and/or marine heat waves result in less productive Atlantic herring growth, the herring industry may decline and affect the lobster industry in PEI (e.g., other bait that is more expensive may need to be purchased). This change could support fewer employment opportunities.
- The fishery has been closed for the last two seasons, affecting livelihoods.
- Storms can also pose significant safety risks for those involved in the Atlantic herring industry

4. Acidification

Scenario: Acidification increases

Acidification on PEI currently represents a **Low** risk to PEI's Atlantic herring industry. This risk increases but remains **Low** by mid-century (Table 47).

[191] Jacob Burbank, et al., "Understanding factors influencing Atlantic herring (*Clupea harengus*) recruitment: From egg deposition to juveniles," *Fisheries Oceanography*, 32, no. 2 (March 2023): 147-159, https://doi.org/10.1111/fog.12621.
[192] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[193] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Table 47. Atlantic herring risk summary for acidification

Acidification: Atlantic Herring							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	3	2	1	2	1.7	**Low (3.3)**	**Low (5.0)**

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions.

Current: (Rating: 2 – Unlikely)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units, and decreasing at a rate of 0.04 units per decade.

Future: (Rating: 3 – Possible)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050.

Consequences

Although acidification is unlikely to affect Atlantic herring directly, acidification could adversely affect prey, which could have ripple effects on Atlantic herring.

Production/Output (Rating: 2 – Minimal)

Although acidification is unlikely to affect Atlantic herring directly, it can cause adverse impacts for some species of plankton that herring feed on. Significant impacts to herring prey abundance could affect herring populations.

Infrastructure (Rating: 1 – Insignificant)

Damage to infrastructure due to acidification is unlikely.

Livelihoods (Rating: 2 – Minimal)

If acidification results in a loss of herring prey abundance, the industry could become less profitable, leading to a minimal disruption to livelihoods and loss of income and employment opportunities. Rating considerations included:

- The Atlantic herring fishery had a value of $1,536,000 in 2021, with a count of 869 licensed herring harvesters.[194]
- Atlantic herring is a source of bait for other industries, most significantly, lobster, which is PEI's most valuable fishery. If herring population changes occur due to acidification impacts on its prey, there may be less productive herring growth, potentially resulting in a decline of the herring industry and affect the lobster industry in PEI (e.g., may need to identify other bait to purchase). This change may support fewer employment opportunities).
- If the impacts of acidification on herring prey, and thus on the Atlantic herring industry, are severe enough, some individuals and families may feel compelled to move away from PEI to seek employment opportunities elsewhere, leading to social displacement

[194] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

5. Hypoxia

Scenario: More frequent hypoxic conditions

Increasing frequency of hypoxia on PEI currently represents a **Low** risk to PEI's Atlantic herring industry. This risk increases but remains **Low** for mid-century (Table 48).

Table 48. Atlantic herring risk summary for hypoxia

Hypoxia: Atlantic Herring							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	1	1	1	1	**Low (3.0)**	**Low (4.0)**

Likelihood

Appendix B Hypoxia provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Hypoxia is worsening in the Gulf of St. Lawrence due to many factors, including warmer upper-ocean temperatures.

Future: (Rating: 4 – Likely)
Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase, potentially causing more frequent or widespread hypoxia events.

Consequences

Hypoxia is not expected to affect PEI's Atlantic herring industry.

Production/Output (Rating: 1 – Insignificant)
Hypoxia is typically not a limiting factor for Atlantic herring, as it is a pelagic, schooling species. Atlantic herring are likely to move to more oxygen dense areas, if available. However, large-scale-hypoxic events could result in die-offs.

Infrastructure (Rating: 1 – Insignificant)
Hypoxia does not affect infrastructure.

Livelihoods (Rating: 1 – Insignificant)
Hypoxia is not expected to impact livelihoods.

Rock Crab (*Cancer irroratus*)

The rock crab (*Cancer irroratus*) is a type of crab found in the Atlantic Ocean. The fishing season for rock crab on PEI is from April to June and August to October. Rock crab are commercially harvested on PEI as a directed fishery with a set quota per license. Rock crab are also a by-catch of the lobster fishing industry and are commonly

Figure 22. Rock crab. Source: CBC News.

used as lobster bait. Thus, risks to rock crab may have ripple effects, such as increased bait prices on the lobster fishery.

The products derived from rock crab on PEI include live, cooked, and frozen crab. Sections of the crab and crab meat are also available in salad, combo, and minced products. In 2021, the PEI rock crab fishing industry recorded a harvest weight of almost 2 million pounds, representing a market value of just over $3.9 million.[195]

Figure 23 summarizes climate risks to rock crab. Post-tropical storms pose the greatest risk due to infrastructure damage (e.g., destruction of fishing gear and vessels) and disruptions to livelihoods in the months following the storm. Although the overall risk rating is lower, rock crab also received a significant consequence rating for the impacts of oceanic/riverine warming on production.

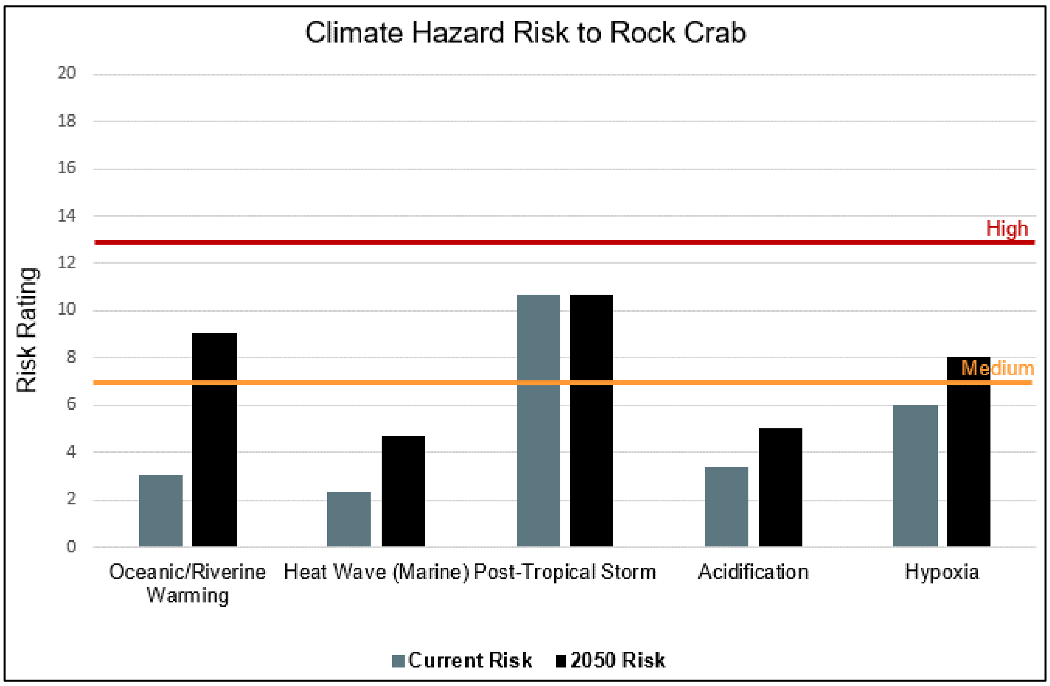

Figure 23. Summary of current and future climate hazard risk to rock crab.

1. Oceanic/Riverine Warming

Scenario: Average temperature rises above 24°C
Species Impact: Larval lethal maximum

Oceanic/riverine warming on PEI currently represents a **Low** risk to PEI's rock crab industry. This risk increases to **Medium** by mid-century (Table 49). Production/output could be most significantly affected by this scenario.

[195] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Table 49. Rock crab risk summary for oceanic/riverine warming

Oceanic/Riverine Warming: Rock Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
1	3	4	2	3	3	**Low (3.0)**	**Medium (9.0)**

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The Rock Crab ratings are relative to the critical sea surface temperature threshold of 24°C.

Current: (Rating: 1 – Rare)
In the Gulf of St. Lawrence, average summer sea surface temperatures currently range from 16°C to 19°C.

Future: (Rating: 3 – Possible)
Under a high emissions scenario, average summer sea surface temperatures are projected to range from 20°C to 23°C by 2050.

Consequences

Oceanic/riverine can lead to reduced harvest for harvesters as rock crab larvae may be unable to survive these warmer temperatures, thereby affecting their income and livelihoods. The ramifications of increased water temperatures for rock crab could be irreversible, since crab may migrate northward.

Production/Output (Rating: 4 – Significant)
There may be a significant disruption or complete loss of production in the rock crab industry. Rock crab larvae are sensitive to warmer conditions, which may impact recruitment of the species or shift them northward, which could create permanent disruptions to yield. Changes in sea ice may also create complications for rock crab prey. Rating considerations included:

- Rock crab larval growth and metamorphosis is temperature dependent. Maximum larval growth rates are observed at 15-18°C, with an upper thermal lethal limit of about 24°C. Rock crab are most sensitive to heat during the larval period. If larvae are exposed to temperatures above 24°C, recruitment for the species may decline and mature adults may move northward to cooler temperatures, reducing harvest in the area over time.
- Mature rock crab are tolerant of a wide temperature range (up to 30°C or higher).
- Modelling of the future range for rock crab only shows projected changes in the southern end of its current range, not around PEI.
- Warmer temperatures under climate change may introduce or increase the prevalence of some predators of the rock crab, such as the black bass.[196]
- Earlier melting of sea ice due to warming oceanic temperatures may result in earlier spring blooms of phytoplankton, potentially causing a mismatch for zooplankton, which feed upon phytoplankton. This relationship could have ripple effects up the food chain, potentially affecting rock crab, which feed on species that rely on plankton.

[196] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Infrastructure (Rating: 2 – Minimal)

There may be minimal damage/disruption to infrastructure due to increased temperatures. Most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on crab pots and other equipment and cause equipment to be more difficult to clean and maintain.

Livelihoods (Rating: 3 – Moderate)

If declines in rock crab production occur, harvesters may face financial hardship and may struggle to switch targeted species. Thus, there may be a moderate disruption to livelihoods resulting in reduced income or employment opportunities. Rating considerations included:

- The rock crab fishery on PEI is of moderate size, compared to other species' industries on the Island. Island exports were worth approximately $3.9 million in 2021 and about 2 million pounds of rock crab were exported.[197]
- Harvesters who rely on rock crab as a primary source of income could face financial hardship if populations move northward or recruitment declines. This is especially true for those who specialize in this fishery and don't have a diversified harvest.
- Some harvesters might attempt to shift to other fisheries, such as lobster or snow crab. However, this would depend on the availability of these species, the harvesters' ability to adapt (including obtaining the necessary licences and equipment), and the market demand for these other species.
- While PEI does not typically rely on sea ice for access to fishing grounds like more northern regions, changes in sea ice can impact the timing of fishing operations. For example, earlier ice melt due to warmer temperatures in the spring could potentially result in the start of fishing season occurring earlier. Alternatively, an absence of sea ice around PEI can lead to colder open waters due to wind chill effects during winter, which may delay the start of productive rock crab fishing periods.[198]

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures above 30°C
Species Impact: Mature lethal limit

Increasing frequency of marine heat waves on PEI currently represents a **Low** risk to PEI's rock crab industry. This risk increases but remains **Low** by mid-century (Table 50).

[197] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
[198] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Table 50. Rock crab risk summary for marine heat wave

Marine Heat Wave: Rock Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
1	2	3	2	2	2.3	**Low (2.3)**	**Low (4.7)**

Likelihood

Appendix B Heat Wave (Marine) provides additional details on likelihood rating assumptions. The Rock Crab ratings are relative to the critical sea surface temperature threshold of 30°C.

Current: (Rating: 1 – Rare)

Summer marine heat waves can range from 20.5°C to 23.5°C.

Future: (Rating: 2 – Unlikely)

Under a high emissions scenario, a summer marine heat wave could range from 24.5°C to 27.5°C by 2050.

Consequences

More frequent marine heat waves pose minimal consequences to PEI's rock crab industry. This hazard could result in small-scale reductions in productivity and outputs, primarily due to impacts to rock crab larvae. If populations experience declines as a result livelihoods and income may be affected.

Production/Output (Rating: 3 – Moderate)

Extreme heat and marine heat waves could result in a minimal reduction in productivity and outputs. Larval rock crab more vulnerable to extreme heat than mature crabs. Rating considerations included:

- Sudden marine heat waves may affect larval stages and cause early hatching but are unlikely to affect mature rock crabs due to their wide thermal tolerance.[199,200] Early hatching could lead to mismatches between plankton and larval rock crab populations, potentially resulting in reduced food availability and reduced recruitment.
- Rock crab may temporarily move farther offshore for cooler waters during heat events, which could result in reduced harvest.[201]

Infrastructure (Rating: 2 – Minimal)

There may be minimal damage/disruption to infrastructure due to increased temperatures. Most equipment could be repaired or replaced at relatively low cost. Rating considerations included:

- Higher temperatures may increase the incidence of biofouling, or the accumulation of organisms on submerged surfaces. Warmer ocean temperatures may result in increased growth rates of some organisms, such as plants, and small animals, potentially leading to greater biofouling. This could increase the weight and drag on crab pots and other equipment and cause equipment to be more difficult to clean and maintain.

[199] "Cancer irroratus, Atlantic rock crab," McGill University, n.d., http://www.geog.mcgill.ca/climatechange/ReportsMap/rock_crabRpt.pdf.
[200] Thomas E. Bigford, "Synopsis of Biological Data on the Rock Crab, Cancer Irroratus Say," National Oceanic and Atmospheric Administration (NOAA) Technical Report NMFS-CIRC-426, 1979, https://repository.library.noaa.gov/view/noaa/4436.
[201] Thomas E. Bigford, "Synopsis of Biological Data on the Rock Crab, Cancer Irroratus Say."

Livelihoods (Rating: 2 – Minimal)
If more days of extreme heat and/or marine heat waves occur, the industry could be less profitable, particularly due to stress on larval crabs, leading to a minimal disruption in livelihoods and loss of income and employment opportunities. Rating considerations included:

- The rock crab industry had a value of $3,934,000 in 2012.[202]
- Atmospheric extreme heat and marine heat waves can also pose safety risks for those involved in the industry.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represents a **Medium** risk to PEI's rock crab industry for both the current period and mid-century (Table 51).

Table 51. Rock crab risk summary for post-tropical storm

Post-Tropical Storm: Rock Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	2	3	3	2.7	**Medium (10.7)**	**Medium (10.7)**

Likelihood
Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)
Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences
While direct consequences to production/output are minimal, infrastructure such as fishing gear and fishing vessels may be destroyed in intense events, which could lead to disruptions to livelihoods. The ramifications of an intense post-tropical storm could linger for months and, should fishing vessels, harbours, or wharves incur significant damage could result in lost employment and/or income.

Production/Output (Rating: 2 – Minimal)
There may be a minimal disruption to production/output. Increased severe storm activity may decrease the number of fishing days in a season, leading to a reduced amount of rock crab caught and if vessels are damaged and unable to function, production may decrease.

[202] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Infrastructure (Rating: 3 – Moderate)

Fishing equipment, fishing vessels, harbours, and wharves may incur damage from a post-tropical storm. Disruptions to infrastructure may take weeks to months to fully fix. Rating considerations included:

- Post-Tropical Storm Fiona resulted in destroyed or lost fishing equipment as well as demolished breakwaters that could no longer protect harbours and floating wharves ripped from mooring systems and washed away.
- Damage to fishing vessels moored in harbour can occur. If severely damaged they may need to be replaced, which can take weeks to months, depending on supply chain conditions.
- Boat hauling capacity ahead of severe storm events is constrained on PEI. This limitation may result in boats remaining in the water during severe weather, increasing their vulnerability to damage.[203]
- Large-scale damage to crab pots may restrict the ability of harvesters to get back on the water quickly.
- Port-tropical storms can also temporarily inundate or damage coastal roadways and bridges restricting access to commercial fishing sites.

Livelihoods (Rating: 3 – Moderate)

Disruption to livelihoods with reduced income or employment opportunities lasting days to months may occur. More significant impact to livelihoods could occur if fishing equipment and vessels incur significant damage. Rating considerations included:

- The rock crab fishery on PEI is of moderate size, compared to other species' industries on the Island. Island exports were worth approximately $3.9 million in 2021 and about 2 million pounds of rock crab were exported.[204]
- If fishing vessels or significant amounts of fishing equipment are damaged during a post-tropical storm event, this may effectively end the rock crab fishing season for afflicted rock crab harvesters, which may have a significant impact on livelihoods of harvesters, especially if they are unable to switch to fishing a different species.

4. Acidification

Scenario: Acidification increases

Acidification on PEI currently represents a **Low** risk to PEI's rock crab industry. This risk increases but remains **Low** by mid-century (Table 52).

Table 52. Rock crab risk summary for acidification

Acidification: Rock Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
2	3	2	1	2	1.7	**Low (3.3)**	**Low (5.0)**

[203] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[204] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions.

Current: (Rating: 2 – Unlikely)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units, and decreasing at a rate of 0.04 units per decade.

Future: (Rating: 3 – Possible)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050.

Consequences

Although direct impacts are minimal, increased acidic conditions could affect the prey base of rock crab, causing them to shift locations or reduce growth rates.

Production/Output (Rating: 2 – Minimal)

There may be a minimal disruption to production/output. Evidence suggests that crustaceans are unlikely to have strong negative responses to increases in acidification. However, rock crab prey, such as mollusks, may experience mortality due to acidification, thereby reducing prey availability for rock crab.[205]

Infrastructure (Rating: 1 – Insignificant)

Acidification does not impact infrastructure relevant to the rock crab industry.

Livelihoods (Rating: 2 – Minimal)

Reductions in rock crab harvest may reduce income opportunities for rock crab harvesters. However, impacts to harvest, and thus livelihoods, are anticipated to be minimal.

5. Hypoxia

Scenario: More frequent hypoxic conditions

Increasing frequency of hypoxia on PEI currently represents a **Low** risk to PEI's rock crab industry and a **Medium** risk by mid-century (Table 53).

Table 53. Rock crab risk summary for hypoxia

Hypoxia: Rock Crab							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	3	1	2	2	**Low (6.0)**	**Medium (8.0)**

Likelihood

Appendix B Hypoxia provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)

Hypoxia is worsening in the Gulf of St. Lawrence due to many factors, including warmer upper-ocean temperatures.

[205] Kroeker et al., "Impacts of Ocean Acidification on Marine Organisms."

Future: (Rating: 4 – Likely)
Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase, potentially causing more frequent or widespread hypoxia events.

Consequences

Hypoxia could cause minimal to moderate consequences to the rock crab industry on PEI, primarily to production/output as crab yield quantity and quality could be affected.

Production/Output (Rating: 3 – Moderate)
A severe increase in acidic conditions could noticeably affect crab yields and quality. Consequences are likely to occur for as long as acidic conditions persist. Rating considerations included:

- Crustaceans are typically sensitive to hypoxic conditions; mature rock crab are known to have an "intermediate" sensitivity to hypoxia, while larval stages are more sensitive.[206]
- The impact of hypoxic conditions is dependent on whether rock crab are stressed from other conditions, including temperature, salinity, and food availability.[207]
- A 2022 study found that rock crab can survive in severe hypoxic conditions but must suppress critical activities to do so, which may hamper growth and reproductive rates in the long-term.[208]

Infrastructure (Rating: 1 – Insignificant)
Hypoxia does not impact infrastructure relevant to the rock crab industry.

Livelihoods (Rating: 2 – Minimal)
Increases in acidic conditions could affect livelihoods for crab harvesters, although it is unlikely that effects would be significant or lengthy enough to eliminate crab fishing in the area altogether. Consequences are likely to occur for as long as acidic conditions persist. Rating considerations included:

- The rock crab fishery on PEI is of moderate size, compared to other species' industries on the Island. Island exports were worth approximately $3.9 million in 2021 and about 2 million pounds of rock crab were exported.[209]
- Harvesters who rely on rock crab as a primary source of income could face financial hardship if crab yields dwindle due to acidification. This is especially true for those who specialize in this fishery and don't have a diversified harvest.

Soft Shell Clams (*Mya arenaria*)

The soft shell clam (*Mya arenaria*) is a small marine bivalve mollusk found in bays and estuaries. Most harvesting of soft shell clams on PEI is done manually using plungers, clam hacks or forks at low tide. However, mechanical harvesters can also be used commercially. Clams are often dug up repeatedly in the same areas. To be harvested, clams must be at least

[206] Guenette, "Chapter 4. A Review of the Physiological Susceptibility of Commercial Species of Fish and Crustaceans of the Northwest Atlantic to Changes in Water Temperature, Dissolved Oxygen, PH and Salinity."
[207] Guenette, "Chapter 4. A Review of the Physiological Susceptibility of Commercial Species of Fish and Crustaceans of the Northwest Atlantic to Changes in Water Temperature, Dissolved Oxygen, PH and Salinity."
[208] Qiwu Jiang, "Effects of Food Deprivation States on Behavioral and Physiological Responses to Hypoxia in Rock Crabs (Cancer Irroratus)" (Memorial University of Newfoundland, 2022), https://research.library.mun.ca/15735/1/thesis.pdf.
[209] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

5 cm in size. The harvesting season on PEI is from May to October and there are 70 full-time commercial harvesters for soft shell clams.[210]

Figure 24. Soft shell clams on PEI. Source: PEI Coastline Shellfish.

Soft shell clams are sold live on PEI. In 2021, the PEI soft shell clam industry recorded a harvest weight of 701,674 pounds, representing a market value of just over $1.7 million.[211]

Figure 25 summarizes climate risks to soft shell clams. Marine heat waves have the highest risk rating, driven by the potential for mortality events and a significant reduction in yield. Although the overall risk rating is lower, acidification also received significant consequence ratings for production impacts.

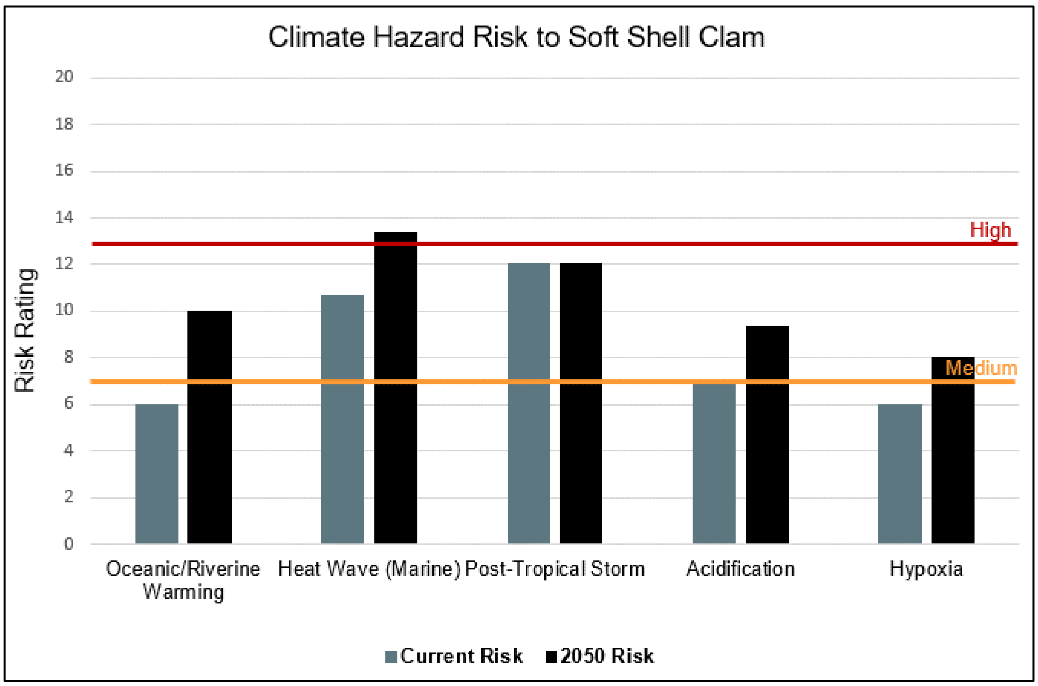

Figure 25. Summary of current and future climate hazard risk to soft shell clams.

Quahogs

Although quahogs were not selected as a focus species for this assessment, they are another important shellfish species on PEI. **In general, quahogs are not expected to be as vulnerable to climate change as soft shell clams.** Quahogs are larger than soft shell clams and have harder and stronger bodies. They are also less sensitive to high temperatures than soft shell clams, with some studies indicating that quahogs can tolerate temperatures up to 33°C.

[210] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[211] PEI Department of Fisheries, Tourism, Sport and Culture. “2021 Fishery Statistics.”

1. Oceanic/Riverine Warming

Scenario: Average temperature rises above 23°C
Impact to Species: Reduced growth rates

Oceanic/riverine warming on PEI currently represents a **Medium** risk to PEI's soft shell clam industry for both the current period and mid-century (Table 54).

Table 54. Soft shell clams risk summary for oceanic/riverine warming

Ocean/Riverine Warming: Soft Shell Clams							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	5	3	1	2	2.0	**Medium (8.0)**	**Medium (10.0)**

Likelihood

Appendix B Oceanic/Riverine Warming provides additional details on likelihood rating assumptions. The soft shell clam ratings are relative to the critical sea surface temperature threshold of 23°C.

Current: (Rating: 4 – Likely)
Recorded July-August summer at coastal sites around PEI range from 11-27°C and average 21°C based on monitoring data. However, temperatures near the shore are likely to be even warmer given the shallow depth.[212]

Future: (Rating: 5 – Almost Certain)
Under a high emissions scenario, July-August temperatures at coastal sites could range from 15-31°C and average 25°C. Temperatures at the shore could be even warmer.

Consequences

Oceanic/riverine warming can affect soft shell clam growth and reproduction. Additionally, ocean warming may reduce the availability of phytoplankton, which is a main food source for soft shell clams. These factors may result in reduced soft shell clam yields.

Production/Output (Rating: 3 – Moderate)
Increases in temperature could result in a noticeable reduction in productivity and outputs as soft shell clams experience increased stress and spend less time within optimal growing temperatures, especially during particularly warm summers. Rating considerations included:

- The fishing process can be stressful for clams. Fishing during warmer temperatures adds more stress, affecting the health, growth, and survival of clams. For example, undersized clams that are left behind may be too stressed to dig back down into the sand leaving them exposed and at risk of mortality. Stressed clams are also less likely to feed, which will slow growth.[213]
- Temperature is the most important factor influencing soft shell clam growth and reproduction. Soft shell clams prefer cooler temperatures, with an optimum temperature

[212] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[213] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

of 17 to 23ºC, and future temperatures at coastal sites are projected to exceed this range.[214]

- Warming temperatures could shift the spawning season from mid-July to mid-August to earlier in the year.[215]
- Earlier melting of sea ice may result in earlier spring blooms of phytoplankton, potentially causing a mismatch for zooplankton, which feed upon phytoplankton. This relationship may affect soft shell clams, which rely on these plankton as a food source.[216]

Infrastructure (Rating: 1 – Insignificant)

Infrastructure impacts from increased ocean temperatures are not expected. Harvesting equipment is removed from the marine environment daily.

Livelihoods (Rating: 2 – Minimal)

If consistent temperatures above the temperature threshold for soft shell clams occur, the industry could be less profitable, leading to a disruption in livelihoods and a loss of income and employment opportunities. Rating considerations included:

- Soft shell clam fishing is a relatively small industry compared to other fish industries on PEI, with a value of $1,713,000 in 2021.[217] If warmer future conditions result in less productive soft shell clam growth, the soft shell clam industry in PEI may decline and could support fewer employment opportunities.
- Changes in sea ice can impact the timing of soft shell clam operations. For example, earlier ice melt due to warmer temperatures in the spring could potentially result in an earlier start of the fishing season.

2. Heat Wave (Marine)

Scenario: More frequent occurrence of temperatures above 28°C
Species Impact: Lethal limit

Increasing frequency of marine heat waves on PEI currently represents a **Medium** risk to PEI's soft shell clams industry and increases to **High** by mid-century (Table 55). Production/output could be most significantly affected by this scenario.

Table 55. Soft shell clams risk summary for marine heat wave

Marine Heat Wave: Soft Shell Clams							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	5	4	1	3	2.7	**Medium (10.7)**	**High (13.3)**

Likelihood

Appendix B Heat Wave (Marine) provides additional details on likelihood rating assumptions. The soft shell clam ratings are relative to the critical sea surface temperature threshold of 28°C.

[214] Mya arenaria, soft-shelled clam," McGill University, n.d. http://www.geog.mcgill.ca/climatechange/ReportsMap/soft_shell_clamRpt.pdf.
[215] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[216] Mya arenaria, soft-shelled clam."
[217] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Current: (Rating: 4 – Likely)
Summer marine heat waves at coastal sites have reached 27-28°C based on monitoring data; however, temperatures near the shore are likely to be even warmer given the shallow depth.[218]

Future: (Rating: 5 – Almost Certain)
Under a high emissions scenario, a summer marine heat wave in coastal waters could reach 31-32°C by 2050. Temperatures at the shore could be even warmer.

Consequences

Soft shell clams are sensitive to high temperatures. This hazard could result in a noticeable reduction in yield as marine heat waves can lead to soft shell clam mortality events, reducing soft shell clam production and affecting livelihoods.

Production/Output (Rating: 4 – Significant)
More frequent and intense marine heat waves could result in a significant reduction in productivity and outputs as marine heat waves can lead to soft shell clam mortality events, reducing soft shell clam production. Rating considerations included:

- Soft shell clams usually do not survive water temperatures above 28°C. Slight temperature increases near this upper bound are known to cause mass mortality events.[219]
- The fishing process can be stressful for clams. Fishing during warmer temperatures adds more stress, affecting the health and survival of clams. For example, undersized clams that are left behind may be too stressed to dig back down into the sand leaving them exposed and at risk of mortality.[220]

Infrastructure (Rating: 1 – Insignificant)
Infrastructure impacts from increased ocean temperatures are not expected. Harvesting equipment is removed from the marine environment daily.

Livelihoods (Rating: 3 – Moderate)
If an increased frequency and/or severity of extreme temperatures and marine heat waves occur, the soft shell clam industry could be less profitable, leading to a significant disruption in livelihoods and a noticeable loss of income and employment opportunities. Rating considerations included:

- Soft shell clam fishing is a relatively small industry compared to other fish industries on PEI, with a value of $1,713,000 in 2021.[221] If more frequent and/or intense marine heat waves result in less productive soft shell clam growth, the soft shell clam industry in PEI may decline and could support fewer employment opportunities.
- Heat events can contribute to harmful algal blooms, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvest areas if conditions become dangerous from a human health perspective. These events are monitored through the CSSP. If necessitated by the CSSP, areas are closed for a

[218] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[219] "Mya arenaria, soft-shelled clam."
[220] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[221] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses and subsequent livelihood impacts.[222]

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represents a **Medium** risk to PEI's soft shell clams industry for both the current period and mid-century (Table 56).

Table 56. Soft shell clams risk summary for post-tropical storm

Post-Tropical Storm: Soft Shell Clams							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	3	2	2	2.3	**Medium (9.3)**	**Medium (9.3)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)
Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

Post-tropical storms can reduce soft shell clam yields by decreasing the number of harvesting days in a season and destroying nearshore clam habitats.

Production/Output (Rating: 3 – Moderate)
Increased frequency and/or intensity of storms could cause noticeable reductions in productivity, especially following damage to nearshore clam habitats. Rating considerations included:

- Increased severe storm activity may decrease the number of harvesting days in a season, leading to a reduced number of clams harvested.
- Nearshore clam habitats and clams are vulnerable to excessive substrate erosion or suffocation from sedimentation burial from storm waves and surge. Bed burials were reported after Post-Tropical Storm Fiona.

Infrastructure (Rating: 2 – Minimal)
Although post-tropical storms can cause significant infrastructure damage, soft shell clam fishing requires very little infrastructure and thus would only be minimally affected. Rating considerations included:

[222] Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546

- Post-Tropical Storm Fiona caused physical damages across Atlantic Canada including demolished breakwaters and destroyed or lost fishing equipment, and restricted access to sites due to flooded or damaged roadways and bridges.[223]

Livelihoods (Rating: 2 – Minimal)

More frequent and/or severe storms could make the soft shell clam industry less profitable, leading to a disruption in livelihoods and a loss of income and employment opportunities. However, this would likely be minimal given that soft shell clam fishing is a relatively small industry on PEI. Rating considerations included:

- Soft shell clam fishing is a relatively small industry compared to other fish industries on PEI, with a value of $1,713,000 in 2021.[224] If more frequent and/or intense post-tropical storms result in less productive soft shell clam growth, the soft shell clam industry in PEI may decline and could support fewer employment opportunities.
- If the impacts of increased frequency and intensity of post-tropical storms on the soft shell clam industry are significant enough, the wellbeing, accessibility of services, and overall welfare of small rural communities that depend on the industry could decrease.
- Nutrient-rich runoff (among other factors) can contribute to harmful algal blooms, which can lead to human health concerns. Government agencies monitor the distribution and abundance of algal blooms and other agents of human health concerns and will close shellfish harvest areas if conditions become dangerous from a human health perspective. These events are monitored through the CSSP.[225] If necessitated by the CSSP, areas are closed for a minimum of 21 days, or 7 days with negative testing results. These closures can result in yield losses and subsequent livelihood impacts.
    - Tidal forces on the south shore of PEI are typically more pronounced than on the north side. This results in greater flushing dynamics on the south shore, leading to fewer hypoxic events in comparison to the north shore. Tidal fluctuations on the south side can reach approximately 9 feet, whereas the north side typically experiences a more modest 2-foot change.[226]

4. Acidification

Scenario: Acidification approaches 7.8 pH
Impact: Decreased shell net calcification rate

Acidification on PEI represents a **Medium** risk to PEI's soft shell clams industry for both the current period and mid-century (Table 57). Production/output could be most significantly affected by this scenario.

223 Fisheries and Oceans Canada, "Government of Canada Support to Rebuild Small Craft Harbours and Recover Lost Fishing Gear Post-Hurricane Fiona."
224 PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."
225 Canadian Shellfish Sanitation Program (CSSP). https://inspection.canada.ca/preventive-controls/fish/cssp/eng/1563470078092/1563470123546

Table 57. Soft shell clams risk summary for acidification

Acidification: Soft Shell Clams							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	4	1	2	2.3	**Medium (7.0)**	**Medium (9.3)**

Likelihood

Appendix B Acidification provides additional details on likelihood rating assumptions. The soft shell clam ratings are relative to the critical pH threshold of 8.0 units.

Current: (Rating: 3 – Possible)

The current pH level of the Gulf of St. Lawrence is approximately 7.7 to 7.9 units and decreasing at a rate of 0.04 units per decade. However, limestone around PEI may buffer acidity effects in PEI's nearshore coastal areas, lowering the likelihood that acidification causes issues for soft shell clams.

Future: (Rating: 4 – Likely)

If acidification continues to increase at a rate of approximately 0.04 pH units per decade, the Gulf can be expected to reach a pH of approximately 7.6 to 7.8 units by 2050. However, limestone around PEI may buffer acidity in PEI's nearshore coastal areas, lowering the likelihood that acidification causes issues for soft shell clams.

Consequences

Soft shell clams are very sensitive to acidification, and may experience decreased shell growth, reduced shell strength, less ability to filter water, among other impacts. This could lead to significant impacts in clam yield, with follow-on effects to livelihoods.

Production/Output (Rating: 4 – Significant)

Soft shell clams are very sensitive to acidification, and future changes in acidification could lead to significant reductions in production and output, which could impact profit and lead to economic losses. Rating considerations included:

- With decreased shell growth and strength, higher dissolution levels, lower dispersal levels, greater burrowing depth, and lower productivity filtering water.[227][228, 229]
- An increase in acidification also decreases the responsiveness of soft shell clams to predators.[230, 231]
- Soft shell clams have also been shown to reject burrowing in acidic sediments, therefore leaving them exposed at the surface and vulnerable to predation.[232]

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[227] Justin B. Ries et al., "Marine calcifiers exhibit mixed responses to CO2-induced ocean acidification," *Geology 37*, no. 12 (Dec 01, 2009): https://doi.org/10.1130/G30210A.1

[228] Helena Fortunato, "Mollusks: Tools in Environmental and Climate Research," *American Malacological Bulletin* 33, no. 2 (November 2015): 310–24, https://doi.org/10.4003/006.033.0208.

[229] "Softshell Clam (Ma arenaria) Vulnerability Ranking," National Oceanic and Atmospheric Administration, n.d., https://www.st.nmfs.noaa.gov/Assets/ecosystems/climate/images/species-results/pdfs/Softshell_Clam.pdf.

[230] T.C. Hiebert, "Mya Arenaria," University of Oregon, 2015, https://oimb.uoregon.edu/wp-content/uploads/2019/03/M_arenaria_2019.pdf.

[231] SA Siedlecki et al., "Projecting Ocean Acidification Impacts for the Gulf of Maine to 2050: New Tools and Expectations," *Elementa: Science of the Anthropocene* 9, no. 1 (May 13, 2021): 00062, https://doi.org/10.1525/elementa.2020.00062.

[232] Timothy P. Curtin et al., "Buffering Muds with Bivalve Shell Significantly Increases the Settlement, Growth, Survival, and Burrowing of the Early Life Stages of the Northern Quahog, Mercenaria Mercenaria, and Other Calcifying Invertebrates," *Estuarine, Coastal and Shelf Science* 264 (January 5, 2022): 107686, https://doi.org/10.1016/j.ecss.2021.107686.

Infrastructure (Rating: 1 – Insignificant)
Damage to infrastructure from acidification is unlikely.

Livelihoods (Rating: 2 – Minimal)
Increased acidification could cause minimal disruption to livelihoods. Soft shell clam fishing is a relatively small industry compared to other fish industries on PEI, with a value of $1,713,000 in 2021.[233] If increased acidification results in less productive soft shell clam growth, the soft shell clam industry in PEI may decline and could support fewer employment opportunities.

5. Hypoxia

Scenario: More frequent hypoxic conditions

Hypoxia on PEI currently represents a **Low** risk to PEI's soft shell clam industry. This risk increases to **Medium** by mid-century (Table 58).

Table 58. Soft shell clam risk summary for hypoxia

Hypoxia: Soft shell clam							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	3	1	2	2	**Low (6.0)**	**Medium (8.0)**

Likelihood

Appendix B Hypoxia provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Hypoxia is worsening in the Gulf of St. Lawrence due to many factors, including warmer upper-ocean temperatures.

Future: (Rating: 4 – Likely)
Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase, potentially causing more frequent or widespread hypoxia events.

Consequences

Increased hypoxia could cause a decrease in harvest due to soft shell clam mortality under severely hypoxic conditions. In turn, the livelihoods of those involved in the soft shell clam industry may be impacted.

Production/Output (Rating: 3 – Moderate)
Soft shell clams have limited hypoxia tolerance and, under severely hypoxic conditions (less than 15% oxygen saturation) can experience mortality. If these severe conditions occur, there is potential to reduce soft shell clam harvest on PEI, especially if conditions persist throughout a full fishing season. Under less severe hypoxic conditions (greater than 15% oxygen saturation), soft shell clams may still exhibit behavioural changes, such as extending their siphons out of the sediment to access oxygen in the water column. While these conditions are less likely to result in mortality, they could still have potential impacts on clam health, growth, and reproduction, which could also affect their populations and harvests over the longer term. Responses of soft

[233] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

shell clams to hypoxia are likely to be influenced by a variety of other factors, including temperature, salinity, food availability, and the presence of other stressors.[234]

Infrastructure (Rating: 1 – Insignificant)

Hypoxia does not affect infrastructure.

Livelihoods (Rating: 2 – Minimal)

Increased hypoxic conditions in soft shell clam waters near PEI may result in decreased harvest for clam harvesters. This could affect livelihoods of soft shell clam harvesters, although the soft shell clam industry is relatively small compared to other fish industries on PEI, with a value of $1,713,000 in 2021.[235]

[234] Rutger Rosenberg, et al., "Hypoxic tolerance of marine benthic fauna," in Marine Ecology Progress Series (1991), https://www.int-res.com/articles/meps/79/m079p127.pdf.
[235] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Processing Sector

This assessment evaluated risks to the seafood processing sector from five key climate hazards. Focus climate hazards were selected based on a sensitivity analysis of processing facilities, storage facilities, buying stations, and inbound/outbound transportation. For additional details on the sensitivity and risk analyses, see Appendix A: Climate Risk and Opportunity Assessment Methodology. Risk ratings are based on the following scenario events:

- **Atmospheric heat wave:** Three consecutive days with temperatures above 29°C
- **Heavy precipitation and flooding:** 100mm of rain in 24 hours
- **Post-tropical storm:** Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022
- **Coastal erosion:** Acceleration of the historic rate of erosion (28 cm/year)
- **Ice storm and freezing rain:** Multi-day severe ice storm/freezing rain event in winter

As shown in Table 59, post-tropical storms pose the greatest risk to the processing sector across all consequence categories and all four asset types followed by the risk of atmospheric heat waves to processing and storage facilities. These risks are driven by the potential for physical infrastructure damage and power outages, which could subsequently affect production and livelihoods.

Potential Opportunities

Although climate change poses many risks to the processing sector on PEI, warming average temperatures may also provide some opportunities. For example, the risk of severe ice storms and freezing rain is expected to decrease. The days- to week-long power outages these events trigger significantly affect operations at processing and storage facilities. As average temperatures warm, it is expected that precipitation will increasingly fall as rain rather than snow and ice and winters will become milder, potentially decreasing the frequency of these events.

A longer growing or fishing season for some species may also lead to more optimal products and a longer operating period at processing facilities (see the aquaculture and commercial fishing opportunities sections). Warming temperatures will also lead to less sea ice coverage, which can have positive and negative effects. Maritime shipping operations will benefit from longer ice-free conditions, but less sea ice can increase erosion, wave action, and fluctuations in temperature.

Table 59. Processing sector climate risk assessment results

Hazard	Current Likelihood	2050 Likelihood	Production/ Output	Infrastructure	Livelihood	Current Risk	Future Risk
Processing Facilities							
Post-Tropical Storm	4	4	3	4	3	**High (13.3)**	**High (13.3)**
Heat Wave (Atmospheric)	3	5	3	2	2	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	3	3	2	**Medium (8.0)**	**Medium (10.7)**
Coastal Erosion	4	5	1	3	1	**Low (6.7)**	**Medium (8.3)**
Ice Storm/Freezing Rain	4	3	2	2	2	**Medium (8.0)**	**Low (6.0)**
Storage Facilities							
Post-Tropical Storm	4	4	3	4	3	**High (13.3)**	**High (13.3)**
Heat Wave (Atmospheric)	3	5	3	2	2	**Medium (7.0)**	**Medium (11.7)**
Heavy Precipitation and Flooding	3	4	2	3	2	**Medium (7.0)**	**Medium (9.3)**
Coastal Erosion	4	5	1	3	1	**Low (6.7)**	**Medium (8.3)**
Ice Storm/Freezing Rain	4	3	2	2	2	**Medium (8.0)**	**Low (6.0)**
Buying Stations							
Post-Tropical Storm	4	4	3	3	2	**Medium (10.7)**	**Medium (10.7)**
Heat Wave (Atmospheric)	3	5	3	2	1	**Low (6.0)**	**Medium (10.0)**
Heavy Precipitation and Flooding	3	4	2	2	2	**Low (6.0)**	**Medium (8.0)**
Coastal Erosion	4	5	1	2	1	**Low (5.3)**	**Low (6.7)**
Ice Storm/Freezing Rain	4	3	1	1	1	**Low (4.0)**	**Low (3.0)**
Inbound/Outbound Transportation							
Post-Tropical Storm	4	4	4	4	2	**High (13.3)**	**High (13.3)**
Coastal Erosion	4	5	1	3	1	**Low (6.7)**	**Medium (8.3)**
Heat Wave (Atmospheric)	3	5	2	2	1	**Low (5.0)**	**Medium (8.3)**
Heavy Precipitation and Flooding	3	4	2	3	1	**Low (6.0)**	**Medium (8.0)**
Ice Storm/Freezing Rain	4	3	2	2	1	**Low (6.7)**	**Low (5.0)**

Processing Facilities

PEI has more than 40 processing facilities that are responsible for processing large volumes of live lobster and other seafood. Facilities are equipped with specialized equipment to hold, clean, process, and package a variety of seafood products to ship. This industry employed 1,300 people in 2021.[236]

Figure 26 summarizes climate risks to processing facilities. Post-tropical storms have the highest risk rating and the most significant consequences of any hazard. Post-tropical storms can significantly damage critical infrastructure, reduce production, and potentially affect livelihoods in the weeks and months following the storm.

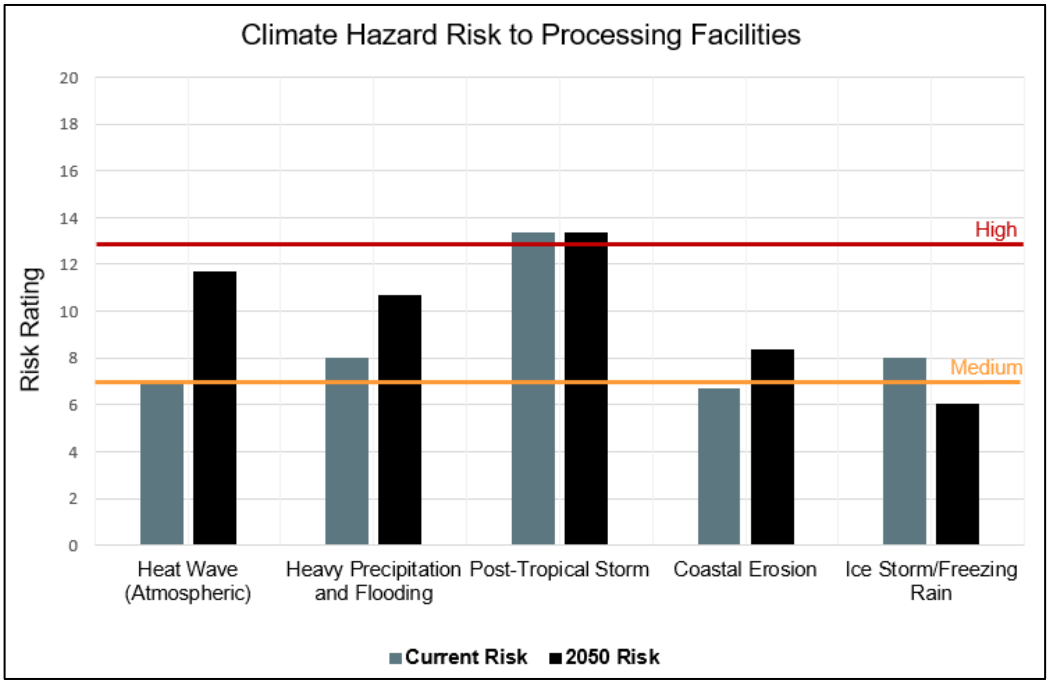

Figure 26. Summary of current and future climate hazard risk to processing facilities.

1. Heat Wave (Atmospheric)

Scenario: Three consecutive days with temperatures above 29°C

Atmospheric heat waves on PEI currently represent a **Medium** risk to PEI's processing facilities. This risk increases but remains **Medium** by mid-century (Table 60).

Table 60. Processing facilities risk summary for heat wave

Heat Wave: Processing Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	3	2	2	2.3	**Medium (7.0)**	**Medium (11.7)**

[236] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Likelihood

Appendix B Heat Wave (Atmospheric) provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Historically, this scenario has occurred 0.05 times per year on average.

Future: (Rating: 5 – Almost Certain)
Future projections indicate this scenario will occur 2.1 times per year on average.

Consequences

Heat waves are a concern for facility operations, particularly if stress on the energy system causes a power outage. A heat wave could also increase cooling demand and costs for the facility. Any disruptions would be temporary for the duration of the heat wave.

Production/Output (Rating: 3 – Moderate)
Production will be temporarily affected if a power outage occurs during the heat wave. Rating considerations included:

- Atmospheric/marine heat waves may change the quantity, quality, and timing of seafood products moving through the facilities due to species impacts detailed in the earlier sections. For example:
  - There may be greater biofouling on products which increases the time and labour to clean and process those products.[237]
  - Products may be exposed to high temperatures and humidity during transport to processing facilities, increasing stress on the species and in some cases causing mortality. This can affect product quality and shelf life.[238]
- If a power outage were to occur from the stress on the energy system for hours to a few days, facilities may not be able to maintain controlled temperatures. This could lead to spoiled products. However, many processing facilities have a backup power supply, especially those responsible for cold storage and live holdings.

Infrastructure (Rating: 2 – Minimal)
While a 3-day heat wave is not expected to cause physical damage to infrastructure or equipment, a heat wave-induced power outage will cause disruptions for up to a few days if there is not a backup power source. Rating considerations included:

- High temperatures will increase cooling demand and costs, especially at facilities with refrigeration.
- If a power outage were to occur from the stress on the energy system, facilities may not be able to maintain controlled temperatures. However, many processing facilities have a backup power supply, especially those responsible for cold storage and live holdings.

Livelihoods (Rating: 2 – Minimal)
An atmospheric heat wave would only disrupt operations during a power outage. Rating considerations included:

[237] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[238] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

- Processing facilities employ approximately 1,300 people.
- A heat wave would only disrupt operations during a power outage for up to a few days. If backup power and fuel is available, operations will continue.
- The amount of product moving through the facilities and the number of staff needed may be affected by other climate-related hazards (i.e., marine heat wave).
- Heat waves may also pose health risks to workers, such as heat stress.

2. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI currently represent a **Medium** risk to PEI's processing facilities. This risk increases but remains **Medium** by mid-century (Table 61).

Table 61. Processing facilities risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Processing Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	3	3	2	2.7	**Medium (8.0)**	**Medium (10.7)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)
This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)
Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

Consequences

The primary concern from heavy precipitation and flooding is damage to facilities and key operational infrastructure. However, damage from a non-coastal heavy precipitation event will likely be isolated to select facilities in flood-prone areas rather than widespread, thus limiting the impact on production or livelihoods.

Production/Output (Rating: 3 – Moderate)
Facilities may need to temporarily close, disrupting production. Rating considerations included:

- Heavy precipitation and flooding may change the quantity, quality, and timing of seafood products moving through the facilities due to species impacts detailed in the earlier sections. For example, CSSP closures can have ripple effects on processing facility operations.[239]
- Not all facilities are equipped with saltwater wells or water recirculation tanks to hold product if flooding led to facility closures. Product would either need to be moved, or lost.

[239] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Infrastructure (Rating: 3 – Moderate)
Heavy precipitation and flooding can cause damage to electrical equipment, buildings, and other key infrastructure at facilities that could take days to months to repair, depending on the severity. Rating considerations included:

- Flooding could damage key infrastructure and operational equipment.
- Flooding could disrupt utility services. For example, a power outage could occur however many facilities have backup power sources on site.

Livelihoods (Rating: 2 – Minimal)
Facilities that require more significant repairs may need to limit or close operations for weeks to months, temporarily reducing income and employment at those locations. However, this scenario is not expected to be widespread and employees may be able to work at other facilities. Rating considerations included:

- Assumption that only a limited number of facilities would experience significant damage from a non-coastal heavy precipitation event.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represents a **High** risk to PEI's processing facilities for both the current period and mid-century (Table 62). Infrastructure could be most significantly affected by this scenario.

Table 62. Processing facilities risk summary for post-tropical storm

Post-Tropical Storm: Processing Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	3	4	3	3.3	**High (13.3)**	**High (13.3)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)
Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

High winds, storm surge, and heavy rain from post-tropical storms could cause significant and widespread consequences for processing facilities. This hazard can reduce production, significantly damage critical infrastructure, and affect livelihoods in the weeks and months following the storm.

Production/Output (Rating: 3 – Moderate)

Facilities may need to close during and after the storm, disrupting production. Rating considerations included:

- Post-tropical storms will affect the quantity of seafood products moving through the facilities in the weeks and months following the storm due to species impacts detailed in the earlier sections. For example, CSSP closures can have ripple effects on processing facility operations.[240]
- Not all facilities are equipped with saltwater wells or water recirculation tanks to hold product if facilities need to close. Product would need to be moved, or it would be lost.
- Damage to coastal roadways and bridges restricting access.

Infrastructure (Rating: 4 – Significant)

About half of PEI's processing facilities are located in a coastal hazard zone and are more susceptible to significant damage and disruption from coastal flooding, storm surge, high winds, and erosion. Rating considerations included:

- Post-Tropical Storm Fiona caused considerable damage to facilities and an extended and widespread power outage for at least a week. While most processing facilities have generators for backup power, the generators are typically only for critical operations due to the fuel supply necessary to maintain all operations for multiple days.[241]
- Storm surge from Post-Tropical Storm Fiona also destroyed electrical systems and some generators.[242]
- A critical infrastructure vulnerability assessment for PEI seafood processing facilities found 27 of 49 facilities are located in a coastal hazard assessment zone:[243]
    - 12 properties are in the high flood hazard zone (property falls within 2020 coastal floodplain with 1% annual chance of flooding today; at least a portion of the area is expected to be permanently inundated at high tide from sea level rise).
    - 3 properties are in the moderate-low flood hazard zone (property falls within 2100 coastal floodplain with 1% annual chance of flooding by 2100; unlikely to experience flooding now, but likelihood of flooding during extreme storms is increasing).
    - 12 properties are in the minimal flood hazard zone (property elevated above 2100 costal floodplain with minimal probability of flooding).

Livelihoods (Rating: 3 – Moderate)

Facilities that require more significant repairs may need to limit or close operations for weeks to months, temporarily reducing income and employment at those locations. Rating considerations included:

- Processing facilities employ 1,300 people.

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[240] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[241] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[242] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[243] Prince Edward Island Department of Fisheries and Communities, "Critical Infrastructure Vulnerability Assessment," 2021.

- Staff may have difficulty accessing facilities during and immediately following an event.[244]
- Assumption that many processing facilities experience damage and disruption, but that some product and employees can be temporarily moved to other facilities while repairs take place.
- Assumption that there is a diversity of products moving through processing facilities so while some seafood products may be hard hit by the storm, employees will still be needed to process other products.

Post-Tropical Storm Fiona and Acadian Supreme Processing Facility

Acadian Supreme, a major seafood processing facility on the Island's south side, encountered disruptions and significant flooding due to Post-Tropical Storm Fiona. Damages were estimated between $600,000 to $700,000, including loss of live lobster and infrastructure damage. With water levels reaching the road, access to the facility for debris clearance, damage assessment, and stored seafood salvage was hindered. Thanks in part to their on-site diesel generator, Acadian Supreme was able to restart operations relatively swiftly. For future preparedness, Acadian Supreme intends to elevate critical equipment and consider the feasibility of waterproofing the electric room.

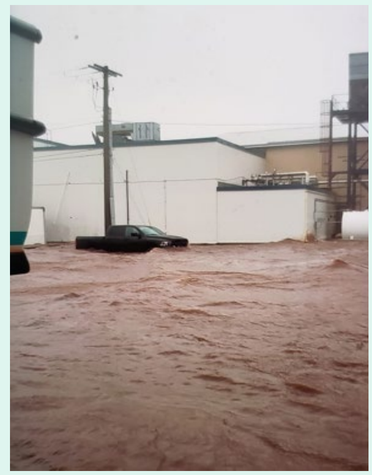

Figure 27. Flooding during Fiona outside of Acadian Supreme.

4. Coastal Erosion

Scenario: Acceleration of the historic rate of erosion (28 cm/year)

Coastal erosion on PEI currently presents a **Low** risk to PEI's processing facilities. This risk increases to **Medium** by mid-century (Table 63).

Table 63. Processing facilities risk summary for coastal erosion

Coastal Erosion: Processing Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	5	1	3	1	1.7	**Low (6.7)**	**Medium (8.3)**

Likelihood

Appendix B Coastal Erosion provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

The annual average rate of erosion on PEI from 1968 to 2010 was 28 cm/year.

[244] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Future: (Rating: 5 – Almost Certain)
From 2000 to 2010, the average annual rate was 40 cm/year, above the historical average. Drivers of coastal erosion are projected to increase in frequency and severity which will continue drive higher rates of erosion.

Consequences

Coastal erosion is a threat to processing facility infrastructure in select locations that experience low to moderate coastal erosion rates.

Production/Output (Rating: 1 – Insignificant)
Coastal erosion is not expected to affect production or output.

Infrastructure (Rating: 3 – Moderate)
Although half of PEI's processing facilities are located in a coastal hazard zone, most do not experience coastal erosion or have low erosion rates. Only one facility has a moderate erosion rate, which is above the historic rate of erosion threshold (28 cm/year). Rating considerations included:

- Depending on the location of the facility, coastal erosion may require repairs to reinforce the structure and slow erosion or may require relocation.
- A critical infrastructure vulnerability assessment for PEI seafood processing facilities found 27 of 49 facilities are located in a coastal hazard assessment zone:[245]
    - 12 properties are in the high flood hazard zone (property falls within 2020 coastal floodplain with 1% annual chance of flooding today; at least a portion of the area is expected to be permanently inundated at high tide from sea level rise).
        - These properties have either N/A (not on shorefront) or low erosion rates.
    - 3 properties are in the moderate-low flood hazard zone (property falls within 2100 coastal floodplain with 1% annual chance of flooding by 2100; unlikely to experience flooding now, but likelihood of flooding during extreme storms is increasing).
    - 12 properties are in the minimal flood hazard zone (property elevated above 2100 costal floodplain with minimal probability of flooding).
        - One property (Halibut PEI Inc.) has a moderate coastal erosion hazard rating, with an average of 37cm/year and maximum 72cm/year.

Livelihoods (Rating: 1 – Insignificant)
Very few facilities are at risk of coastal erosion and could implement resilience measures or relocate.

5. Ice Storm/Freezing Rain

Scenario: Multi-day severe ice storm/freezing rain event in winter

Severe ice storms and freezing rain events on PEI currently represent a **Medium** risk to PEI's processing facilities. This risk decreases to **Low** by mid-century (Table 64).

[245] Prince Edward Island Department of Fisheries and Communities, "Critical Infrastructure Vulnerability Assessment," 2021.

Table 64. Processing facilities risk summary for ice storm/freezing rain

Ice Storm/Freezing Rain: Processing Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	3	2	2	2	2	**Medium (8.0)**	**Low (6.0)**

Likelihood

Appendix B Ice Storm/Freezing Rain provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historical climate data on ice days and frost days as well as the frequency of past multi-day severe ice storms and freezing rain events suggest these events are likely to occur.

Future: (Rating: 3 – Possible)
It is expected that precipitation will increasingly fall as rain rather than snow and ice and winters will become milder, potentially decreasing the frequency of these events.

Consequences

Ice storms and freezing rain are a concern for facility operations when they cause power outages. Any disruptions would be temporary for up to a few days.

Production/Output (Rating: 2 – Minimal)
Ice and freezing rain can bring down power lines and cause widespread power outages, which could affect production. While power outages are less of a concern from a cooling and refrigeration standpoint since temperatures are near freezing, they are a concern for operating water recirculation systems. Loss of power could cause stress or mortality for live holdings. However, most processing facilities have a backup power supply, especially those responsible for cold storage and live holdings.

Infrastructure (Rating: 2 – Minimal)
Ice and freezing rain can coat and potentially damage critical infrastructure, including bringing down power lines. Disruptions could last for up to a few days, especially if there is not a backup power source or sufficient fuel supply for generators.

Livelihoods (Rating: 2 – Minimal)
There are lower rates of employment in the winter months and an event would only disrupt production during a power outage, which would last up to a few days at most. If facilities remain open during this period, travel conditions may be dangerous for employees.

Storage Facilities

PEI has storage facilities that are responsible for holding large volumes of seafood until they can be processed or shipped. Facilities are equipped with specialized equipment, such as saltwater wells or water recirculation tanks for live holdings and large-scale refrigeration capability for storage. This industry employed 1,300 people in 2021.[246]

[246] PEI Department of Fisheries, Tourism, Sport and Culture. "2021 Fishery Statistics."

Figure 28 summarizes climate risks to storage facilities. Post-tropical storms have the highest risk rating and the most significant consequences of any hazard. Post-tropical storms can significantly damage critical infrastructure, reduce production, and potentially affect livelihoods in the weeks and months following the storm.

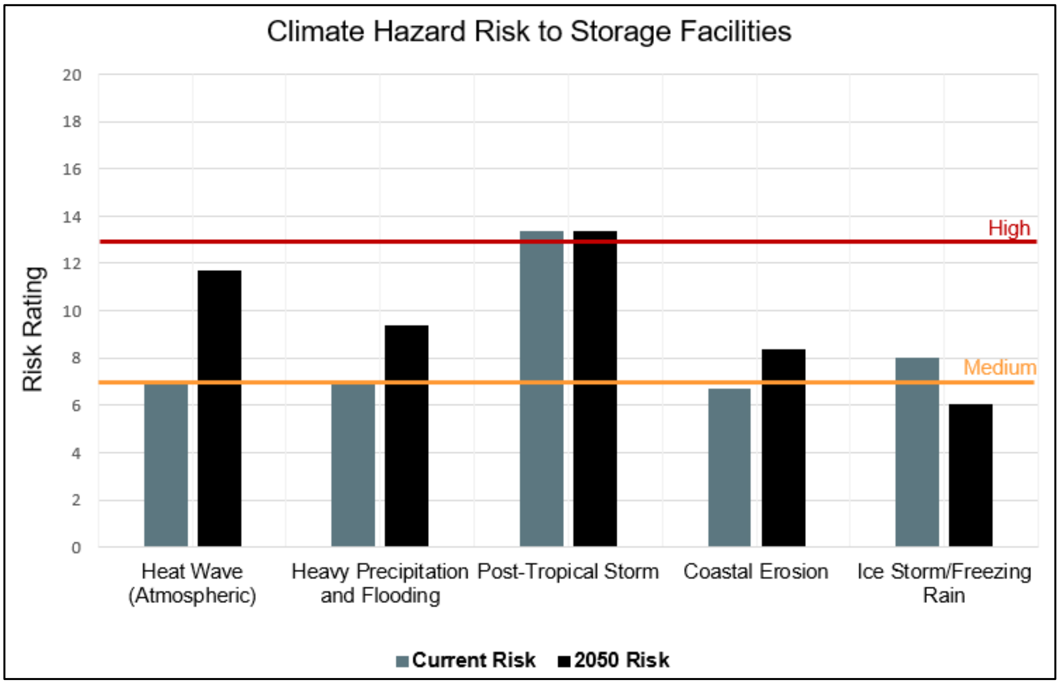

Figure 28. Summary of current and future climate hazard risk to storage facilities.

1. Heat Wave (Atmospheric)

Scenario: Three consecutive days with temperatures above 29°C

Atmospheric heat waves on PEI currently represents a **Medium** risk to PEI's storage facilities. This risk increases but remains **Medium** into mid-century (Table 65).

Table 65. Storage facilities risk summary for heat wave

Heat Wave: Storage Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	3	2	2	2.3	**Medium (7.0)**	**Medium (11.7)**

Likelihood

Appendix B Heat Wave (Atmospheric) provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Historically, this scenario has occurred 0.05 times per year on average.

Future: (Rating: 5 – Almost Certain)
Future projections indicate this scenario will occur 2.1 times per year on average.

Consequences

Heat waves are a concern for facility operations, particularly if stress on the energy system caused a power outage. A heat wave could also increase cooling demand and costs for the facility. Any disruptions would be temporary for the duration of the heat wave.

Production/Output (Rating: 3 – Moderate)

Production will be temporarily affected if a power outage occurs during a heat wave. Rating considerations included:

- Atmospheric/marine heat waves may change the quantity, quality, and timing of seafood products moving through the facilities due to species impacts detailed in the earlier sections. For example, live products under increased stress may be lower quality or have a shorter shelf life.[247]
- If a power outage were to occur from the stress on the energy system, facilities may not be able to maintain controlled temperatures or oxygenation levels. This could lead to spoiled products. However, many storage facilities have a backup power supply, especially those responsible for cold storage and live holding.

Infrastructure (Rating: 2 – Minimal)

While a 3-day heat wave is not expected to cause physical damage to infrastructure or equipment, a heat wave-induced power outage will cause disruptions for up to a few days if there is not a backup power source. Rating considerations included:

- High temperatures will increase cooling demand and costs, especially at facilities with refrigeration.
- If a power outage were to occur from the stress on the energy system, facilities may not be able to maintain controlled temperatures. However, many storage facilities have a backup power supply, especially those responsible for cold storage and live holdings.

Livelihoods (Rating: 2 – Minimal)

An atmospheric heat wave would only disrupt operations during a power outage. Rating considerations included:

- A heat wave would only disrupt operations during a power outage for up to a few days. If backup power and fuel is available, operations will continue.
- The amount of product moving through the facilities and the number of staff needed may be affected by other climate-related hazards (i.e., marine heat wave).
- Heat waves may also pose health risks to workers, such as heat stress.

2. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI currently represent a **Medium** risk to storage facilities. This risk increases but remains **Medium** into mid-century (Table 66).

[247] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Table 66. Storage facilities risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Storage Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	2	3	2	2.3	**Medium (7.0)**	**Medium (9.3)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)

This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)

Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

Consequences

The primary concern from heavy precipitation and flooding is damage to facilities and key operational infrastructure. However, damage from a non-coastal heavy precipitation event will likely be isolated to select facilities in flood-prone areas rather than widespread, thus limiting the impact on production or livelihoods.

Production/Output (Rating: 2 – Minimal)

Facilities may need to temporarily close, disrupting production. Rating considerations included:

- Heavy precipitation and flooding may change the quantity, quality, and timing of seafood products moving through the facilities due to species impacts detailed in the earlier sections.
- If facilities needed to temporarily close, storage facilities should be well equipped to hold product. If not, product would either need to be moved, or lost.

Infrastructure (Rating: 3 – Moderate)

Heavy precipitation and flooding can cause damage to electrical equipment, buildings, and other key infrastructure at facilities that could take days to months to repair, depending on the severity. Rating considerations included:

- Flooding could damage key infrastructure and operational equipment.
- Flooding could disrupt utility services. For example, a power outage could occur however many facilities have backup power sources on site.

Livelihoods (Rating: 2 – Minimal)

Facilities that require more significant repairs may need to limit or close operations for weeks to months, temporarily reducing income and employment at those locations. However, this scenario is not expected to be widespread and employees may be able to work at other facilities. Rating considerations included:

- Operations are heavily reliant on functional equipment and other key infrastructure. Damage to key infrastructure could stall operations.

- Assumption that only a limited number of facilities would experience significant damage from a non-coastal heavy precipitation event.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **high** risk to PEI's storage facilities both for the current period and into mid-century (Table 67). Infrastructure could be most significantly affected by this scenario.

Table 67. Storage facilities risk summary for post-tropical storm

Post-Tropical Storm: Storage Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	3	4	3	3.3	**High (13.3)**	**High (13.3)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)
Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

High winds, storm surge, and heavy rain from post-tropical storms could cause significant and widespread consequences for storage facilities. This hazard can reduce production, significantly damage critical infrastructure, and affect livelihoods in the weeks and months following the storm.

Production/Output (Rating: 3 – Moderate)
Facilities would need to temporarily close during and following the storm. Rating considerations included:

- Post-tropical storms can affect the quantity of seafood products being stored at facilities in the weeks and months following the storm due to species impacts detailed in the earlier sections.
- If facilities needed to temporarily closed, storage facilities should be well equipped to hold product. If not, product would either need to be moved or it could be lost. Storage facilities have a larger inventory than processing facilities at risk of spoilage if a power outage, for example, were to occur during the event and there was not sufficient backup power to maintain temperature and oxygenation levels. This is of greatest concern for live storage. Cold storage in an unopened freezer can last for four days without power.[248]

[248] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

- Damage to coastal roadways and bridges restricting access.

Infrastructure (Rating: 4 – Significant)
Some facilities may be more susceptible to significant damage and disruption from coastal flooding, storm surge, high winds, and erosion. Damage is expected to be widespread and affect functionality of the facility. Rating considerations included:

- Post-Tropical Storm Fiona caused considerable damage to facilities and an extended and widespread power outage for at least a week. While most storage facilities have generators for backup power, it can be challenging to secure enough fuel to maintain all operations for multiple days.[249]
- Storm surge from Post-Tropical Storm Fiona also destroyed electrical systems and some generators.[250]
- Storage facilities for live products are typically located closer to the coast than processing facilities.[251]

Livelihoods (Rating: 3 – Moderate)
Facilities that require more significant repairs may need to limit or close operations for weeks to months, temporarily reducing income and employment at those locations. Rating considerations included:

- Staff may have difficulty accessing facilities during and immediately following an event.[252]
- Assumption that many storage facilities experience damage and disruption, but that some product and employees can be temporarily moved to other facilities while repairs take place.
- Assumption that there is a diversity of products moving through storage facilities so operations would not completely shut down if certain seafood products are hard hit.

4. Coastal Erosion

Scenario: Acceleration of the historic rate of erosion (28 cm/year)

Coastal erosion on PEI currently represents a **Low** risk to PEI's storage facilities. This risk increases to **Medium** by mid-century (Table 68).

Table 68. Storage facilities risk summary for coastal erosion

Coastal Erosion: Storage Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	5	1	3	1	1.7	**Low (6.7)**	**Medium (8.3)**

[249] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[250] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[251] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[252] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Likelihood

Appendix B Coastal Erosion provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
The annual average rate of erosion on PEI from 1968 to 2010 was 28 cm/year.

Future: (Rating: 5 – Almost Certain)
From 2000 to 2010, the average annual rate was 40 cm/year, above the historical average. Drivers of coastal erosion are projected to increase in frequency and severity which will continue drive higher rates of erosion.

Consequences

Coastal erosion could be a threat to storage facility infrastructure, but overall will not cause significant disruptions.

Production/Output (Rating: 1 – Insignificant)
Coastal erosion is not expected to affect production or output.

Infrastructure (Rating: 3 – Moderate)
Depending on the location of the facility, coastal erosion may require repairs to reinforce the structure and slow erosion or may require relocation. Storage facilities for live products are typically located closer to the coast than processing facilities.[253]

Livelihoods (Rating: 1 – Insignificant)
It is assumed that most storage facilities are not located along the shoreline. Those that are at risk of coastal erosion could implement resilience measures or relocate.

5. Ice Storm/Freezing Rain

Scenario: Multi-day severe ice storm/freezing rain event in winter

Severe ice storms and freezing rain events on PEI currently represent a **Medium** risk to PEI's storage facilities. This risk decreases to **Low** by mid-century (Table 69).

Table 69. Storage facilities risk summary for ice storm/freezing rain

Ice Storm/Freezing Rain: Storage Facilities							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	3	2	2	2	2	**Medium (8.0)**	**Low (6.0)**

Likelihood

Appendix B Ice Storm/Freezing Rain provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historical climate data on ice days and frost days as well as the frequency of past multi-day severe ice storms and freezing rain events suggest these events are likely to occur.

[253] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Future: (Rating: 3 – Possible)
It is expected that precipitation will increasingly fall as rain rather than snow and ice and winters will become milder, potentially decreasing the frequency of these events.

Consequences

Ice storms and freezing rain are a concern for facility operations when they cause power outages. Any disruptions would be temporary for up to a few days.

Production/Output (Rating: 2 – Minimal)
Ice and freezing rain can bring down power lines and cause widespread power outages, which could affect production. While power outages are less of a concern from a cooling and refrigeration standpoint since temperatures are near freezing, they are a concern for operating water recirculation systems. Loss of power could cause stress or mortality for live holdings. However, many facilities have a backup power supply, especially those responsible for cold storage and live holdings.

Infrastructure (Rating: 2 – Minimal)
Ice and freezing rain can coat and potentially damage critical infrastructure, including bringing down power lines. Disruptions could last for up to a few days, especially if there is not a backup power source or sufficient fuel supply.

Livelihoods (Rating: 2 – Minimal)
There are lower rates of employment in the winter months and an event would primarily disrupt production during a power outage, which would last up to a few days at most. If facilities remain open during this period, travel conditions may be dangerous for employees.

Buying Stations

Buying stations are located around the province where seafood is immediately purchased after harvesters return with a harvest. Most buying stations are rudimentary mobile structures used by the commercial fisheries. However, there are some permanent buying station structures. Buying stations are distinct from landing sites, which are not evaluated in this assessment.

Figure 29 summarizes climate risks to buying stations. Post-tropical storms pose the greatest risk to buying stations, especially those that are permanent structures. No climate hazard received a high risk rating or a significant consequence rating for this asset.

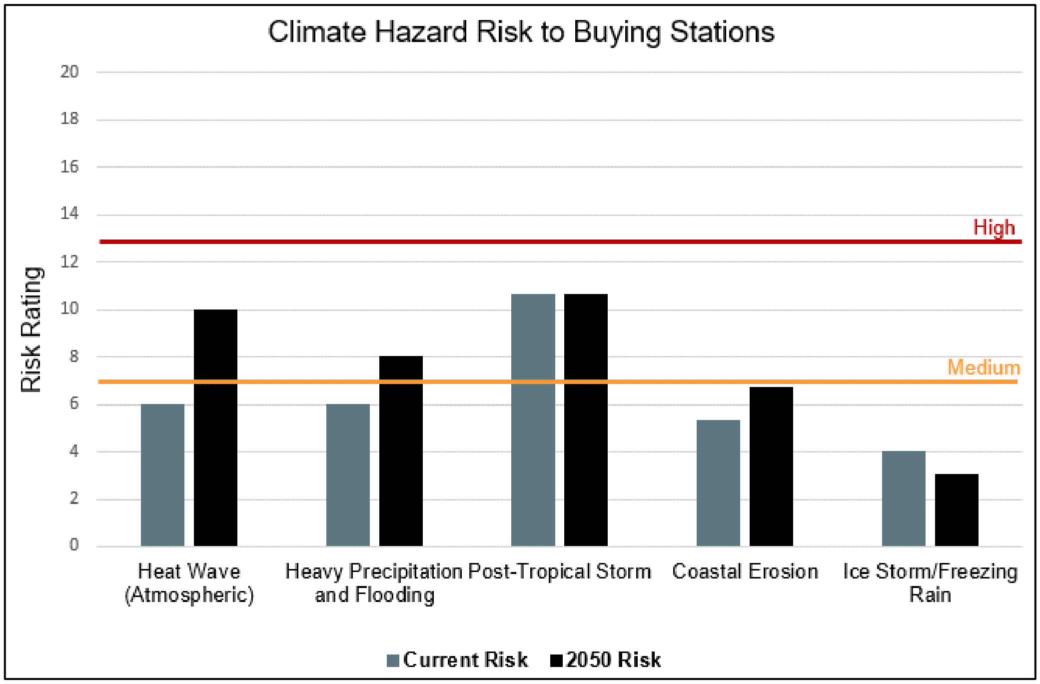

Figure 29. Summary of current and future climate hazard risk to buying stations.

1. Heat Wave (Atmospheric)

Scenario: Three consecutive days with temperatures above 29°C

Atmospheric heat waves on PEI currently represent a **Low** risk to PEI's buying stations. This risk increases to **Medium** by mid-century (Table 70).

Table 70. Buying stations risk summary for heat wave

Heat Wave: Buying Stations							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	3	2	1	2	**Low (6.0)**	**Medium (10.0)**

Likelihood

Appendix B Heat Wave (Atmospheric) provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Historically, this scenario has occurred 0.05 times per year on average.

Future: (Rating: 5 – Almost Certain)
Future projections indicate this scenario will occur 2.1 times per year on average.

Consequences

Heat waves may affect the quantity and quality of seafood at buying stations, but otherwise the consequences are minimal and temporary.

Production/Output (Rating: 3 – Moderate)

Atmospheric/marine heat waves may change the quantity, quality, and timing of seafood available at buying stations. Seafood products exposed to heat will experience increased stress which can decrease quality and affect shelf life.[254]

Infrastructure (Rating: 2 – Minimal)

Heat waves are not expected to cause physical damage but may increase cooling needs and costs (e.g., ice, shaded or covered storage bins).[255]

Livelihoods (Rating: 1 – Insignificant)

A 3-day heat wave is not expected to disrupt livelihoods. For outdoor workers, heat waves may lead to heat stress and other health risks.

2. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI currently represent a **Low** risk to PEI's buying stations. This risk increases to **Medium** by mid-century (Table 71).

Table 71. Buying stations risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Buying Stations							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	2	2	2	2	**Low (6.0)**	**Medium (8.0)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)

This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)

Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

Consequences

Due to the mobility and simplicity of most buying stations, consequences are expected to be minimal and temporary.

Production/Output (Rating: 2 – Minimal)

Heavy precipitation and flooding may change the quantity, quality, and timing of seafood available at buying stations.

[254] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

[255] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Infrastructure (Rating: 2 – Minimal)

Many buying stations are mobile and could be moved in advance of an anticipated flood event. Flooding is not expected to cause much damage to buying stations. However, if an event occurs unexpectedly, there could be damage to the infrastructure or operational equipment.

Livelihoods (Rating: 2 – Minimal)

Buying stations may temporarily close or receive fewer customers during a flooding event, but they are expected to reopen quickly with minimal disruption.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represent a **Medium** risk to PEI's buying stations for both the current period and mid-century (Table 72).

Table 72. Buying stations risk summary for post-tropical storm

Post-Tropical Storm: Buying Stations							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	3	3	2	2.7	**Medium (10.7)**	**Medium (10.7)**

Likelihood

Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)

Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences

High winds, storm surge, and heavy rain from post-tropical storms could cause damage to buying stations, especially those that are not mobile. This hazard can also reduce the quantity and quality of seafood at buying stations.

Production/Output (Rating: 3 – Moderate)

Buying stations would likely need to temporarily close. The quantity and quality of seafood available at buying stations could also be affected in the weeks and months following the storm.

Infrastructure (Rating: 3 – Moderate)

Fixed buying stations are more susceptible to damage and may require repairs in the weeks and months following the storm. Rating considerations included:

- Many buying stations are mobile and could be moved or stored in advance of a storm.
- Fixed buying stations could experience damage to infrastructure and operational equipment from coastal flooding, storm surge, high winds, and erosion.

- Fiona caused considerable damage to harbours and facilities and an extended power outage.
- Damage to coastal roadways and bridges restricting access.

Livelihoods (Rating: 2 – Minimal)
Facilities that require more significant repairs may need to limit or close operations for weeks to months, temporarily reducing income and employment at those locations.

4. Coastal Erosion

Scenario: Acceleration of the historic rate of erosion (28 cm/year)

Coastal erosion on PEI represents a **Low** risk to PEI's buying stations through the current period. This risk increases but remains **Low** into mid-century (Table 73).

Table 73. Buying stations risk summary for coastal erosion

Coastal Erosion: Buying Stations							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	5	1	2	1	1.3	**Low (5.3)**	**Low (6.7)**

Likelihood

Appendix B Coastal Erosion provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
The annual average rate of erosion on PEI from 1968 to 2010 was 28 cm/year.

Future: (Rating: 5 – Almost Certain)
From 2000 to 2010, the average annual rate was 40 cm/year, above the historical average. Drivers of coastal erosion are projected to increase in frequency and severity which will continue drive higher rates of erosion.

Consequences

Coastal erosion is a minor threat to fixed buying stations, but otherwise is not expected to cause significant disruptions.

Production/Output (Rating: 1 – Insignificant)
Coastal erosion is not expected to affect production or output.

Infrastructure (Rating: 2 – Minimal)
Most buying stations are mobile and can be easily relocated. Depending on the location of the fixed buying stations, coastal erosion may require repairs to reinforce the structure and slow erosion or relocation.

Livelihoods (Rating: 1 – Insignificant)
Most buying stations are mobile and will be unaffected.

5. Ice Storm/Freezing Rain

Scenario: Multi-day severe ice storm/freezing rain event in winter

Severe ice storms and freezing rain events on PEI currently represent a **Low** risk to PEI's buying stations. This risk remains **Low** by mid-century (Table 74).

Table 74. Buying stations risk summary for ice storm/freezing rain

Ice Storm/Freezing Rain: Buying Stations							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	3	1	1	1	1	**Low (4.0)**	**Low (3.0)**

Likelihood

Appendix B Ice Storm/Freezing Rain provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historical climate data on ice days and frost days as well as the frequency of past multi-day severe ice storms and freezing rain events suggest these events are likely to occur.

Future: (Rating: 3 – Possible)
It is expected that precipitation will increasingly fall as rain rather than snow and ice and winters will become milder, potentially decreasing the frequency of these events.

Consequences

Ice storms and freezing rain have limited consequences for buying stations.

Production/Output (Rating: 1 – Insignificant)
Ice and freezing rain are not expected to affect production.

Infrastructure (Rating: 1 – Insignificant)
Ice and freezing rain can temporarily coat the buying station in ice but are not expected to cause damage.

Livelihoods (Rating: 1 – Insignificant)
Buying stations already have limited operation during winter months.

Inbound/Outbound Transportation

The seafood industry is heavily reliant on ground transportation for shipping product across the Confederation Bridge or Northumberland Ferries and out of PEI. Large trucks typically travel to Halifax or Moncton, where product is then further transported to Boston, New York, and other major markets by a variety of methods (ground, air, or water). Very little product is transported out of Charlottetown by air or water. This risk assessment focused on inbound/outbound transportation on PEI until product is off the island. It also focused on impacts to ground transportation as that is the primary mode of transportation for the industry.

Figure 30 summarizes climate risks to inbound/outbound transportation on PEI. Post-tropical storms have the highest risk rating and most significant consequences of any hazard. Post-tropical storms could cause significant damage, delays, or closures limiting the ability to transport products on/off the island.

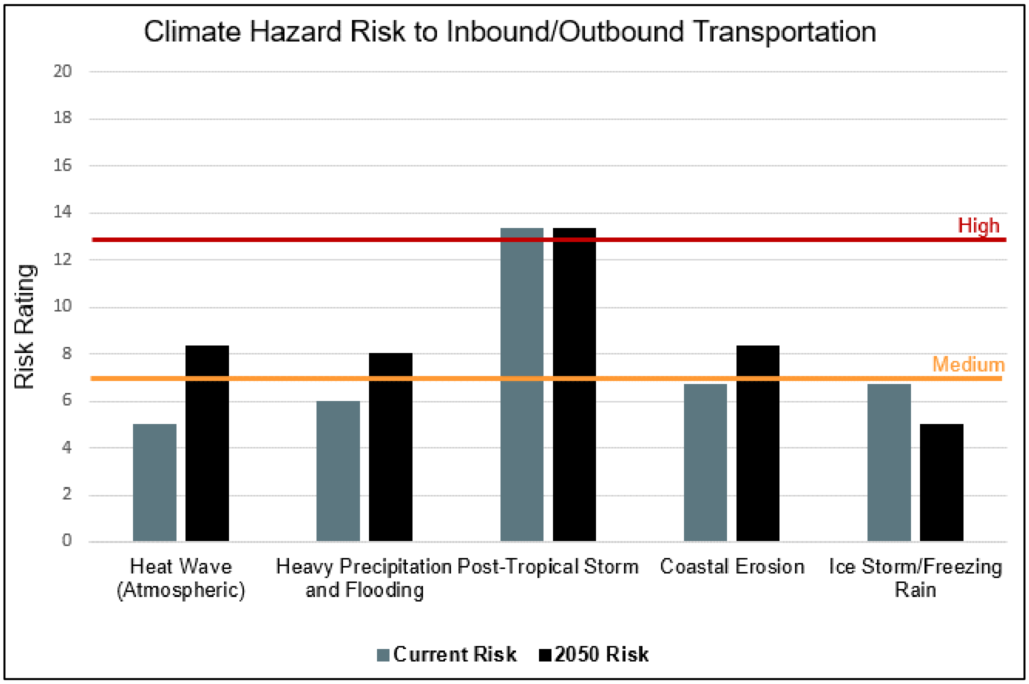

Figure 30. Summary of current and future climate hazard risk to inbound/outbound transportation.

1. Heat Wave (Atmospheric)

Scenario: Three consecutive days with temperatures above 29°C

Increasing frequency of atmospheric heat waves on PEI currently represents a **Low** risk to PEI's inbound/outbound transportation. This risk increases to **Medium** by mid-century (Table 75).

Table 75. Inbound/outbound transportation risk summary for heat wave

Heat Wave: Inbound/Outbound Transportation							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	5	2	2	1	1.7	**Low (5.0)**	**Medium (8.3)**

Likelihood

Appendix B Heat Wave (Atmospheric) provides additional details on likelihood rating assumptions.

Current: (Rating: 3 – Possible)
Historically, this scenario has occurred 0.05 times per year on average.

Future: (Rating: 5 – Almost Certain)
Future projections indicate this scenario will occur 2.1 times per year on average.

Consequences

Atmospheric heat waves are not expected to disrupt inbound/outbound transportation operations.

Production/Output (Rating: 2 – Minimal)

Atmospheric/marine heat waves may change the quantity and timing of seafood needing transport but does not affect the ability to transport products. To avoid spoilage, product may also need to be transported more quickly.[256]

Infrastructure (Rating: 2 – Minimal)

Heat waves are not expected to cause physical damage to transportation infrastructure but may increase cooling demand and costs for refrigerated transport.

Livelihoods (Rating: 1 – Insignificant)

Heat waves are not expected to disrupt transportation operations. There may be temporary heat-related health risks for outdoor workers.

2. Heavy Precipitation and Flooding

Scenario: 100 mm of rainfall in 24 hours

Heavy precipitation and flooding events on PEI currently represent a **Low** risk to PEI's inbound/outbound transportation. This risk increases to **Medium** by mid-century (Table 76).

Table 76. Inbound/outbound transportation risk summary for heavy precipitation and flooding

Heavy Precipitation and Flooding: Inbound/Outbound Transportation							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
3	4	2	3	1	2	**Low (6.0)**	**Medium (8.0)**

Likelihood

Appendix B Heavy Precipitation and Flooding provides additional details on likelihood rating assumptions for this scenario.

Current: (Rating: 3 – Possible)

This scenario is the historic 1-in-25-year rain event, which has a 4% annual chance of occurring.

Future: (Rating: 4 – Likely)

Future projections indicate that this scenario is expected to occur more frequently by mid-century with a 10% annual chance of occurrence.

Consequences

Heavy precipitation and flooding could disrupt transportation operations during and shortly after an event, but they are not expected to have long-term consequences. A non-coastal heavy precipitation event is not expected to cause significant damage to the Confederation Bridge.

[256] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Production/Output (Rating: 2 – Minimal)
Flooding could cause road/bridge closures and delays, but disruptions are not expected to last more than hours to days. Detours may add travel time but will not close inbound/outbound transportation. A heavy precipitation and flood event is not expected to cause prolonged closure of Confederation Bridge, which does not have an alternative detour route.

Infrastructure (Rating: 3 – Moderate)
Flooding can cause significant damage to or complete wash outs of roads and bridges that could take months to repair. A heavy precipitation and flood event is not expected to cause significant damage or prolonged closure of Confederation Bridge. Vehicles could also experience flood damage.[257]

Livelihoods (Rating: 1 – Insignificant)
Flooding could cause temporary road/bridge closures and delays during and shortly after the event, but this is not expected to affect income or employment.

3. Post-Tropical Storm

Scenario: Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022

Post-tropical storms on PEI represents a **High** risk to PEI's inbound/outbound transportation for both the current period and mid-century (Table 77). Production/output, infrastructure, and livelihoods could all be significantly affected by this scenario.

Table 77. Inbound/outbound transportation risk summary for post-tropical storm

Post-Tropical Storm: Inbound/Outbound Transportation							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	4	4	4	2	3.3	**High (13.3)**	**High (13.3)**

Likelihood
Appendix B Post-Tropical Storm provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historically, severe storms are likely to occur on PEI approximately once every 3-10 years.

Future: (Rating: 4 – Likely)
Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years.

Consequences
Post-tropical storms pose significant consequences to inbound/outbound transportation operations for the seafood industry. These ratings assume a worst-case scenario in which Confederation Bridge is compromised for more than two days (past events have closed the

[257] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

bridge for up to two days). If the Confederation Bridge does not experience significant damage that requires prolonged closures, consequences may be more moderate.

Production/Output (Rating: 4 – Significant)

Post-tropical storms could cause significant damage, delays, or closures of roads, bridges, and port infrastructure, including the critical Confederation Bridge limiting the ability to transport products on/off the island. Rating considerations included:

- Prolonged closure of the Confederation Bridge can cause significant economic shocks to the seafood industry, which includes both the fishery and aquaculture sectors. Closures of a week, month, or quarter could all reduce industry productivity by 76-100%.
- Past high wind and post-tropical storm events have caused travel restrictions for high-sided vehicles or complete closure of the Confederation Bridge for hours up to two days in length. Ferries and marine shipping centres have also temporarily closed during events.
- In anticipation of a storm, some facilities increase production, processing, and packaging of products in the days before the storm to avoid any disruptions to buyers waiting for products.[258]

Infrastructure (Rating: 4 – Significant)

Post-tropical storms can cause significant damage to or complete wash outs of roads, bridges, and port infrastructure that could take weeks to years to repair depending on the severity. While past post-tropical storms have not caused significant damage to the Confederation Bridge or prolonged closures, it is possible. Rating considerations included:

- Post-tropical storms can temporarily inundate or damage coastal roadways and bridges and disrupt access to fuel sources.
- Post-tropical storms can also result in damage to vehicles. [259]

Livelihoods (Rating: 2 – Minimal)

Post-tropical storms cause road/bridge closures, travel restrictions, and delays in the days and weeks following an event as the island recovers. These impacts can affect livelihoods for those that transport products and can have ripple effects on livelihoods across the industry. In addition, while the Confederation Bridge has only been closed for two days at most in the past, a longer closure is possible, which could severely affect income and employment. Rating considerations included:

- Prolonged closure of the Confederation Bridge can cause significant economic shocks to the seafood industry, which includes both the fishery and aquaculture sectors:[260]
    - Closures of a week, month, or quarter could all reduce industry productivity by 76-100%.
    - Estimated job losses for the industry are expected to be 15-21 jobs for a week-long closure; 77-104 jobs for a month-long closure; and 256-339 jobs for a quarter-long closure.

[258] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[259] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.
[260] Fellows et al., "Economic Loss Analysis to Prince Edward Island Resulting from a Prolonged Closure of the Confederation Bridge."

- Past high wind and post-tropical storm events have caused travel restrictions for high-sided vehicles or complete closure of the Confederation Bridge for hours up to two days in length.

4. Coastal Erosion

Scenario: Acceleration of the historic rate of erosion (28 cm/year)

Coastal erosion on PEI currently represents a **Low** risk to PEI's inbound/outbound transportation. This risk increases to **Medium** by mid-century (Table 78).

Table 78. Inbound/outbound transportation risk summary for coastal erosion

Coastal Erosion: Inbound/Outbound Transportation							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	5	1	3	1	1.7	**Low (6.7)**	**Medium (8.3)**

Likelihood

Appendix B Coastal Erosion provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)

The annual average rate of erosion on PEI from 1968 to 2010 was 28 cm/year.

Future: (Rating: 5 – Almost Certain)

From 2000 to 2010, the average annual rate was 40 cm/year, above the historical average. Drivers of coastal erosion are projected to increase in frequency and severity which will continue to drive higher erosion rates.

Consequences

Coastal erosion may affect some transportation infrastructure but is not expected to cause significant delays or disruptions to inbound/outbound transportation.

Production/Output (Rating: 1 – Insignificant)

Coastal erosion is not expected to affect production or output.

Infrastructure (Rating: 3 – Moderate)

Depending on the location of key transportation infrastructure (major roads, bridges, airport), coastal erosion may require repairs to reinforce structures and slow erosion or require relocation. Rating considerations included:

- Coastal erosion hazard mapping from the University of PEI identified 126 vehicle bridges and 50 kilometres of roads at risk of erosion over the next 80 years.[261]
- Assumption that there are detours available for many of these exposed transportation assets so disruptions to operations may be minimal (e.g., increased travel time).

Livelihoods (Rating: 1 – Insignificant)

Transportation routes are expected to be fully functional. If a route is compromised, there is likely a detour available adding travel time, but not significantly disrupting operations.

[261] Prince Edward Island, "Prince Edward Island (PEI) Climate Change Risk Assessment."

5. Ice Storm/Freezing Rain

Scenario: Multi-day severe ice storm/freezing rain event in winter

Severe ice storms and freezing rain events on PEI represents a **Low** risk to PEI's inbound/outbound transportation for the current period. This risk decreases and remains **Low** by mid-century (Table 79).

Table 79. Inbound/outbound transportation risk summary for ice storm/freezing rain

Ice Storm/Freezing Rain: Inbound/Outbound Transportation							
Likelihood		**Consequences**				**Risk**	
Current	2050	Production / Output	Infrastructure	Livelihoods	Overall Consequence	Current	2050
4	3	2	2	1	1.7	**Low (6.7)**	**Low (5.0)**

Likelihood

Appendix B Ice Storm/Freezing Rain provides additional details on likelihood rating assumptions.

Current: (Rating: 4 – Likely)
Historical climate data on ice days and frost days as well as the frequency of past multi-day severe ice storms and freezing rain events suggest these events are likely to occur.

Future: (Rating: 3 – Possible)
It is expected that precipitation will increasingly fall as rain rather than snow and ice and winters will become milder, potentially decreasing the frequency of these events.

Consequences

Ice storms and freezing rain can cause travel delays, closures, and dangerous conditions. However, any disruptions to operations would be temporary for up to a few days.

Production/Output (Rating: 2 – Minimal)
Slick roads or downed trees and power lines can cause travel delays and closures. However, these are expected to be resolved within hours to days. In anticipation of a storm, some facilities may increase production, processing, and packaging of products in advance of the storm to avoid any disruptions to buyers waiting for products.[262]

Infrastructure (Rating: 2 – Minimal)
Ice and freezing rain will coat roads, bridges, and other transportation infrastructure for the duration of the event but should clear relatively quickly with none to minimal damage to the infrastructure.

Livelihoods (Rating: 1 – Insignificant)
Slick roads or downed trees and power lines can cause travel delays and closures. However, these are expected to be resolved quickly without disrupting livelihoods.

[262] Seafood Industry Representatives, *Workshop - PEI Climate Change Risk and Opportunity Assessment for the Seafood Industry, Draft Results*. August 2023.

Appendix A: Climate Risk and Opportunity Assessment Methodology

The climate risk and opportunity assessment involved a multi-step process detailed below (Figure 31) and close collaboration with the PEI Department of Fisheries, Tourism, Sport and Culture (DFTSC). The DFTSC was responsible for selecting the focus species and hazards for this assessment.

To ground truth the findings of the risk and opportunity assessment and build buy-in across the industry, the DFTSC also held a series of workshops with industry representatives in August 2023. The purpose of these workshops was to vet and discuss high priority risks facing each sector and begin to identify potential adaptation options to address priority risks.

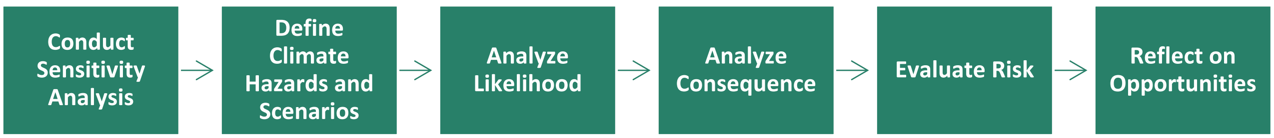

Figure 31. Climate risk and opportunity assessment process diagram.

Step 1. Conduct Sensitivity Analysis

The climate sensitivity analysis first identified potential sensitivities of key species and infrastructure to 10 climate change hazards. The purpose of this exercise was to research key climate sensitivities and impacts and help narrow the focus of the climate change risk assessment to the most significant climate hazards. DFTSC selected the focus species and infrastructure for the analysis, emphasizing those that are economically valuable to the province (see textbox).

ICF conducted a desk-top analysis to identify key sensitivities and critical thresholds for each species (aquaculture, commercial) or infrastructure (processing) and climate hazard. ICF researched and considered the effects of climate change on factors, such as:

- Growth rate
- Life Cycle
- Migration
- Morbidity and mortality
- Reproduction
- Migration
- Habitat quality
- Competition and predation
- Pests and diseases
- Infrastructure resilience
- Supply chain considerations
- Livelihoods

Focus per Subsector

Aquaculture:

- Mussels
- Oysters
- Rainbow trout
- Atlantic salmon

Commercial fishing:

- Lobster
- Snow crab
- Atlantic bluefin tuna
- Atlantic mackerel
- Atlantic herring
- Rock crab
- Soft shell clams

Seafood processing:

- Processing facilities
- Storage facilities
- Buying stations
- Inbound/outbound transportation

ICF and DFTSC then rated the sensitivity (significant, moderate, minimal) of each species/infrastructure to each climate hazard based on available information and professional judgment. These relative sensitivity ratings were used to determine which hazards were most critical to assess in the climate change risk assessment. Table 80 lists the 5 key climate hazards ultimately selected for further analysis per sector.

Table 80. Climate hazards selected for risk assessment analysis per sector

Aquaculture Sector	Commercial fishing sector	Processing Sector
1. Oceanic/riverine warming 2. Heat wave 3. Heavy precipitation and flooding 4. Post-tropical storm 5. Acidification	1. Oceanic/riverine warming 2. Heat wave 3. Post-tropical storm 4. Acidification 5. Hypoxia	1. Heat wave 2. Heavy precipitation and flooding 3. Post-tropical storm 4. Coastal erosion 5. Ice storm/freezing rain

Step 2. Define Climate Hazards and Scenarios

To better evaluate likelihood and consequence, ICF defined specific scenarios for each of the climate hazards (Table 7). Each scenario represents one possible permutation of that hazard and is used to illustrate the types of consequences associated with the hazard. The likelihood and consequence ratings are specific to these scenarios.

The sensitivity analysis identified several critical thresholds at which point a species begins to experience significant impacts. For climate hazards with species-specific thresholds, the scenario is defined by those thresholds. For climate hazards without species-specific thresholds, scenarios are equivalent to those used in the PEI Climate Change Risk Assessment (2021) for consistency.

Table 81. Climate hazard scenarios

Hazard	Scenario	Focus per Sector		
		Aquaculture	Commercial	Processing
Oceanic/ riverine warming	Average water temperature rises above a species-specific threshold for adults that results in reduced growth, reduced recruitment, or some other indicated non-lethal limit threshold.	X	X	
Heat wave	Marine: More frequent occurrence of water temperatures above a species-specific lethal limit for adults for mature specimens (if available).	X	X	
	Atmospheric: Three consecutive days with temperatures above 29°C.	X		X
Heavy precipitation and flooding	100mm of rain in 24 hours.	X		X
Post-tropical storm	Multi-day post-tropical storm analogous to Post-Tropical Storm Fiona in 2022.	X	X	X

Hazard	Scenario	Focus per Sector		
		Aquaculture	Commercial	Processing
Acidification	Acidification reaches a species-specific threshold (if available).	X	X	
Hypoxia	More frequent hypoxic conditions.		X	
Coastal erosion	Acceleration of the historic rate of erosion (28 cm/year).			X
Ice storm/ freezing rain	Multi-day severe ice storm/freezing rain event in winter.			X

Step 3. Analyze Likelihood

Risk is a function of the likelihood of a hazard scenario occurring, and the consequences of that hazard scenario. ICF rated the likelihood of each climate hazard scenario on a scale of 1 to 5 to represent the degree of certainty that the scenario will occur in a given timeframe; in this case, by 2050.

Climate hazards can be either discrete (e.g., heat wave) or ongoing (e.g., oceanic warming). Evaluating the likelihood of these hazards is fundamentally different:

- **Discrete climate events (no sensitivity threshold):** Likelihood is measured by the expected frequency of the hazard in a given time period. The sensitivity analysis did not identify a critical threshold specific to individual species.
- **Ongoing climate hazards (sensitivity threshold):** Likelihood is measured by the probability that a critical threshold–a defined tipping point at which significant impacts occur–is exceeded by a given time period. The sensitivity analysis identified critical thresholds specific to each species, which are used as the tipping points for this assessment.

The likelihood rating scale in Table 82 provides the rubric for evaluating the likelihood of discrete and ongoing climate hazards, which is consistent with the rubric from the province-wide PEI Climate Change Risk Assessment. The assessment evaluated likelihood for both a baseline time period and future time period (2050) to capture how the likelihood of the climate hazard scenarios changes over time. Likelihood ratings were based on the best available climate science or existing research. Details on the sources used to assess likelihood for each hazard are in Appendix B: Likelihood Rating Descriptions.

Table 82. Likelihood rating scale

Likelihood	Rating	Criteria for Discrete Climate Hazards (no sensitivity threshold)	Criteria for Ongoing Climate Hazards (sensitivity threshold)
Almost certain	5	Event is expected to happen about once every two years or more frequently (i.e., annual chance ≥ 50%*).	Event is almost certain to cross critical threshold.
Likely	4	Event is expected to happen about once every 3-10 years (i.e., 10% ≤ annual chance < 50%).	Event is expected to cross critical threshold. It would be surprising if this did not happen.

Likelihood	Rating	Criteria for Discrete Climate Hazards (no sensitivity threshold)	Criteria for Ongoing Climate Hazards (sensitivity threshold)
Possible	3	Event is expected to happen about once every 11-50 years (i.e., 2% ≤ annual chance < 10%).	Event is just as likely to cross critical threshold as not.
Unlikely	2	Event is expected to happen about once every 51-100 years (i.e., 1% ≤ annual chance < 2%).	Event is not anticipated to cross critical threshold.
Rare	1	Event is expected to happen less than about once every 100 years (i.e., annual chance <1%).	Event is almost certain not to cross critical threshold.

*Annual chance is the probability that an event will occur in a given year

Step 4. Analyze Consequence

ICF analyzed the consequences of each climate hazard scenario across three key dimensions:

- **Production/Output:** The quantity and quality of seafood harvested, produced, or processed. Includes the harvest or aquaculture production of species that contribute to the overall output and supply of seafood products.
- **Infrastructure:** Physical assets, facilities, and systems that support the harvesting of commercial seafood and aquaculture production. This includes fishing vessels, fishing equipment, and aquaculture farms, along with associated aquaculture equipment that enable the harvest or growth of species. Notably, seafood processing facilities, storage facilities, buying stations, and transportation networks are **not** considered in this category for aquaculture and commercial species. Infrastructure under these categories are considered independently, as part of the seafood processing sector.
- **Livelihoods:** Economic activities and employment opportunities related to the harvesting and processing of commercial seafood and aquaculture production. This includes jobs in fishing, aquaculture, processing, and those who provide and sell equipment for such activities. Livelihoods also involve the social and economic wellbeing of individuals and communities dependent on the seafood industry for their sustenance and income. The relative size of the industry related to each species is considered within this category. Notably, seafood processing facilities, storage facilities, buying stations, and transportation networks are **not** considered in this category for aquaculture and commercial species. Livelihoods under these categories are considered independently, as part of the seafood processing sector.

Table 83 provides the consequence rating scale. Each consequence dimension was rated on a 1 to 4 scale based on impacts through 2050. The overall consequence score is an average of the three ratings for production/output, infrastructure, and livelihoods. Consequence ratings are based on findings from the climate sensitivity analysis (Step 1), additional research, and professional judgment.

Table 83. Consequence rating scale

Rating	Production/Output	Infrastructure	Livelihoods
Significant (4)	Significant disruption or complete loss of production that lasts months to years and the industry experiences a very significant profit reduction or even net economic losses related to the species.	Significant, and/or widespread damage or failure to infrastructure. Repairs or replacements are costly and take months to years.	Significant loss of income or employment lasting months to years for fisheries or sectors where a significant number of livelihoods are supported relative to the seafood industry as a whole.
Moderate (3)	Noticeable reduction in productivity and outputs that lasts weeks to months, however, the industry does not experience a complete loss of profit related to the species.	Partial damage or limited disruption to infrastructure. Any infrastructure failures are not widespread and do not result in an inability of the fishery/facility to function. Repairs or workarounds last weeks to months.	Moderate loss of income or employment opportunities lasting weeks to months for fisheries or sectors where a significant number of livelihoods are supported relative to the seafood industry as a whole; OR Significant loss of income or employment lasting months to years for fisheries or sectors where a minimal to moderate number of livelihoods are supported relative to the seafood industry as a whole.
Minimal (2)	Minimal disruption to production/output that is relatively quickly resolved, and the industry experiences limited reduction in profit related to the species.	Minimal disruption to infrastructure. Repairs or workarounds can be resolved within days.	Minimal loss of income or employment opportunities lasting weeks to months for fisheries or sectors where a significant number of fisheries are supported relative to the seafood industry as a whole; OR Moderate loss of income or employment lasting months to years for fisheries or sectors where a minimal to moderate number of livelihoods are supported relative to the seafood industry as a whole.
Insignificant (1)	No impact on production/output.	No damage or disruption to infrastructure.	No disruption to livelihoods.

Step 5. Evaluate Risk

Risk is a function of likelihood and consequence. To evaluate risk, ICF combined the likelihood and consequence ratings for each climate hazard scenario. ICF calculated risk scores for both present day and 2050.

The three consequence category ratings were averaged to calculate an overall consequence score, then multiplied by the likelihood score to compute a total risk score, as shown in the formula below.

Risk = Likelihood × Overall Consequences

where

Overall Consequences = Average (Production/Output, Infrastructure, Livelihood)

Table 84 and Table 85 provide the final risk rating matrix and corresponding score-to-rating rubric.

Table 84. Climate risk rating matrix

	Consequence			
Likelihood	**Insignificant**	**Minimal**	**Moderate**	**Significant**
Almost Certain	Low	Medium	High	High
Likely	Low	Medium	Medium	High
Possible	Low	Low	Medium	Medium
Unlikely	Low	Low	Low	Medium
Rare*	Low	Low	Low	Low

*Scenarios that received a "rare" likelihood rating for both the current and future time period were not evaluated further and received a Negligible overall risk rating.

Table 85. Risk rating rubric

Risk Score	Risk Rating
No score*	Negligible
1-6	Low
7-12	Medium
13-20	High

*Scenarios that received a "rare (1)" likelihood rating for both the current and future time period were not evaluated further and received a Negligible overall risk rating.

Step 6. Reflect on Opportunities

Climate change has the potential to provide some opportunities to all three sectors on PEI. ICF conducted a literature review on the potential benefits of climate change to the aquaculture, commercial fishing, and seafood processing sectors and applied professional judgment to identify potential opportunities for PEI.

Appendix B: Likelihood Rating Descriptions

This appendix details the evidence base on current and future conditions for each climate hazard evaluated in the risk assessment and how they were evaluated against the rubric in Table 86 to determine appropriate likelihood ratings.

Table 86. CCRA likelihood rating scale for discrete and ongoing climate hazards

Likelihood	Rating	Criteria for Discrete Climate Hazards (no sensitivity threshold)	Criteria for Ongoing Climate Hazards (sensitivity threshold)
Almost certain	5	Event is expected to happen about once every two years or more frequently (i.e., annual chance ≥ 50%*).	Event is almost certain to cross critical threshold.
Likely	4	Event is expected to happen about once every 3-10 years (i.e., 10% ≤ annual chance < 50%).	Event is expected to cross critical threshold. It would be surprising if this did not happen.
Possible	3	Event is expected to happen about once every 11-50 years (i.e., 2% ≤ annual chance < 10%).	Event is just as likely to cross critical threshold as not.
Unlikely	2	Event is expected to happen about once every 51-100 years (i.e., 1% ≤ annual chance < 2%).	Event is not anticipated to cross critical threshold.
Rare	1	Event is expected to happen less than about once every 100 years (i.e., annual chance <1%).	Event is almost certain not to cross critical threshold.

*Annual chance is the probability that an event will occur in a given year

Oceanic/Riverine Warming

Current: Historical data collected by Fisheries and Oceans Canada Monitoring programs indicate that the northwest Atlantic Ocean is warming.[263] Sea surface temperatures hit record levels in 2012 and 2014, with 2012 being the warmest year observed since satellite records began in 1985.[264] The bodies of water closest to PEI include the Gulf of St. Lawrence, which saw a 100-year record high between 2012 and 2016.[265] Data from 1985 to 2017 reveal that sea surface temperature in the Gulf of St. Lawrence has been increasing at a rate of approximately 0.46°C per decade.[266, 267]

Earlier, Warmer Springs

The PEI Climate Change Risk Assessment (2021) found that increasing air temperatures as well as rising sea surface temperatures will also drive earlier, warmer springs. The arrival of above freezing temperatures may shift by at least two weeks by 2050.

[263] Lemmen, Donald S and Bush, E. *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada, 2019. https://changingclimate.ca/CCCR2019/.
[264] Fisheries and Oceans Canada. *Canada's Oceans Now: Atlantic Ecosystems 2018*. 2019. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40781987.pdf.
[265] Fisheries and Oceans Canada. *Canada's Oceans Now 2020*. 2020. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40939236.pdf.
[266] Sea surface temperature is averaged over the ice-free period of the year (May to November).
[267] Lemmen, Donald S and Bush, E. *Canada's Changing Climate Report*.

Temperatures at other depths are also increasing. Data collected from 1917 to 2017 indicate a 0.25°C and 0.23°C increase per decade for water depths of 200 m and 300 m respectively.[268] Average sea surface temperatures vary spatially and seasonally in the Gulf of St. Lawrence. Average winter sea surface temperatures are typically -1.3 to 0.9°C and **average summer sea surface temperatures range from 16 to 19°C**.[269, 270]

Shallow coastal waters in the bays and estuaries are typically warmer than the Gulf of St. Lawrence. Observed temperature logs at mussel and oyster sites recorded temperatures as high as 27-28°C in July-August 2022 and August 2021. **Recorded July-August temperatures at these coastal sites range from 11-27°C and average 21°C.**[271]

Future: The Northwest Atlantic is projected to continue warming in the future. Under a high emissions scenario (RCP 8.5), winter sea surface temperatures around PEI are projected to increase by up to 3°C by 2050 compared to the baseline (1986-2005). Similarly, summer sea surface temperatures are projected to increase by up to 4°C by 2050 compared to the baseline (1986-2005).[272] Projected changes in sea surface temperatures are due to changes in large-scale ocean circulation, as well as a slight northward expansion of the subtropical gyre and shift of the Gulf stream.[273] This translates to average winter sea surface temperatures of 1.7 to 3.9°C and **average summer sea surface temperatures of 20 to 23°C**.

Assuming a similar magnitude of change for coastal water temperatures, **July-August temperatures at these coastal sites could range from 15-31°C and average 25°C.**

The likelihood of these projected changes crossing a critical sensitivity threshold varies for each species. See Table 87 below for the thresholds and likelihood ratings for each species.

Table 87. Species-specific thresholds and likelihood ratings for oceanic/riverine warming.

Species	Threshold	Current Likelihood Rating	Future Likelihood Rating
	Gulf range of values	*16-19°C*	*20-23°C*
Lobster	25°C	**1** (Rare)	**2** (Unlikely)
Snow Crab	7°C	**5** (Almost Certain)	**5** (Almost Certain)
Atlantic Bluefin Tuna	30°C	**1** (Rare)	**1** (Rare)
Atlantic Mackerel	22°C	**2** (Unlikely)	**4** (Likely)
Atlantic Herring	22.5°C	**2** (Unlikely)	**4** (Likely)
Rock Crab	24°C	**1** (Rare)	**3** (Possible)
	Coastal observed values	*11-27°C (average 21°C)*	*15-31°C (average 25°C)*
Mussels	22°C	**3** (Possible)	**5** (Almost Certain)
Oysters	32°C	**1** (Rare)	**2** (Unlikely)
Soft Shell Clams	23°C	**4** (Likely)	**5** (Almost Certain)

[268] Lemmen, Donald S and Bush, E. *Canada's Changing Climate Report*.
[269] Galbraith, P S, et al. "Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2021." Ottawa, ON: Fisheries and Oceans Canada, 2022. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41072248.pdf.
[270] "Charlottetown Water Temperature." Accessed June 10, 2023. https://www.seatemperature.org/north-america/canada/charlottetown.htm.
[271] "PEI Mussel and Oyster Water Temperature Visualization Tool." Accessed July 10, 2023. https://dfc.modailmara.ca/.
[272] Lemmen, Donald S and Bush, E. *Canada's Changing Climate Report*.
[273] Lemmen, Donald S and Bush, E. *Canada's Changing Climate Report*.

Heat Wave (Atmospheric)

Current: Modelled hindcast climate data indicate that heat waves of at least 3 consecutive days above 29°C have occurred, on average, 0.05 times per year, in the period 1980-2020.[274] This translates to a 5% annual chance of occurring, or a **current likelihood rating of 3 out of 5**.

Future: Projected data for the 2041-2060 time period estimate that such heat waves will occur 2.1 times per year on average, by mid-century. This is consistent with other sources that indicate a likely increase in the frequency of heat waves across North America as well as an increase in overall frequency of extreme hot days (>27.5°C) on PEI.[275, 276] This translates to **a future likelihood rating of 5 out of 5.**

Heat Wave (Marine)

Current: Waters in the Northwest Atlantic are warming four times faster than the global average.[277] With rising temperatures, the frequency, intensity, and duration of marine heat wave events are increasing.[278] The intensity of a marine heat wave describes how hot the event is compared to normal temperatures and is often evaluated using the sea surface temperature anomaly (°C). Like average sea surface temperatures, marine heat wave intensities vary spatially and seasonally. The 2012 Northwest Atlantic Heat wave was one of the most severe marine heat waves on record in the region, with a duration of 132 days and a maximum intensity of 4.5°C above average sea surface temperature.[279, 280]

Given the scarcity of observed marine heat wave data, we extrapolated maximum temperature values during marine heat waves using observed maximum heat wave intensities and observed average sea surface temperatures for summer and winter (see Oceanic/Riverine Warming for more details on average sea surface temperatures).[281] From 2015 to 2016, observed marine heat waves typically had intensities of approximately 3 to 4°C greater than average sea surface temperature.[282] The maximum observed marine heat wave intensity around PEI was during the 2012 heat wave, which reached an intensity of 4.5°C greater than average sea surface temperature. We added this value to observed summer and winter average sea surface temperatures to estimate maximum temperatures during a marine heat wave. Given an average sea surface temperature of 16°C to 19°C during summer months, **a severe marine heat wave**

[274] Value based on ICF analysis of data from ClimateData.ca. Values are for the PCIC12 multi-model ensemble. To represent the climate of the entire Island, climate projections were pulled from 3 grids, located in the west (near O'Leary), central (near Charlottetown), and east (near Souris) areas of the province. Projected values are under SSP5-8.5 50th percentile.
[275] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report."
[276] National Research Council, *Climate and Social Stress: Implications for Security Analysis*. 2013.
[277] Perez, E, et al. "Understanding Physical Drivers of the 2015/16 Marine Heat waves in the Northwest Atlantic." *Scientific Reports* 11, no. 1 (September 2, 2021): 17623. https://doi.org/10.1038/s41598-021-97012-0.
[278] Hayashida, H, et al. "Insights into Projected Changes in Marine Heat waves from a High-Resolution Ocean Circulation Model." *Nature Communications* 11, no. 1 (August 28, 2020): 4352. https://doi.org/10.1038/s41467-020-18241-x.
[279] Hobday, A, et al. "Categorizing and Naming Marine Heat waves." *Oceanography* 31, no. 2 (June 1, 2018). https://doi.org/10.5670/oceanog.2018.205.
[280] Chen, K, et al. "The Role of Atmospheric Forcing versus Ocean Advection during the Extreme Warming of the Northeast U.S. Continental Shelf in 2012."
[281] The method described for extrapolating potential marine heat wave projections based on observed data is a simplified estimation and has limitations. This approach may not fully capture the range of potential heat wave intensities or consider long-term climate variability. Comprehensive climate models and further research are recommended for more reliable projections.
[282] Chen, K, et al. "The Role of Atmospheric Forcing versus Ocean Advection during the Extreme Warming of the Northeast U.S. Continental Shelf in 2012." *Journal of Geophysical Research: Oceans* 120, no. 6 (2015): 4324–39. https://doi.org/10.1002/2014JC010547.

in the summer could range from 20.5°C to 23.5°C.[283, 284] See below for the calculation of current marine heat wave temperatures (Figure 32).

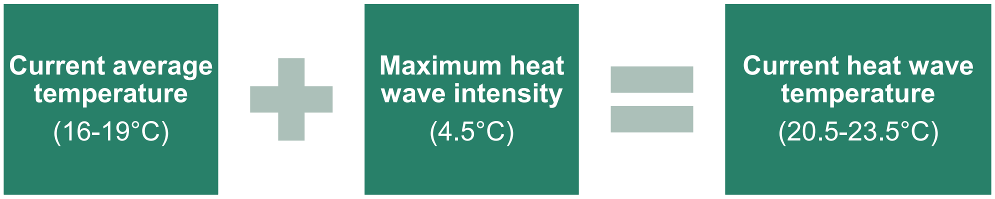

Figure 32. Current marine heat wave temperature calculation. Values shown correspond to sea surface temperatures during the summer.

Shallow coastal waters in the bays and estuaries are typically warmer than the Gulf of St. Lawrence. Observed temperature logs at **mussel and oyster sites recorded temperatures as high as 27-28°C** in July-August 2022 and August 2021.

Future: Under future warming, marine heat waves events are projected to become more frequent, intense, and longer-lasting.[285] There are limited regional projections of changes in marine heat wave intensity. As an estimate for future marine heat wave, the expected average change in sea surface temperature was added to the estimated current heat wave temperature. Therefore, given that average summer temperatures are projected to increase by 4°C by 2050, **a severe marine heat wave in the summer could range from 24.5°C to 27.5°C.** See below for the calculation of future marine heat wave temperatures in the Gulf of St. Lawrence (Figure 33).

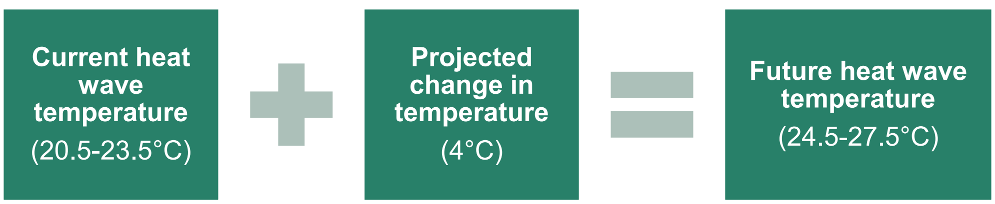

Figure 33. Future marine heat wave temperature calculation for the Gulf of St. Lawrence. Values shown correspond to sea surface temperatures during the summer.

Assuming a similar magnitude of change for coastal water temperatures, **a severe marine heat wave in the summer could range from 31-32°C at coastal aquaculture sites.** See below for the calculation of future marine heat wave temperatures in coastal waters (Figure 34).

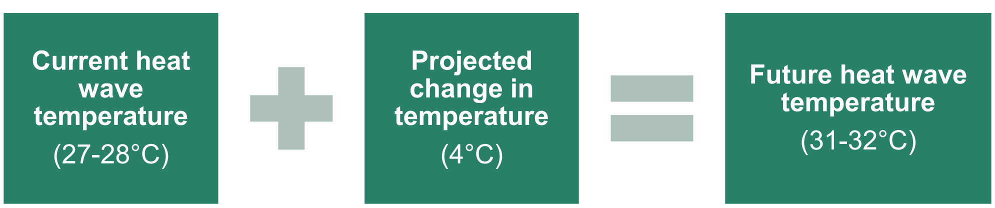

Figure 34. Future marine heat wave temperature calculation for coastal waters around PEI. Values shown correspond to sea surface temperatures during the summer.

[283] Howarth et al., "Assessing Climate Change Vulnerability of Seafood Industry-Dependent Communities in Nova Scotia."
[284] Ben Zisserson and Adam Cook, "Impact of Bottom Water Temperature Change on the Southernmost Snow Crab Fishery in the Atlantic Ocean," *Fisheries Research* 195 (November 1, 2017): 12–18, https://doi.org/10.1016/j.fishres.2017.06.009.
[285] Laufkötter, Charlotte, Jakob Zscheischler, and Thomas L. Frölicher. "High-Impact Marine Heat waves Attributable to Human-Induced Global Warming."

The likelihood of these projected changes crossing a critical sensitivity threshold varies for each species. See Table 88 below for the thresholds and likelihood ratings for each species.

Table 88. Species-specific thresholds and likelihood ratings for marine heat wave.

Species	Threshold	Current Likelihood Rating	Future Likelihood Rating
	Gulf values	*23.5°C*	*27.5°C*
Lobster	33.4°C	**1** (Rare)	**1** (Rare)
Snow Crab	12°C	**5** (Almost Certain)	**5** (Almost Certain)
Atlantic Bluefin Tuna	33°C	**1** (Rare)	**1** (Rare)
Atlantic Mackerel	28.5°C	**2** (Unlikely)	**4** (Likely)
Atlantic Herring	25.5°C	**3** (Possible)	**5** (Almost Certain)
Rock Crab	30°C	**1** (Rare)	**2** (Unlikely)
	Coastal values	*28°C*	*32°C*
Mussels	27°C	**4** (Likely)	**5** (Almost Certain)
Oysters	36°C	**1** (Rare)	**2** (Unlikely)
Soft Shell Clams	28°C	**4** (Likely)	**5** (Almost Certain)

Heavy Precipitation and Flooding

Current: The scenario of 100 mm of rainfall in 24 hours is equivalent to today's "1-in-25-year" rain event, which currently has a 4% chance of occurring in any year.[286] This evidence supports a **current likelihood rating of 3 out of 5**.

Future: Based on data for Charlottetown, the historical 24-hour, 25-year rain event (based on 1967-2016) is expected to become the 10-year rain event by 2050 under RCP 8.5. This means that this rainfall scenario is expected to happen more frequently, as a 10-year rain event has a 10% annual chance of occurring. This is consistent with other sources that indicate an increase in the frequency and intensity of extreme precipitation events in Atlantic Canada, which is expected to continue beyond 2050. This results in a **future likelihood rating of 4 out of 5**.

Post-Tropical Storm

Current: The current likelihood rating was determined from severe storm data ranging from 1900-2019. From 1900-1949 severe storms (average sustained wind speed of 63 kilometres per hour or greater) occurred equivalent to a 12% annual chance on PEI. From 1950-1999 the equivalent annual chance was 22% and from 2000-2019, the equivalent annual chance was 20% indicating an increase in likelihood since the start of the 20th century.[287] Atlantic Canada in general has a greater annual chance of severe storms than PEI specifically, with Nova Scotia currently experiencing a one in three, or 33% equivalent annual chance of a severe storm.[288] This evidence supports a **current likelihood rating of 4 out of 5**, as severe storms are likely to occur on PEI approximately once every 3-10 years.

[286] Environment and Climate Change Canada, *IDF Curves - Charlottetown 24 hr return period*. 2020.
[287] Ketch, L., A Climatology of Hurricanes for Canada Improving Our Awareness of the Threat. 2005.
[288] Dangerfield, K. Hurricanes in Canada: How often they hit and who is at risk. 2017 [cited 2020 September]; Available from: https://globalnews.ca/news/3700345/hurricane-canada-wherestorm-will-hit/.

Future: The 2050 likelihood of post-tropical storms on PEI is less certain, although there is widespread agreement that Atlantic Canada will see an increase in both storm frequency and severity and that Atlantic coast hurricanes will experience a northward shift.[289, 290, 291] Sea level and sea surface temperatures are also expected to increase by 2050, further supporting the notion that severe storms will increase in frequency and intensity.[292, 293] Although severe storms are projected to increase in frequency, post-tropical storms are unlikely to occur more than once every two years, thus the **future likelihood rating remains 4 out of 5**.

Acidification

Current: Acidification is increasing in both open-ocean waters and coastal waters. Nearshore and coastal waters are more vulnerable to acidification than open-ocean waters because they have less capacity to buffer carbon dioxide. [294] Acidification is also exacerbated by freshwater inputs from rivers and sea ice melt.[295] However, studies show that more alkaline river runoff can instead buffer acidification.[296] River runoff could be made more alkaline if it passes over a limestone bottom since limestone buffers acidity. There is some limestone present on PEI and around the Gulf of St. Lawrence, so river runoff may be reducing acidity in the Gulf and surrounding estuaries and bays.[297] However, the effect of river runoff on coastal waters around PEI is ultimately uncertain, as some studies cite river runoff as a contributing factor to acidity in the Gulf of St. Lawrence.[298]

Since the 1930's, the pH of the Gulf of St. Lawrence has been decreasing at a rate of approximately 0.04 units per decade.[299] Published data on pH in the waters surrounding PEI is relatively limited, and much like water temperature, pH varies spatially. Data collected in 2011 and 2014 indicate that waters in the Gulf of St. Lawrence was **approximately 7.7 to 7.9 pH**.[300, 301, 302]

Future: Acidification is expected to increase in the 21st century under all future emissions scenarios.[303] If acidification continues to increase at a rate of approximately 0.04 pH per decade, **the Gulf of St. Lawrence can be expected to reach approximately 7.6 to 7.8 pH in 2050**.

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289 Horton, R.M. and J. Liu, Beyond Hurricane Sandy: What Might the Future Hold for Tropical Cyclones in the North Atlantic? http://dx.doi.org/10.1142/S2345737614500079, 2014.
290 Loder, J., et al., Aspects of climate change in the Northwest Atlantic off Canada. 2013.
291 Kossin, J.P., et al., Climate Science Special Report: Fourth National Climate Assessment. 2017. p. 257-276
292 Loder, J., et al., Aspects of climate change in the Northwest Atlantic off Canada. 2013.
293 Atlantic Climate Adaptation Solutions Association. Sea Level Rise and Storm Surge Hazard Mapping in Prince Edward Island. 2020; Available from: https://atlanticadaptation.ca/en/islandora/object/acasa%3A635.
294 Lemmen, Donald S and Bush, E. Canada's Changing Climate Report.
295 Lemmen, Donald S and Bush, E. Canada's Changing Climate Report.
296 "River Runoff Creates a Buffer Zone for Ocean Acidification in the Gulf of Mexico." *NOAA's Atlantic Oceanographic and Meteorological Laboratory* (blog), February 15, 2022. https://www.aoml.noaa.gov/river-runoff-creates-a-buffer-zone-for-ocean-acidification-in-the-gulf-of-mexico/.
297 "Soils of Canada." Agriculture and Agri-Food Canada. 2023. https://www.agr.gc.ca/atlas/apps/aef/main/index_en.html?AGRIAPP=3&APPID=e87af05bd35848598994b13f45a24a25&WEBMAP-EN=c225cc78d5b142d58eacefae91cc535b&WEBMAP-FR=ad0b6822a33e411683f99979a1167efa&mapdescription=true&print=true&breadcrumb=can,agr,b10,b3&adjust_to_viewport=true.
298 "Ocean Acidification in the Gulf of St. Lawrence." Maurice Lamontagne Institute. 2021-2024. https://oceandecade.org/actions/ocean-acidification-in-the-gulf-of-st-lawrence/.
299 Fisheries and Oceans Canada. *Canada's Oceans Now: Atlantic Ecosystems 2018*.
300 Fisheries and Oceans Canada. *State-of-the-Ocean Report for the Gulf of St. Lawrence Integrated Management (GOSLIM) Area*. 2012. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/345310.pdf.
301 Mucci, A, et al. "Acidification of Lower St. Lawrence Estuary Bottom Waters." *Atmosphere-Ocean* 49 (September 1, 2011): 206–18. https://doi.org/10.1080/07055900.2011.599265.
302 Lavoie, D, et al. "The Gulf of St. Lawrence Biogeochemical Model: A Modelling Tool for Fisheries and Ocean Management." *Frontiers in Marine Science* 8 (2021). https://www.frontiersin.org/articles/10.3389/fmars.2021.732269.
303 Lemmen, Donald S and Bush, E. *Canada's Changing Climate Report*.

The likelihood of these projected changes crossing a critical sensitivity threshold varies for each species. See Table 89 below for the thresholds and likelihood ratings for each species.

If a species-specific threshold was not available, then a current likelihood of **2 out of 5** and a future likelihood of **3 out of 5** was used. These ratings consider the limited evidence for acidification-driven detrimental effects for commercial species evaluated in this assessment but acknowledge impacts may occur in the future as acidification increases.

Table 89. Species-specific thresholds and likelihood ratings for acidification.

Species	Threshold	Current Likelihood Rating	Future Likelihood Rating
	Range of values	*7.7-7.9 pH*	*7.6-7.8 pH*
Mussels	7.6 pH	**2** (Unlikely)	**3** (Possible)
Oysters	7.1 pH	**1** (Rare)	**1** (Rare)
Lobster	7.7 pH	**3** (Possible)	**4** (Likely)
Snow Crab	No threshold	**2** (Unlikely)	**3** (Possible)
Atlantic Bluefin Tuna	No threshold	**2** (Unlikely)	**3** (Possible)
Atlantic Mackerel	No threshold	**2** (Unlikely)	**3** (Possible)
Atlantic Herring	No threshold	**2** (Unlikely)	**3** (Possible)
Rock Crab	No threshold	**2** (Unlikely)	**3** (Possible)
Soft Shell Clams	7.8 pH	**3** (Possible)	**4** (Likely)

Hypoxia

Current: Hypoxia, or low levels of dissolved oxygen, is worsening in most ocean waters due to increased upper-ocean temperatures. One natural cause of hypoxia is stratification in the water column, which is when heavier seawater mixes with less dense freshwater.[304, 305] This can restrict the supply of oxygen to bottom waters, creating hypoxic conditions.[306] Nutrient pollution or eutrophication from agricultural runoff or wastewater discharge can also lead to hypoxia by causing harmful algal blooms, or the rapid overgrowth of certain species of algae.[307] When algae die and sink to the bottom of the water, they decompose and consume oxygen. During algal blooms, this can lead to more frequent and intense hypoxic conditions.[308]

The subsurface oxygen concentrations in the Northwest Atlantic have decreased, meaning they are becoming more hypoxic.[309] Coastal and inland waters are more vulnerable to hypoxia than open-ocean waters because eutrophication is higher in these waters.[310] Hypoxia in the deep waters of the Gulf of St. Lawrence has been progressively worsening.[311] The waters of the Gulf are considered to be hypoxic below a dissolved oxygen value of 100 µM, which corresponds to

[304] "Hypoxia." National Oceanic and Atmospheric Administration (NOAA). Accessed June 19, 2023. https://oceanservice.noaa.gov/hazards/hypoxia/.
[305] World Resources Institute. "Eutrophication and Hypoxia," March 7, 2019. https://www.wri.org/initiatives/eutrophication-and-hypoxia.
[306] "Hypoxia." National Oceanic and Atmospheric Administration (NOAA).
[307] University of Michigan. "Harmful Algal Blooms (HABs) & Hypoxia." Accessed June 19, 2023. https://ciglr.seas.umich.edu/wp-content/uploads/2019/12/HABs-Hypoxia-Fact-Sheet.pdf.
[308] University of Michigan. "Harmful Algal Blooms (HABs) & Hypoxia."
[309] Lemmen, Donald S and Bush, E. Canada's Changing Climate Report.
[310] Lemmen, Donald S and Bush, E. Canada's Changing Climate Report.
[311] Fisheries and Oceans Canada. "Hypoxia," December 3, 2018. https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2012/page03-eng.html.

approximately 30% saturation.[312] Dissolved oxygen decreased to its lowest annual average in 2016 at a saturation level of approximately 18%.[313] Anoxia occurs when dissolved oxygen levels reach zero. From 2018 to 2022, there were 119 anoxic events in estuaries around PEI.[314]

Many factors are worsening hypoxia in the Gulf of St. Lawrence, including warmer ocean temperatures, meriting a **current likelihood rating of 3 out of 5.**

Future: Many factors contribute to hypoxic conditions and there are unknowns about how each factor will change in the future. However, the climate-related drivers of hypoxia are expected to increase with climate change. For example, rising water temperatures coupled with more frequent and intense storms can significantly disturb stratification of the water column, which can increase dissolved oxygen at the bottom of the water.[315, 316, 317] More intense storms can also increase eutrophication associated with runoff.[318] Additionally, warmer water temperatures can lead to more frequent, intense, and widespread algal blooms.[319] All these factors can reduce subsurface oxygen concentrations, potentially causing more frequent and widespread hypoxic conditions in the future, meriting a **future likelihood rating of 4 out of 5**.[320]

Coastal Erosion

Current: The average rate of coastal erosion on PEI from 1968 to 2010 was 28 cm annually.[321] From 2000 to 2010, however, there was significantly more erosion, with an average annual loss of 40 cm.[322] Erosion rates differ across PEI, with till bluffs and the Gulf of St. Lawrence coast experiencing annual average erosion rates of 74 cm from 1935-1990[323] and some sites on the Island experiencing as much as 200 cm of erosion in a given year.[324] Hurricane Fiona caused significant coastal erosion on PEI in 2022, with almost 100 cm of erosion in some spots.[325] This was the worst erosion damage PEI has experienced in close to a

Figure 35. Satellite images of PEI before and after Hurricane Fiona in 2022.

[312] Blais, M, et al. "Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence during 2020." Ottawa, ON: Fisheries and Oceans Canada, 2021. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41012008.pdf.
[313] Fisheries and Oceans Canada. Canada's Oceans Now: Atlantic Ecosystems 2018.
[314] PEI. "Tracking Anoxic Events in PEI." August 4, 2023. https://storymaps.arcgis.com/stories/578ff53bd0704f56a0867d36ae80bdd0.
[315] US EPA. "Hypoxia 101." March 24, 2015. https://www.epa.gov/ms-htf/hypoxia-101.
[316] Li, Xuan, Tinglin Huang, Weixing Ma, Xin Sun, and Haihan Zhang. "Effects of Rainfall Patterns on Water Quality in a Stratified Reservoir Subject to Eutrophication: Implications for Management." *The Science of the Total Environment* 521–522 (July 15, 2015): 27–36. https://doi.org/10.1016/j.scitotenv.2015.03.062.
[317] Virginia Institute of Marine Science. "Dead Zones and Climate Change." Accessed July 10, 2023. https://www.vims.edu/research/topics/dead_zones/climate_change/index.php.
[318] US EPA. "Hypoxia 101." March 24, 2015. https://www.epa.gov/ms-htf/hypoxia-101.
[319] US EPA. "Climate Change and Harmful Algal Blooms." September 5, 2013. https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms.
[320] Lemmen, Donald S and Bush, E. Canada's Changing Climate Report.
[321] Webster, T., Coastline Change in Prince Edward Island, 1968-2010 and 2010. 2012.
[322] Webster, T., Coastline Change in Prince Edward Island, 1968-2010 and 2010. 2012.
[323] Lemmen, D.S., et al., Canada's Marine Coasts in a Changing Climate. 2016, Government of Canada: Ottawa, ON. p. 274.
[324] Russell, N. 'We're the most vulnerable': Measuring P.E.I.'s erosion from land and sky. 2019 2019-06-17 [cited 2020 September]; Available from: https://www.cbc.ca/news/canada/prince-edward-island/pei-coastal-erosion-drones-1.5171990.
[325] Yarr, Kevin. "P.E.I. National Park Dunes Suffer 'extremely Dramatic' Erosion from Fiona | CBC News." CBC, September 27, 2022. https://www.cbc.ca/news/canada/prince-edward-island/pei-fiona-national-park-dune-damage-1.6597053.

century, with Fiona causing multiple years' worth of erosion in just a few hours (see Figure 35).[326]

Determining a "critical threshold" level of coastal erosion, or the point at which significant impact occurs, is difficult since erosion rates can differ dramatically in either direction from one decade to the next. These factors considered, the *long-term* historical rate (1968-2010) of 28 cm per year was used as the critical threshold; meaning annual average erosion beyond 28 cm is considered beyond the critical threshold, while annual erosion rates under 28 cm is below the critical threshold. Since the annual average rate of erosion is just about as likely to cross the critical threshold as not, the **current likelihood rating is 3 out of 5**.

Future: Future likelihood of advancing beyond the critical threshold of 28 cm of erosion per year will be dictated by changes in severity and frequency of events that drive coastal erosion, such as severe storms, storm surge, sea level rise, and reduction of sea ice.[327] In fact, wintertime sea ice, which serves as an effective barrier that decreases wave energy along the coastline, has been declining at a rate of 8.3% per decade from 1969-2016.[328] Considering the 2000-2010 erosion rate of 40 cm/year and because the drivers of coastal erosion are projected to increase in frequency and severity on PEI by 2050[329,330], it is almost certain that the critical threshold will be exceeded by 2050. **Thus, the future likelihood rating is 5 out of 5.**

Ice Storm/Freezing Rain

Current: While projections are not available for the frequency of severe ice storms or freezing rain events, other climate variables can help us understand the changing likelihood for this hazard, including ice days, frost days, ice accretion thickness, and patterns in total precipitation. Ice and frost days are two available variables that can indicate the frequency in temperature conditions that are conducive to ice storms and freezing rain (i.e., freezing or below freezing temperatures).

Ice days are defined as days when the daily maximum temperature does not exceed 0°C. From 1950 to 2005, Charlottetown has experienced an annual average of about 71 ice days per year, though this number has been decreasing over time (the number of ice days in 2005 was 14 days less than the number of ice days in 1950).[331] Frost days are defined as days when daily minimum temperature is less than 0°C and indicates that conditions are below freezing (usually overnight). In the historical period of 1950 to 2005, Charlottetown experienced an average of 155 frost days per year, and the number of annual frost days in 2005 was 18 days less than that of 1950.[332] This evidence, as well as the frequency of past multi-day severe ice storms and freezing rain events, merits a **current likelihood rating of 4 out of 5** (e.g., an event approximately once every 3-10 years)**.**

Future: The downward trends in ice days and frost days are projected to continue throughout the 21st century. The average number of ice days per year (in the period 2041-2060) is

[326] Logan, Cloe. "Hurricane Fiona Washed Away P.E.I. Coastline in Hours." Canada's National Observer, September 29, 2022. https://www.nationalobserver.com/2022/09/29/news/hurricane-fiona-washed-away-pei-coastline-hours.
[327] Atlantic Climate Adaptation Solutions Association, Coastal Climate Change in Prince Edward Island: Shoreline Protection.
[328] Derksen, C., et al., Changes in snow, ice, and permafrost across Canada; Chapter 5 in Canada's Changing Climate Report. 2019. p. 194-260.
[329] Shaw, R.W., Coastal Impacts of Climate Change and Sea-Level Rise on Prince Edward Island. 2001.
[330] Webster, T., Coastline Change in Prince Edward Island, 1968-2010 and 2010. 2012.
[331] Climate Data Canada, Ice Days. 2023.
[332] Climate Data Canada, Frost Days. 2023.

projected to be 40 (RCP 8.5), which represents a 44% decrease in the number of ice days from the historical to the mid-century average. The number of annual frost days is projected to decrease to a 2041-2060 average of about 112 frost days per year (RCP 8.5) (a 28% decrease from the historical average).

Ice accretion thickness can also provide insights on freezing rain, particularly for how much ice accumulates on exposed surfaces. This variable is affected by freezing rain, which freezes on contact with a sub-freezing surface, surface wind speed, and surface air temperature. Change in ice thickness for multiple global mean temperature change scenarios are projected to decrease in Atlantic Canada relative to the 1986-2016 baseline, particularly under the 2°C and 3°C global warming scenarios.[333] There is high uncertainty and internal model variability in these projections.

In PEI, total precipitation has decreased over the past 50 years.[334] The direction of change for precipitation projections is uncertain. Some sources indicate PEI could experience a 6% decrease from the current levels of precipitation through the 2040s[335], while others indicate that Charlottetown, for example, may experience an 9.5% increase in total annual precipitation for 2041-2060 compared to 1950-2005.[336] However, given the historic and projected trends of increased temperatures and decreased ice and frost days and ice accretion thickness, it is expected that precipitation will increasingly fall as rain rather than snow and ice. There is some uncertainty – winters are projected to become milder, but precipitation is expected to become more variable. Given this evidence and keeping uncertainty in mind, the **future likelihood rating is reduced to 3 out of 5.**

[333] Environment and Climate Change Canada, 2020 Climate-Resilient Buildings and Core Public Infrastructure: An Assessment of the Impact of Climate Change on Climatic Design Data in Canada. 2021.
[334] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report."
[335] S. Arnold and A. Fenech, "Prince Edward Island Climate Change Adaptation Recommendations Report."
[336] Climate Data Canada, Total Precipitation. 2023.