Salish Sea Science Roundtable

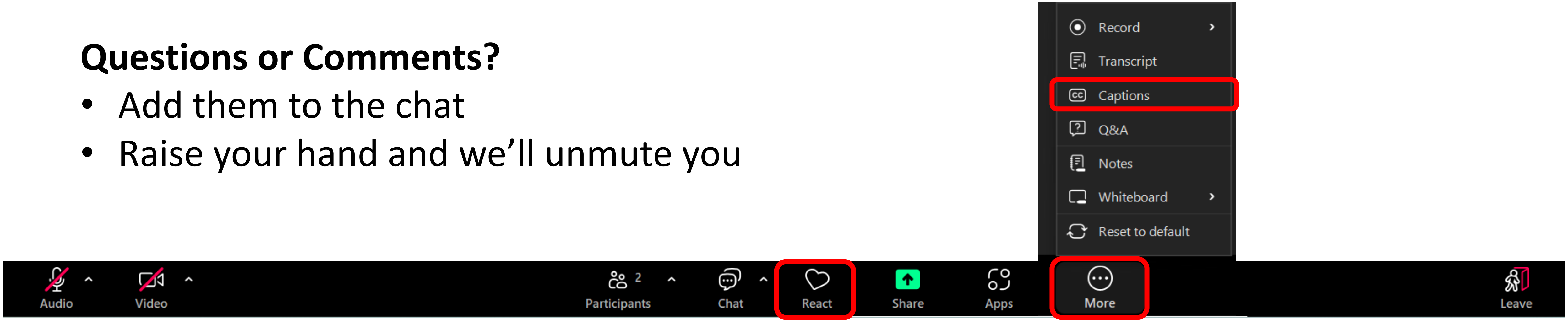
Navigating the Roundtable

Welcome! While we wait, please:

- Update your name to include your pronouns and organization
- Introduce yourself in the chat and recommend a future roundtable topic
- Message Marielle with any access needs

Questions or Comments?

- Add them to the chat
- Raise your hand and we'll unmute you



The slides and recording will be available on [Puget Sound Institute's website]

Land Acknowledgement

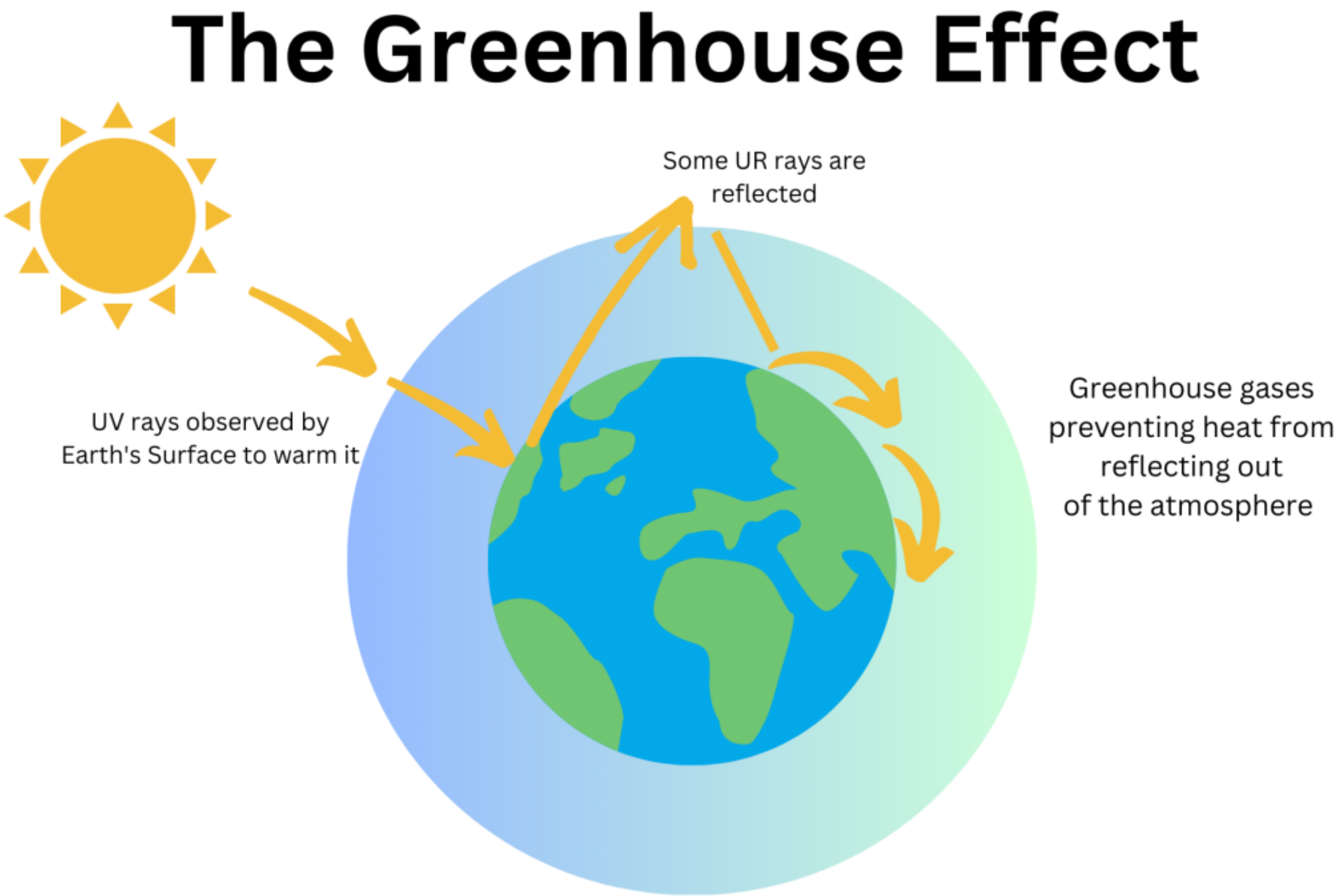
The UW Tacoma community acknowledges that we learn, teach, work and live on the ancestral land of the Coast Salish people. In particular, our campus is situated on traditional lands of the Puyallup Tribe of Indians. We recognize that this is a difficult and painful history, and we understand we must play an active role in remembering, not just what happened to Indigenous communities; post settlement, but also the rich history that existed long before colonization. This land acknowledgement is one small act in an ongoing process of honoring the past while working together with local Tribes to build a more inclusive and thoughtful community.

Assessing Effects of Multiple Climate Change Stressors on Marine Invertebrates and Developing Mitigation Techniques to Minimize Impacts

Chris Pearce

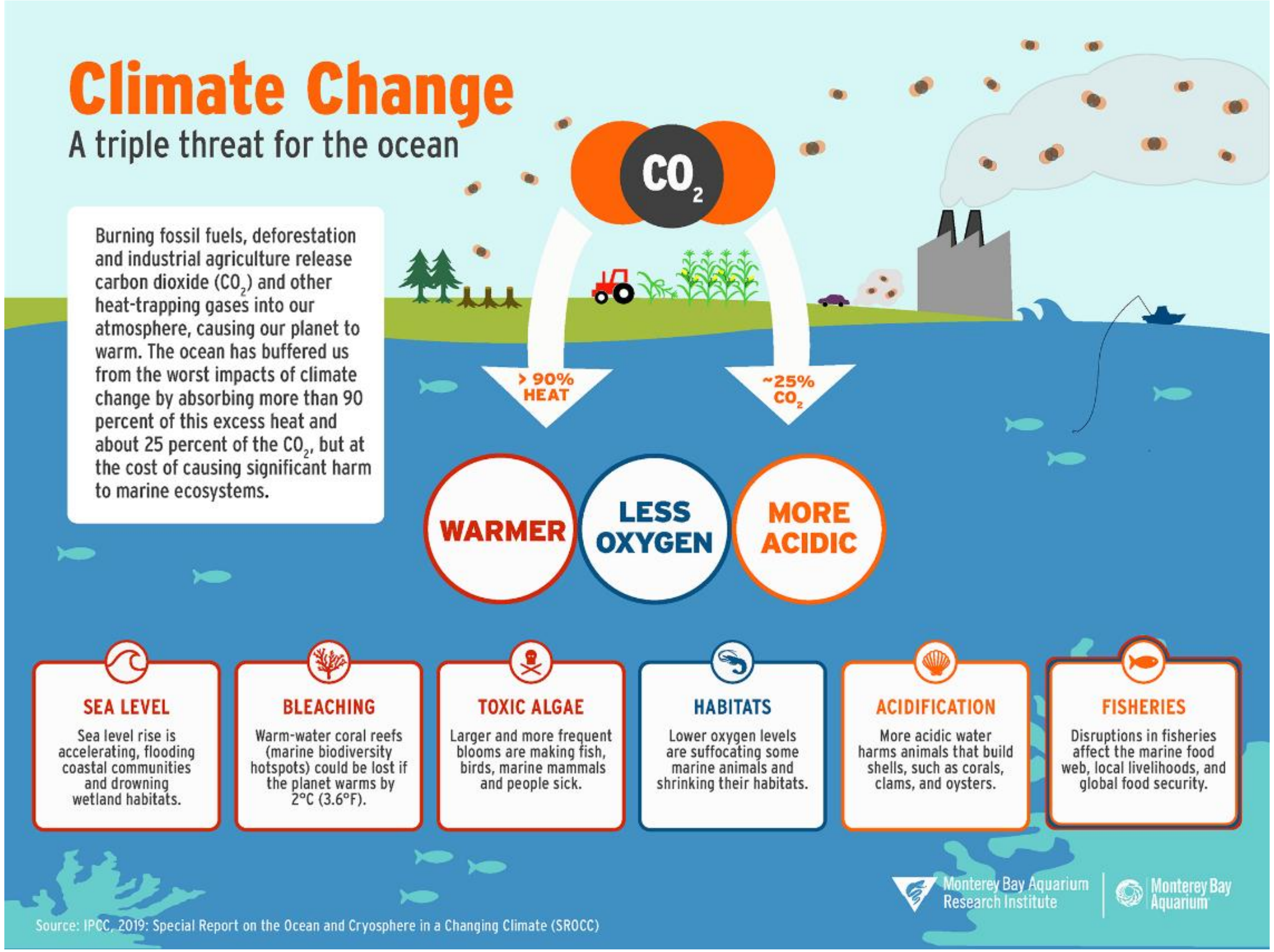
Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC

Climate Change Cause



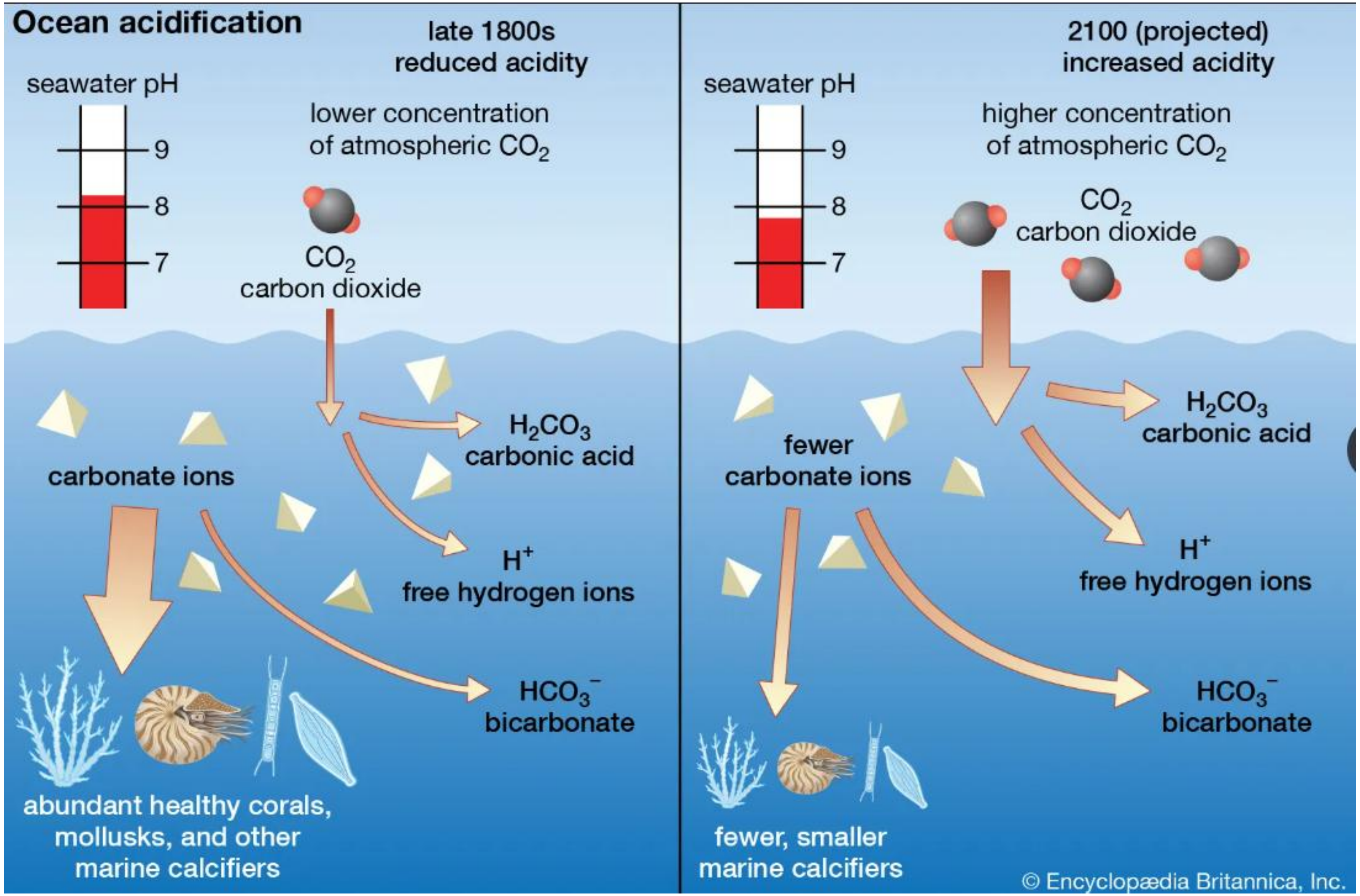
Source: Planet Pulse

Climate Change in the Ocean



Source: MBARI

Ocean Acidification

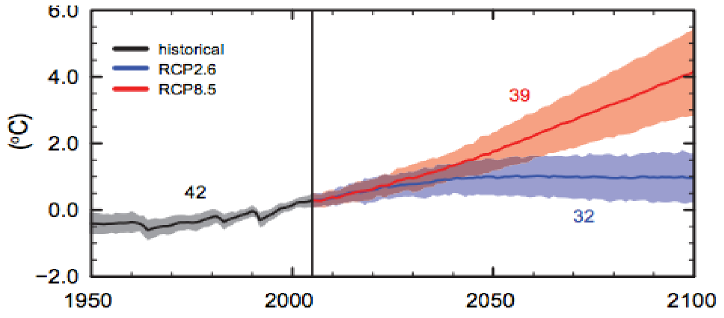


- Two forms of calcium carbonite in shellfish: aragonite versus calcite.

- Aragonite/calcite saturation <1 is problematic.

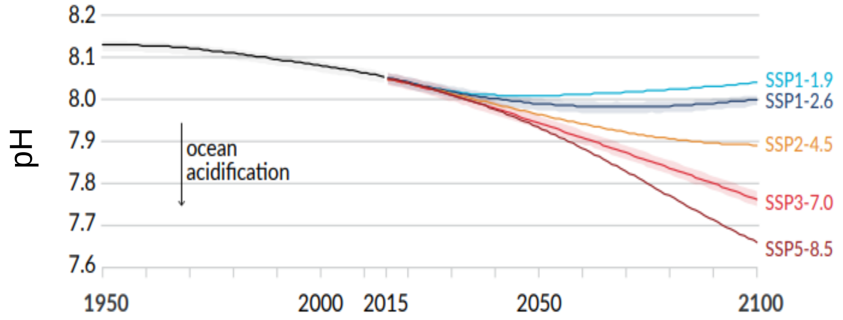
Source: Britannica, Inc.

Long-term Climate Change



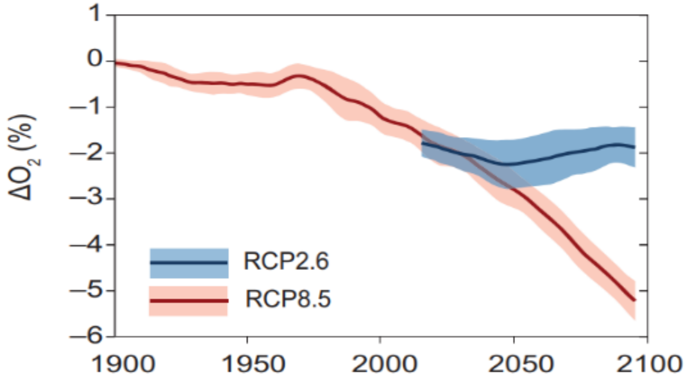
Seawater temperature change by 2100:

- RCP2.6: increase of 0.3−1.7°C
- RCP8.5: increase of 2.6−4.8°C



Seawater pH change by 2100:

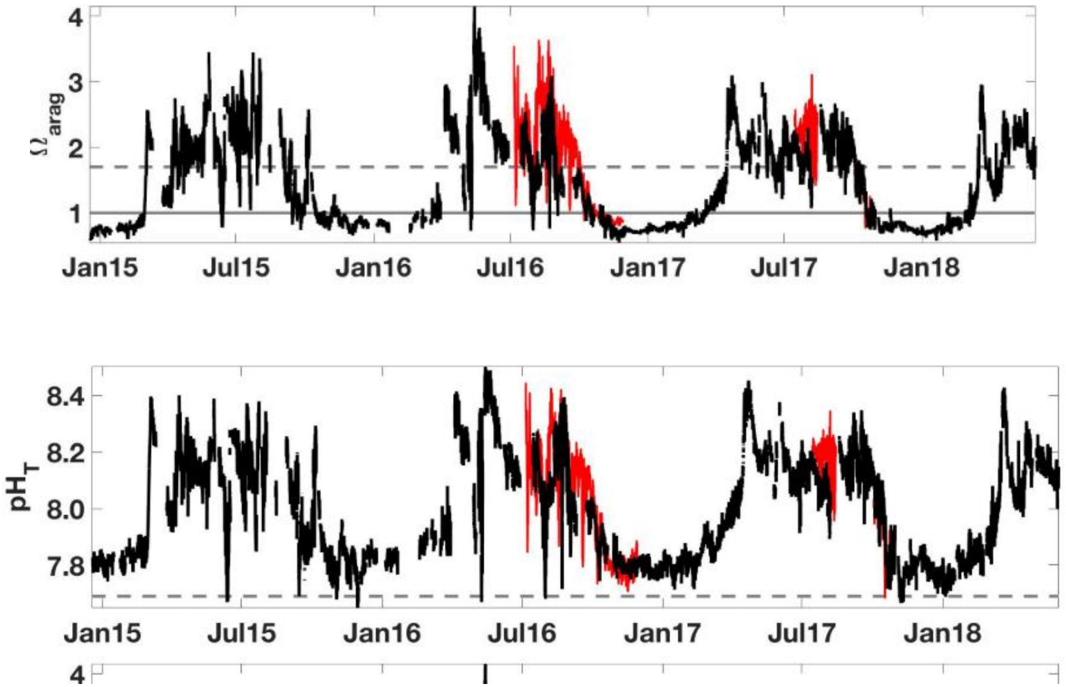
- SSP1-2.6: decline of ~0.12 units
- SSP5-8.5: decline of ~0.50 units



Seawater DO change by 2100:

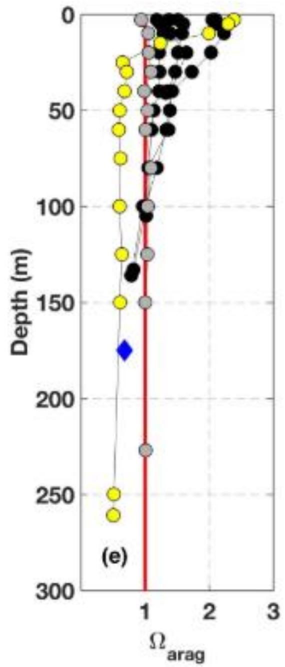
- RCP2.6: decline of ~2%
- RCP8.5: decline of ~5%

Acute Stressor Events



Source: Evans *et al*. (2019)

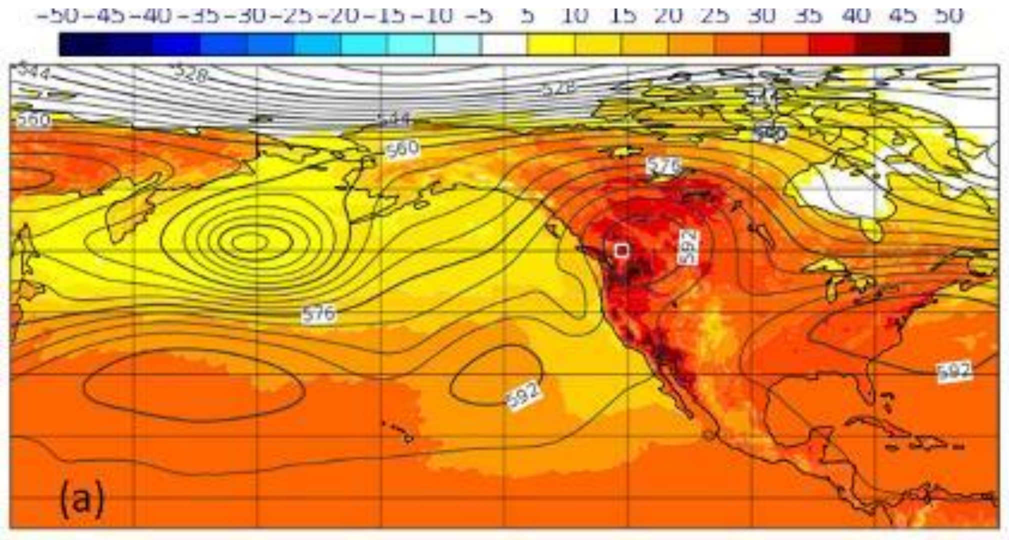
In recent years, high-CO_2 events have also been observed during summer months (*e.g.* July 2016 event) = upwelling events.



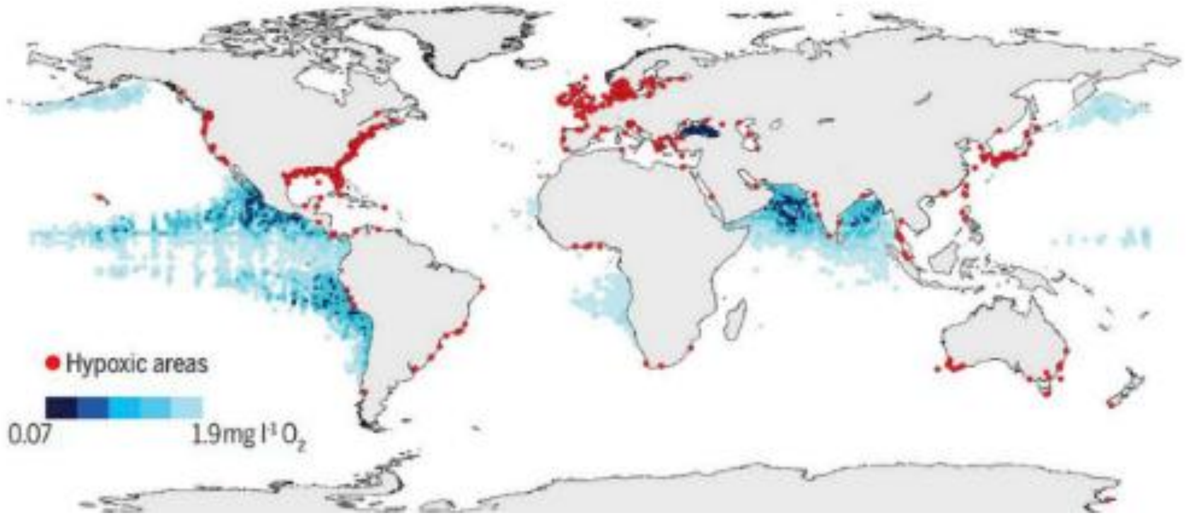
The Salish Sea water column has low pH events at surface (aragonite saturation <1) during winter months.

Note: Upwellings have resulted in high larval mortality in shellfish hatcheries.

Acute Stressor Events



Source: Emerton *et al*. (2022)



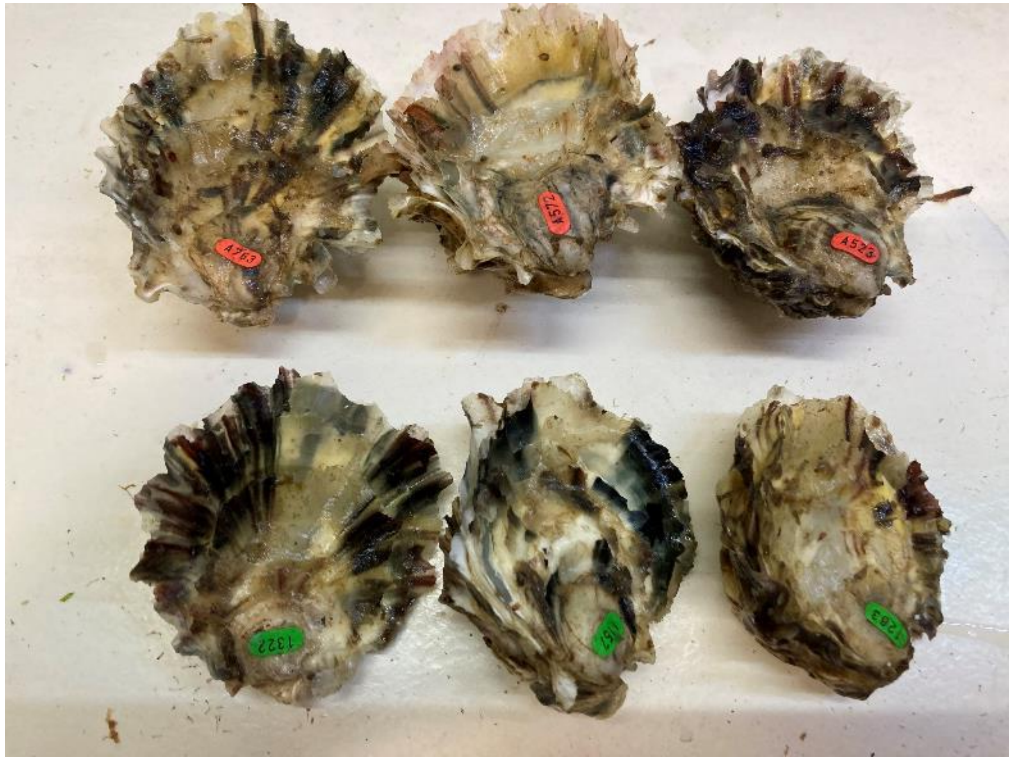
Source: Limburg *et al*. (2020)

Heatwave events
(June 2021)

Hypoxic events

Anthropogenic nutrients have exacerbated or caused O_2 declines to <2 mg liter^{-1} (<63 µmol liter^{-1}) (red dots), as well as ocean oxygen-minimum zones at 300 m of depth (blue shaded regions).

What We Work On



Pacific oyster
(*Crassostrea gigas*)

Importance:

- Support regional and Indigenous economies
- Support wild fisheries and aquaculture
- Traditional food resource
- Provide ecosystem services

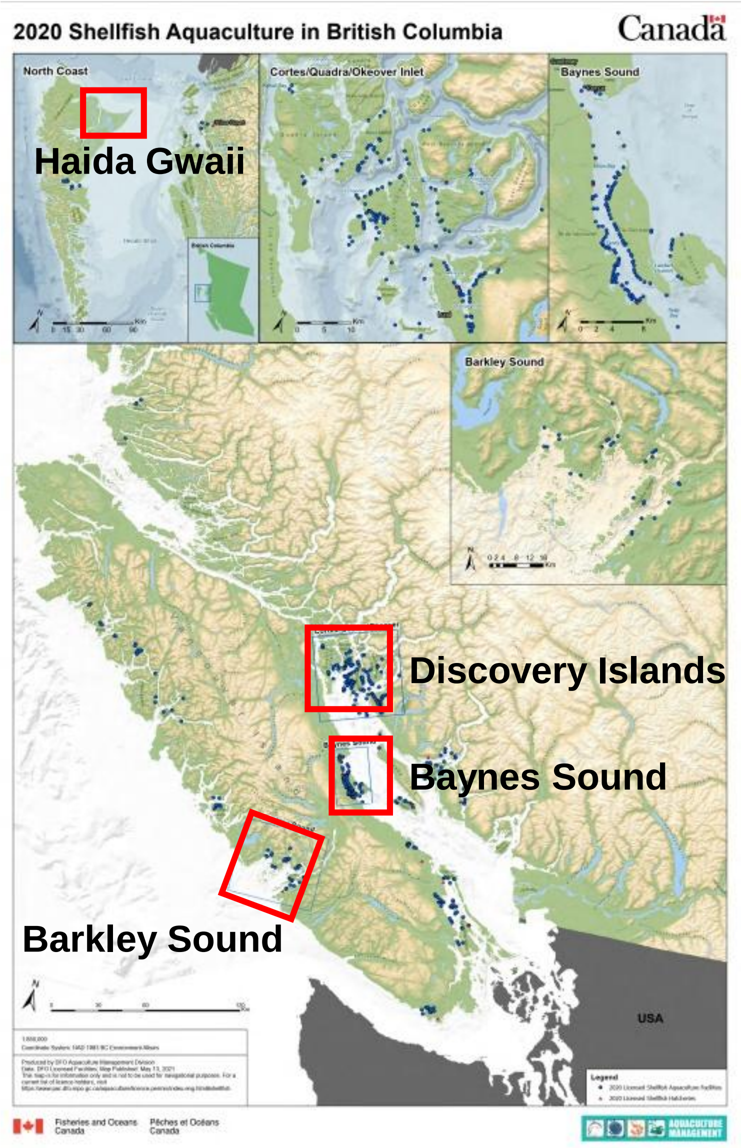
Climate change threat:

- Non-motile
- Intertidal species
- Thermo-conforming
- Calcareous shells

Multi-stressor impacts:

- Growth
- Survival
- Respiration
- Gene function

Where We Work: Field



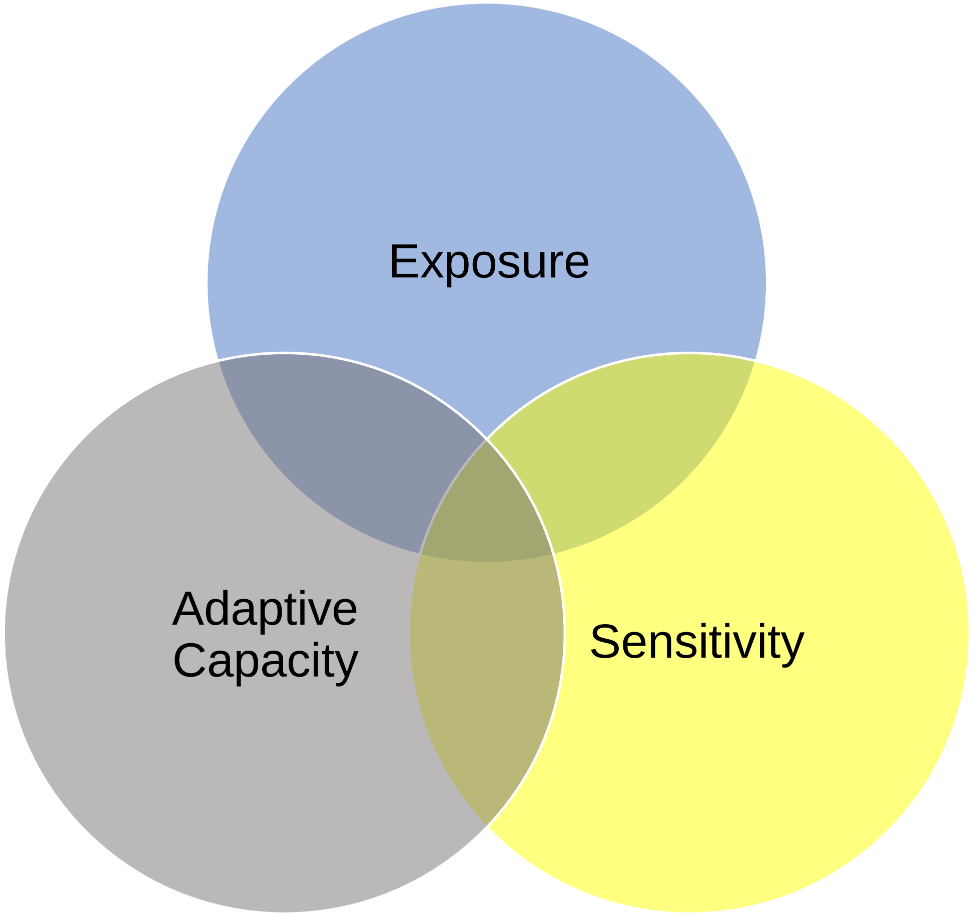
Where We Work: Laboratory

Fisheries & Oceans Climate Change & Ocean Acidification Laboratory

Canada

FOCCOAL

What Determines a Species' Vulnerability versus Resilience?



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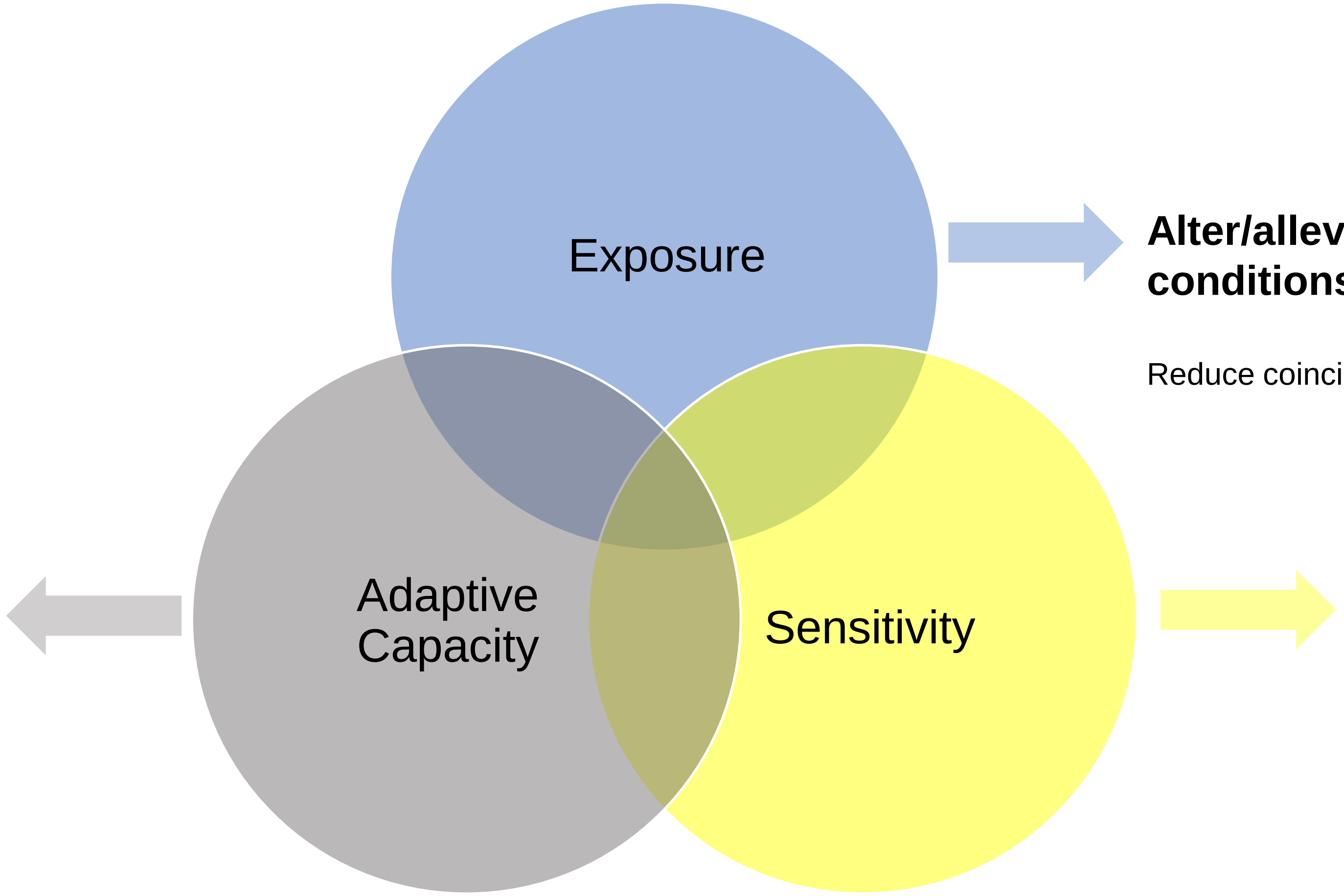


Alter/alleviate exposure conditions

Reduce coinciding stressor conditions

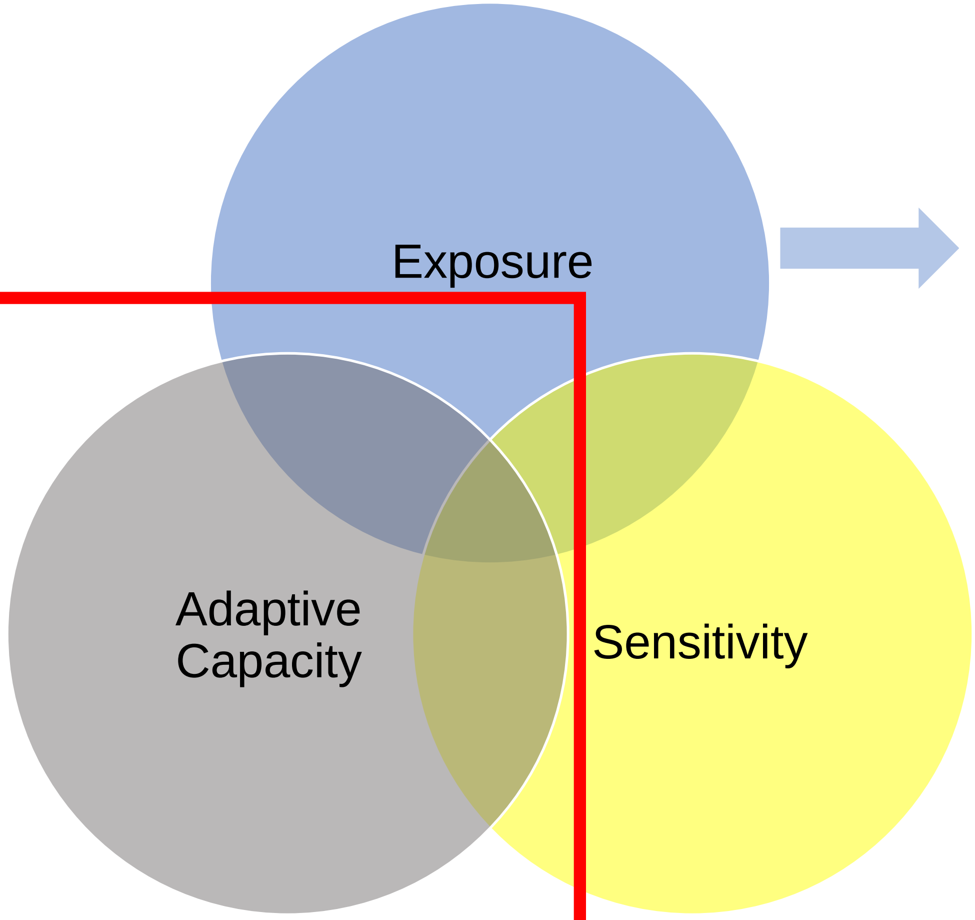
Manipulate adaptive capacity

Use of breeding programs

Decrease sensitivity to stressor conditions

Improve ability to respond and recover

What Determines a Species' Vulnerability versus Resilience?



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Selective Breeding

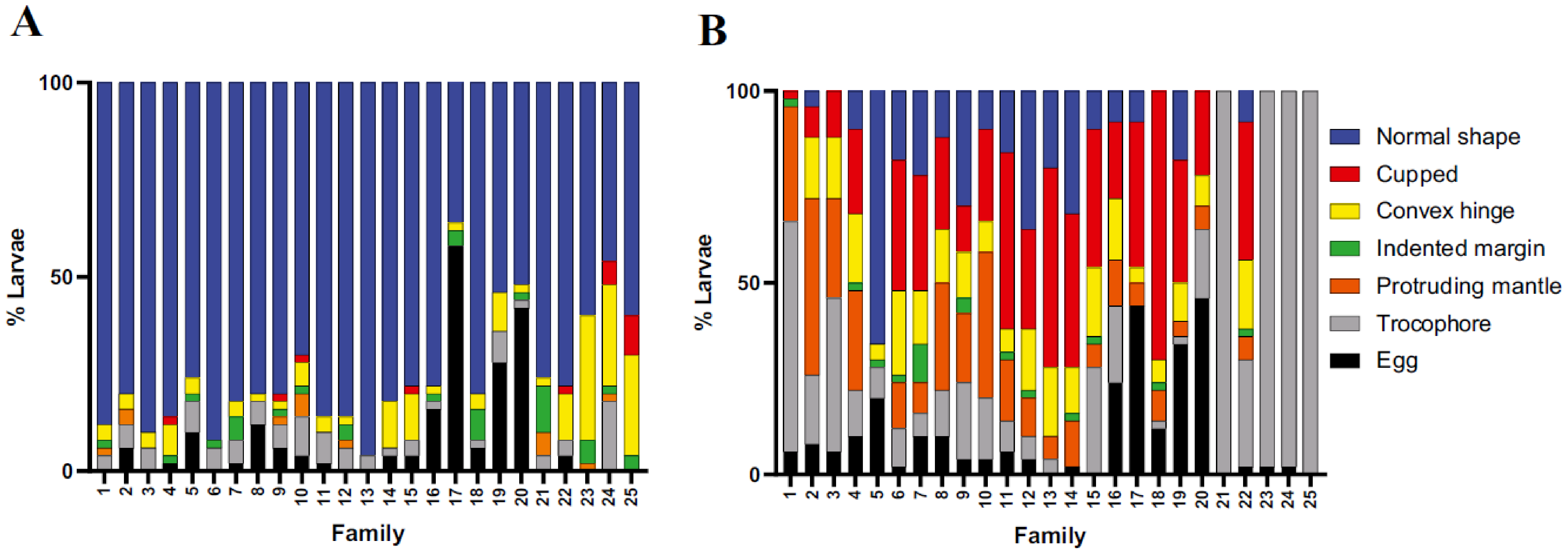
Produce multiple genetic families (N=25) by crossing broodstock from commercial and wild source populations.

Larval rearing at Deep Bay Marine Field Station.

		MALES								
		M1	M2	M3	M4	M5	M6	M7	M8	M9
FEMALES	F1									
	F2									
	F3									
	F4									
	F5									
	F6									
	F7									
	F8									
	F9									

Breeding design (pair-mated families).

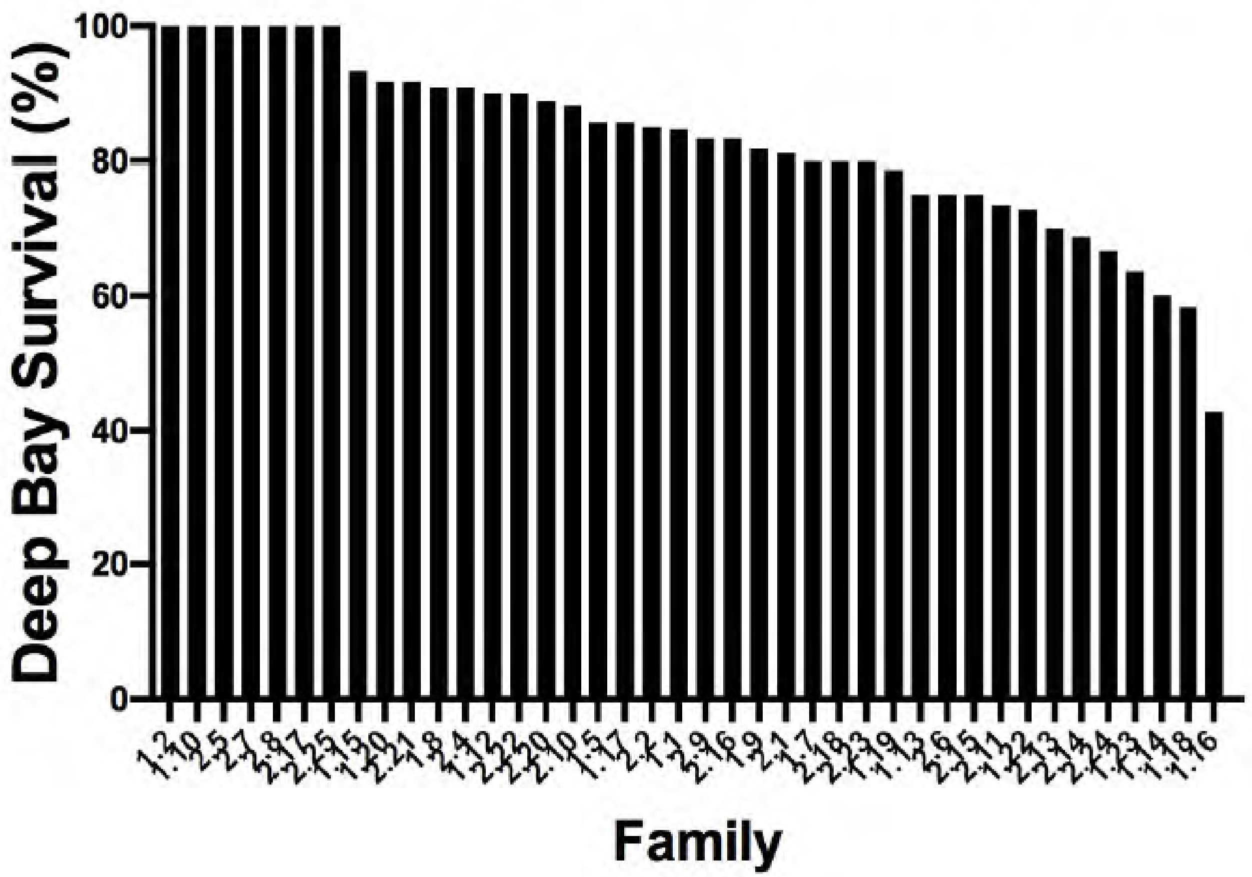
Selective Breeding



Oyster larval development (24 hr) across N = 25 genetic families under (A) ambient and (B) OA (aragonite undersaturated) conditions.

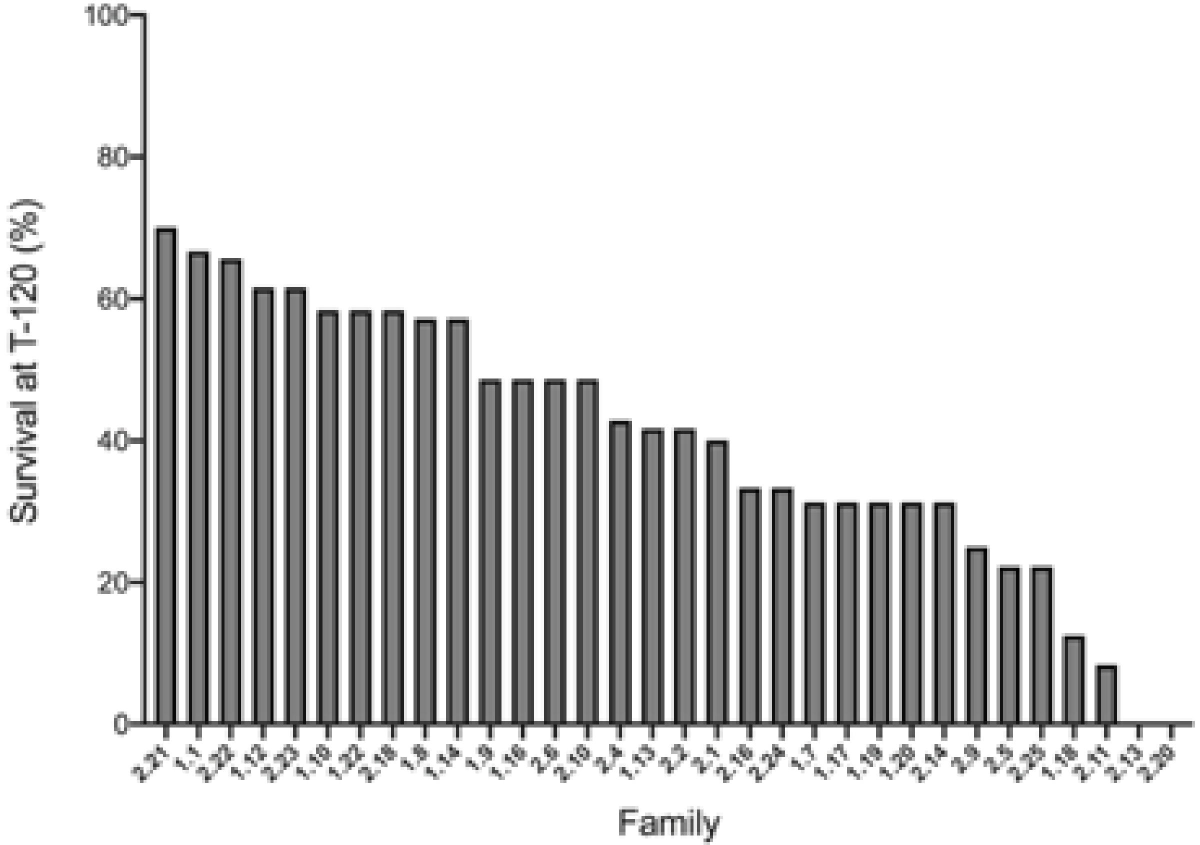
Source: Wright-La Greca *et al.* (2022)

Selective Breeding



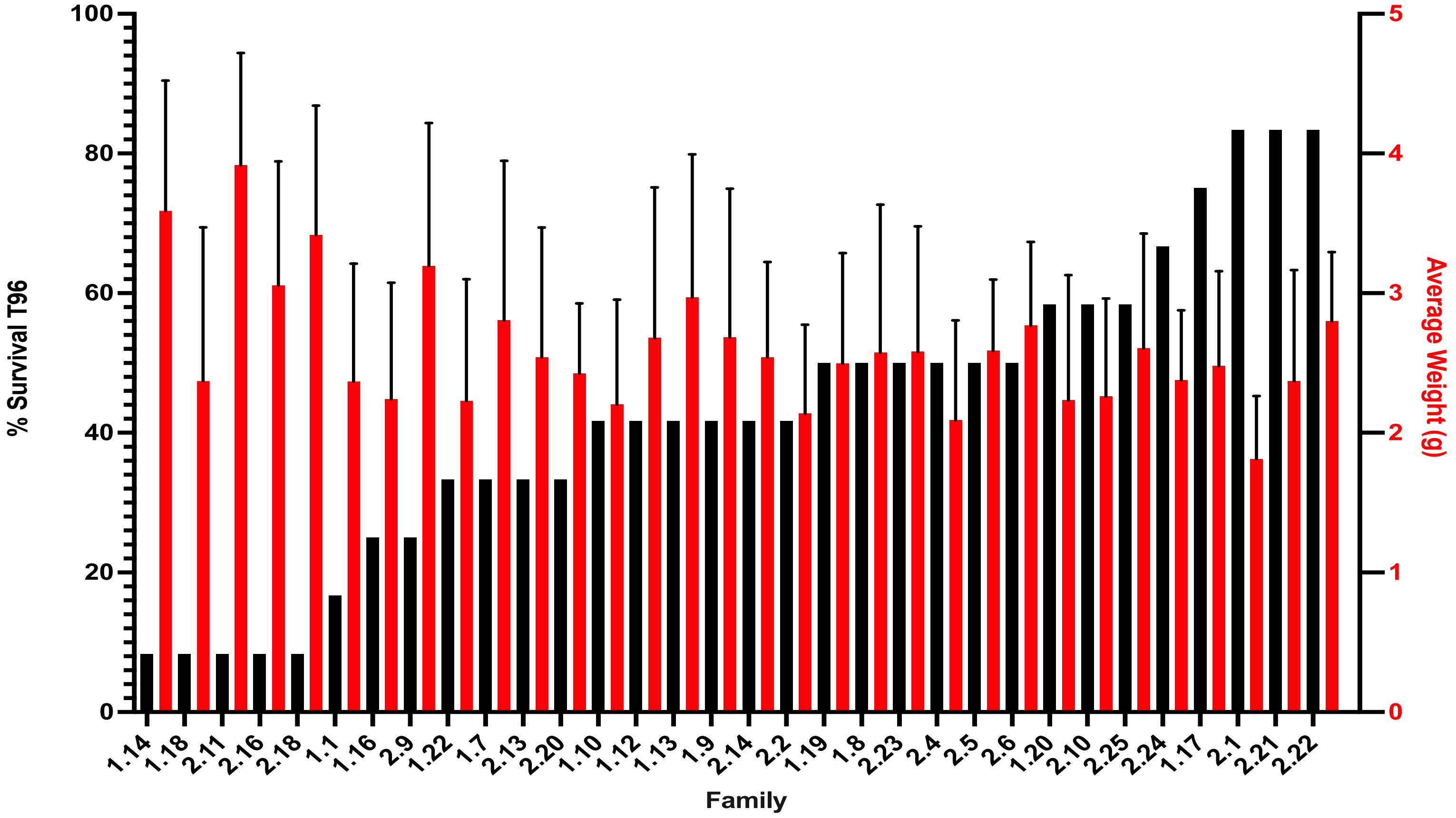
Oyster survival (%) of various families after 1-year grow-out at Deep Bay.

Selective Breeding



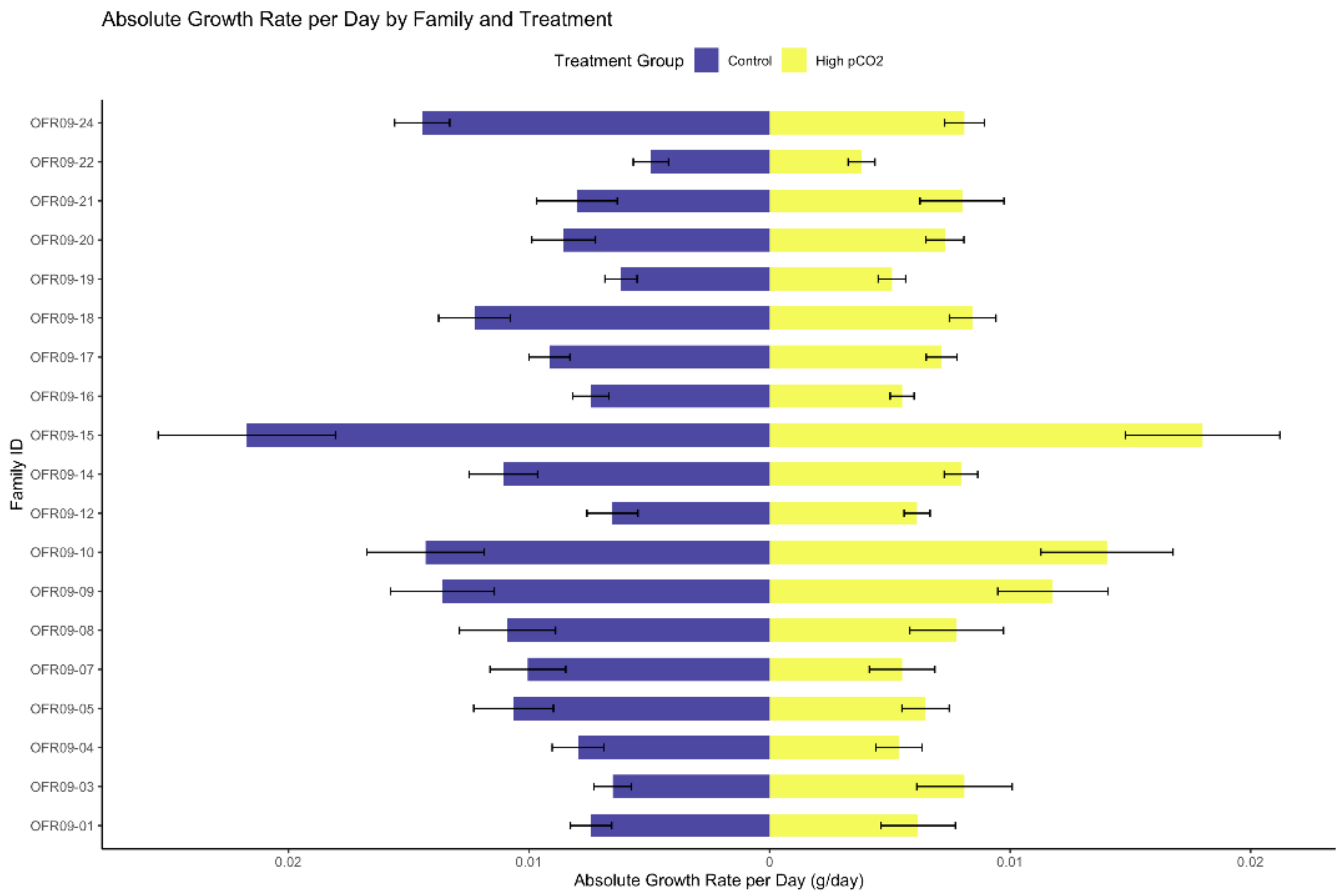
Juvenile oyster survival (%) of various families following a 120-hour challenge with *Vibrio aestuarianus*. Source: Khtikian (2021).

Selective Breeding



Juvenile oyster survival (%) (black bars) and wet weight (red bars) of various families following a 96-hour challenge with *Vibrio aestuarianus*. Source: Khtikian (2021).

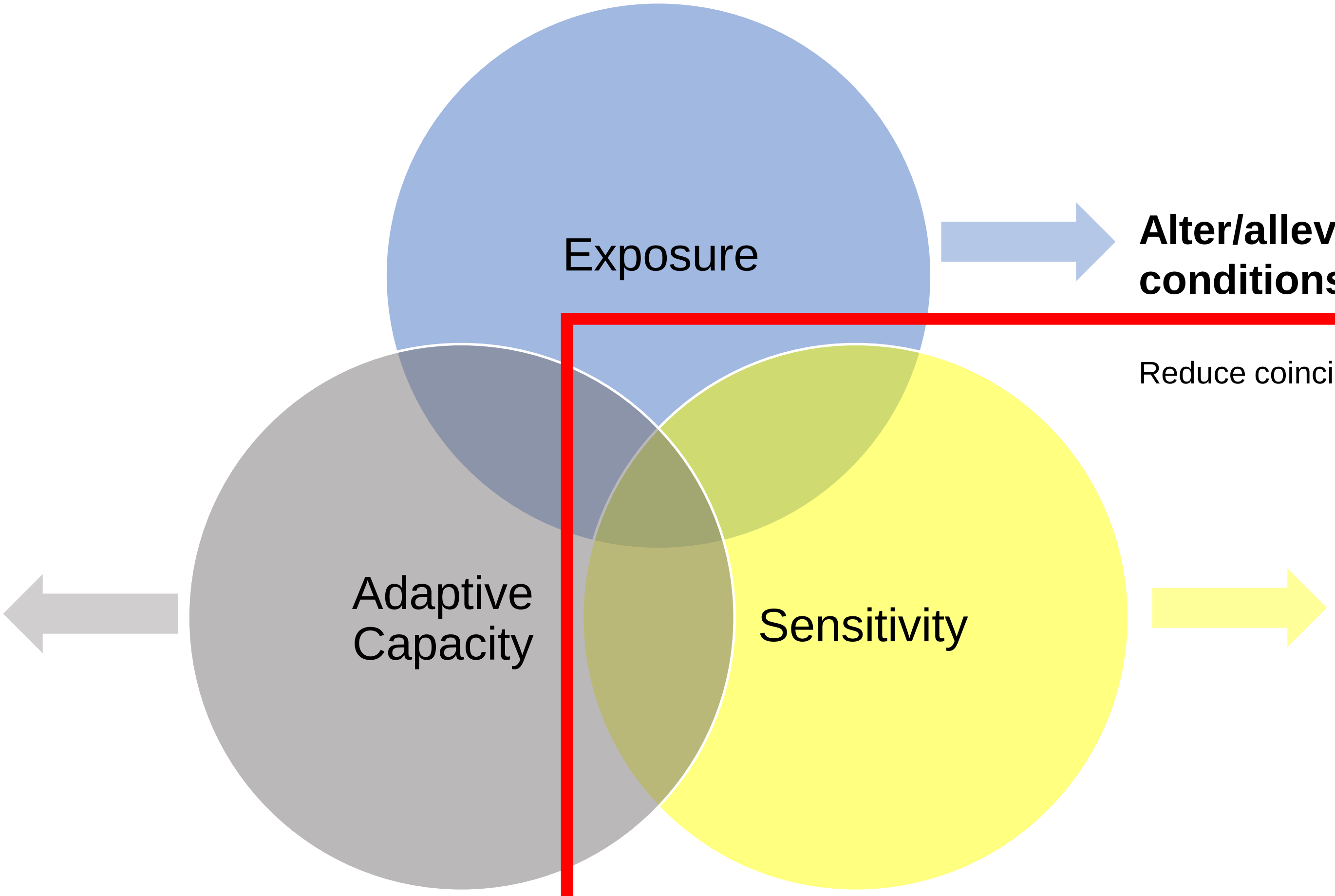
Selective Breeding



Juvenile oyster growth rate across N = 19 genetic families under ambient (blue) and OA (aragonite undersaturated) (yellow) conditions.

Source: Orr (2024)

What Determines a Species' Vulnerability versus Resilience?



Alter/alleviate exposure conditions

Reduce coinciding stressor conditions

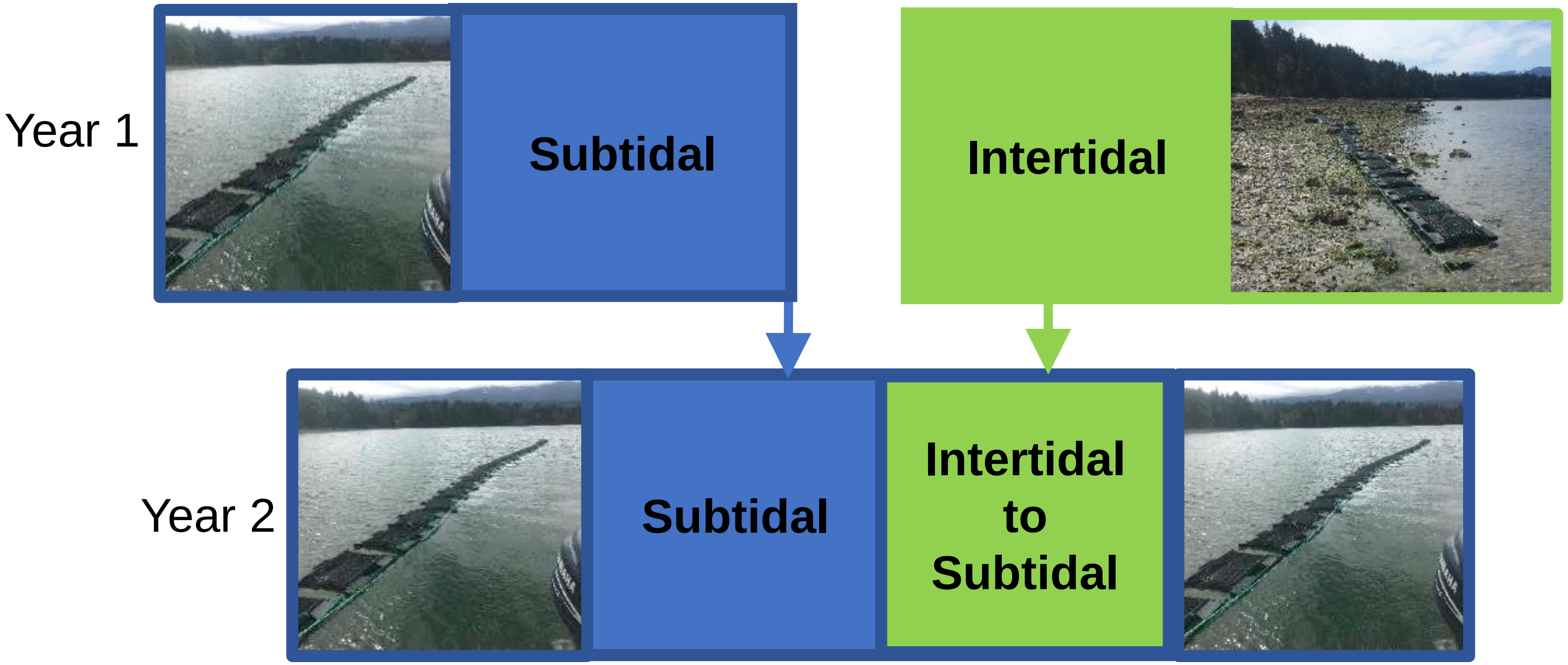
Manipulate adaptive capacity

Use of breeding programs

Decrease sensitivity to stressor conditions

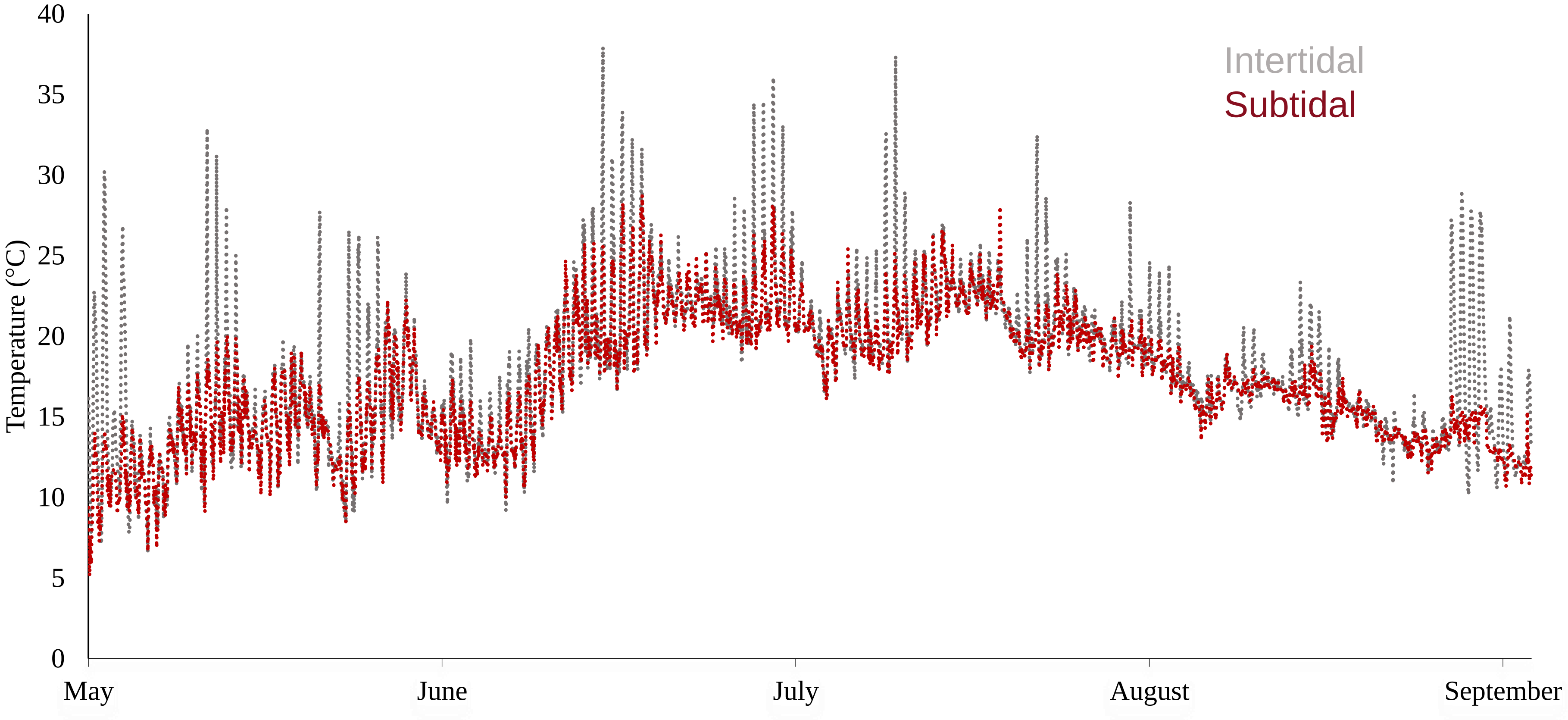
Improve ability to respond and recover

Decrease Sensitivity/Priming



1. Years 1 (2021) and 2 (2022): Field - Tracked survival, growth, and condition index at three farms.
2. Year 1: Laboratory challenge - Compared survival during acute warming.
3. Year 2: Laboratory challenge - Compared survival during acute warming and *Vibrio* challenge.
4. Year 2: Field - Compared microbiome and gene expression response in relation to a natural heatwave event.

Decrease Sensitivity/Priming



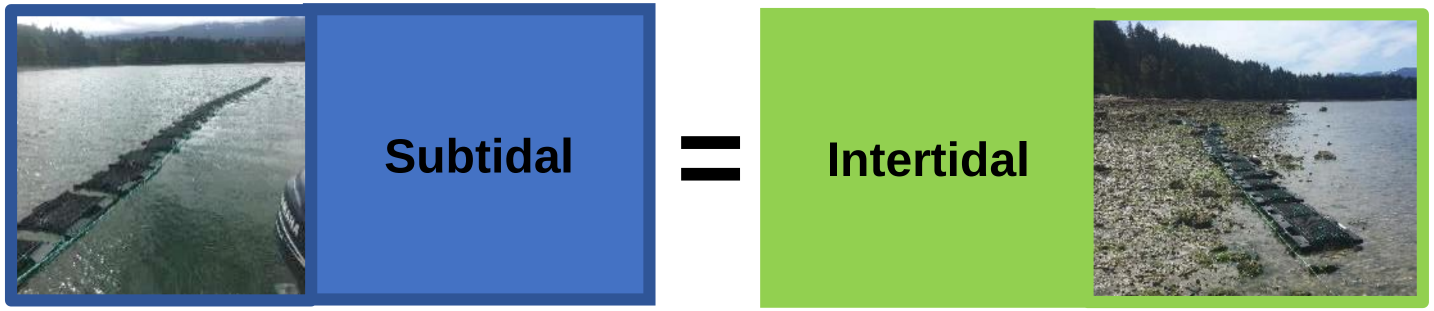
Source: Mackenzie et al. (2024)

Decrease Sensitivity/Priming

Year 1: Survival, Growth, Condition Index

- No significant differences in survival (≥90%) between intertidal and subtidal treatments at all farms between March and September 2021.

- No significant differences in shell length or condition index in intertidal and subtidal treatments at all farms by end of the first growing season (Summer 2021).



Source: Mackenzie et al. (2024)

Decrease Sensitivity/Priming

Year 1: Laboratory Acute Warming Experiment

- Carried out after one summer under intertidal or subtidal conditions.

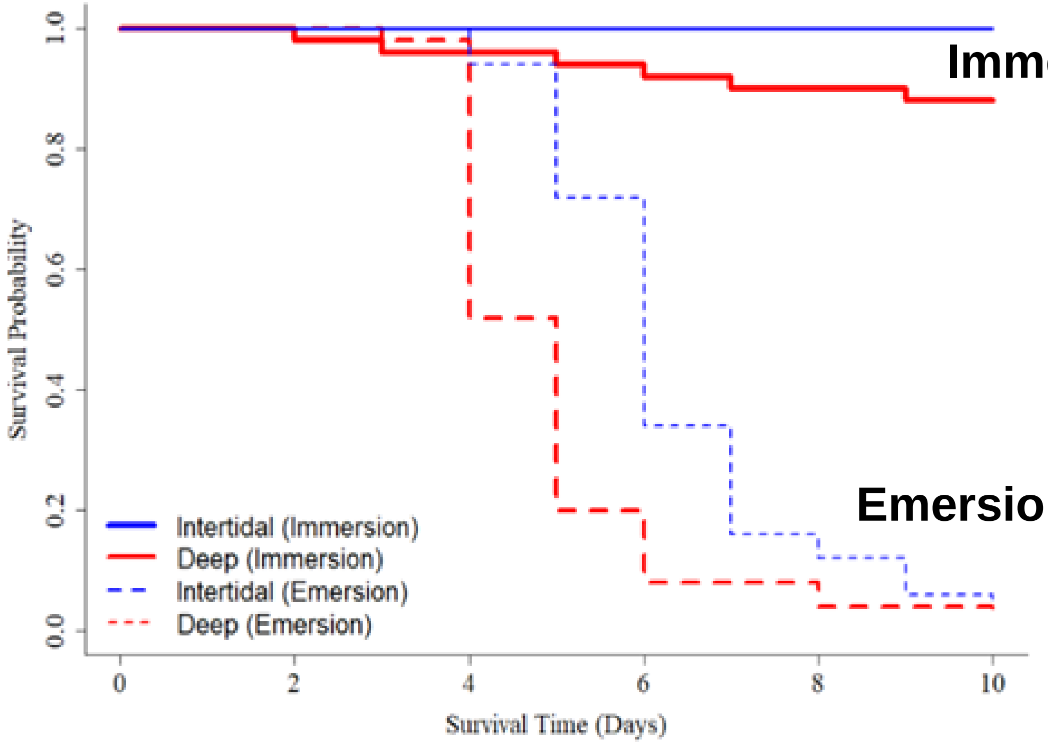
- Ran at 16, 20, 24°C for 10 days under constant Immersion (IM) and constant Emersion (EM) conditions.

- Under IM at 20°C: Intertidal oysters had significantly greater survival than subtidal oysters (100 vs 90% at day 10).

- Under EM at 20°C: Intertidal oysters had greater time at 100% survival than subtidal oysters (4 vs 2 days).

- Results generally similar for 16 and 24°C.

20°C



Immersion

Emersion

Subtidal **<** **Intertidal**

Source: Mackenzie et al. (2024)

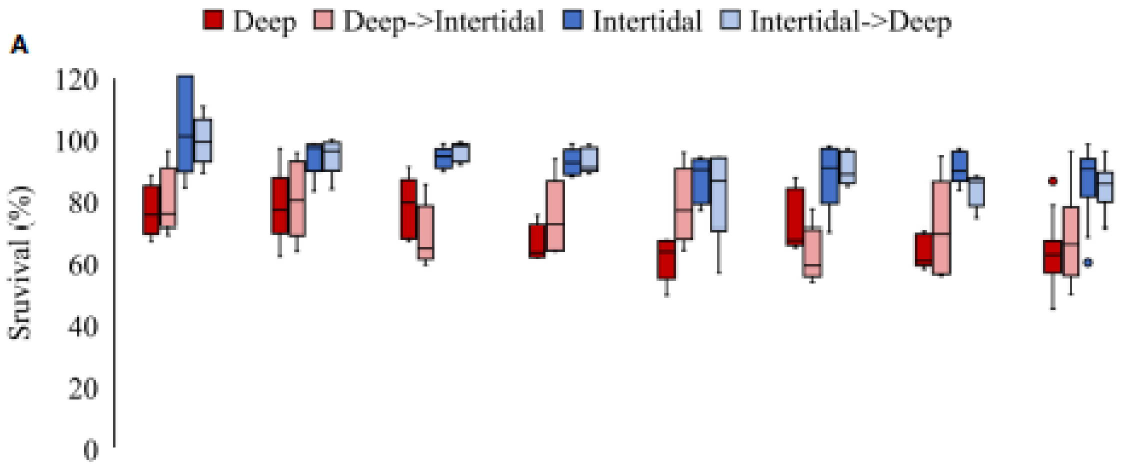
Decrease Sensitivity/Priming

Year 2: Survival, Growth, Condition Index (post-transplant)

- Significant differences in survival at end of the field trial at one of three site (Deep Bay).

- Higher survival (~20% increase) in intertidal than subtidal oysters.

- No significant differences in shell length or condition index between the two treatments.



Subtidal < **Intertidal**

Source: Mackenzie et al. (2024)

Decrease Sensitivity/Priming

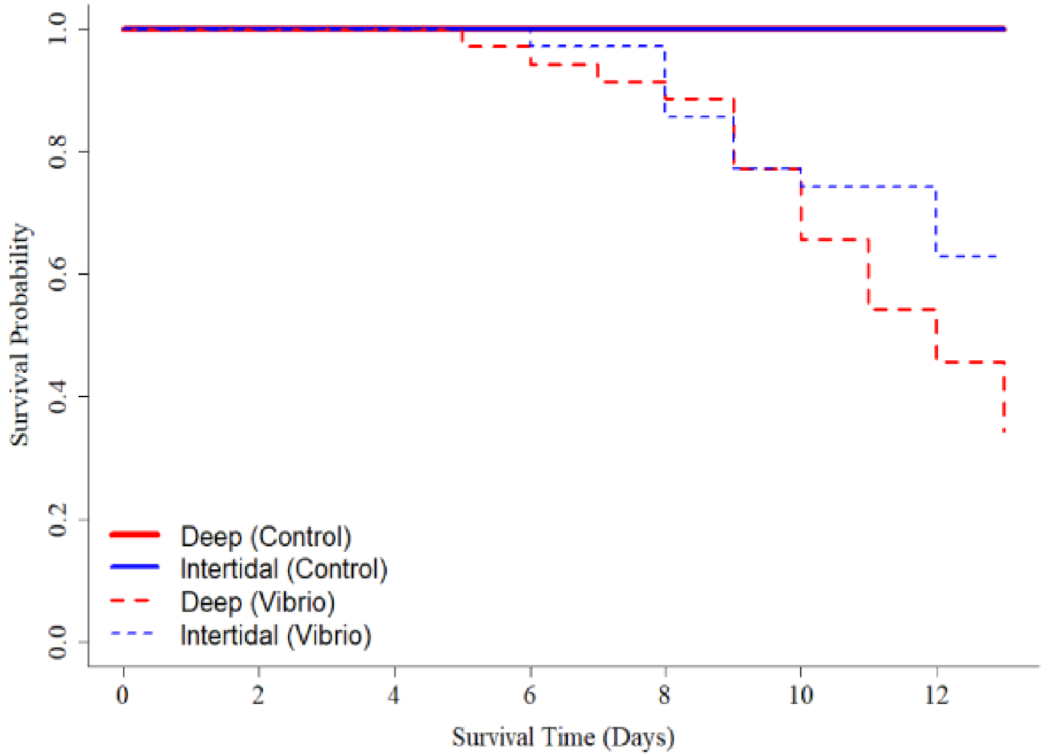
Year 2: Laboratory Temperature and *Vibrio* Stressors Experiment

- Carried out after one summer under transplant conditions.

- Ran at 16 and 24°C with *Vibrio* and without (control) for 13 days.

- At 24°C, no significant differences in survival between intertidal and subtidal oysters either with or without *Vibrio*.

- At 16°C + *Vibrio*, intertidal oysters had increased survival time and greater overall survival after 13 days.



Subtidal < **Intertidal**

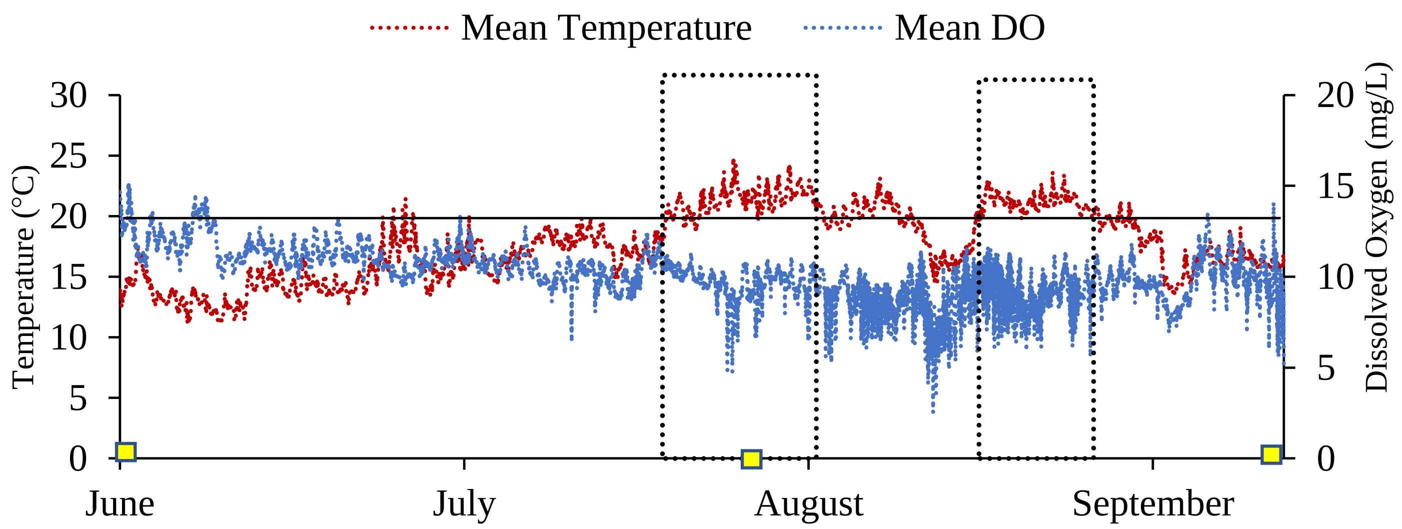
Source: Mackenzie et al. (2024)

Decrease Sensitivity/Priming

Year 2: Heatwave Comparison - Gene Expression and Microbiome

Does culture environment alter microbiome (MB) and gene expression (GE) in relation to a heatwave event?

- Compared oyster GE and MB of intertidal and subtidal treatments at Deep Bay farm.
- Compared oyster MB at three timepoints: pre-transfer, pre-HW, post-HW.
- Compared oyster GE at three timepoints: pre-HW, HW, post-HW.



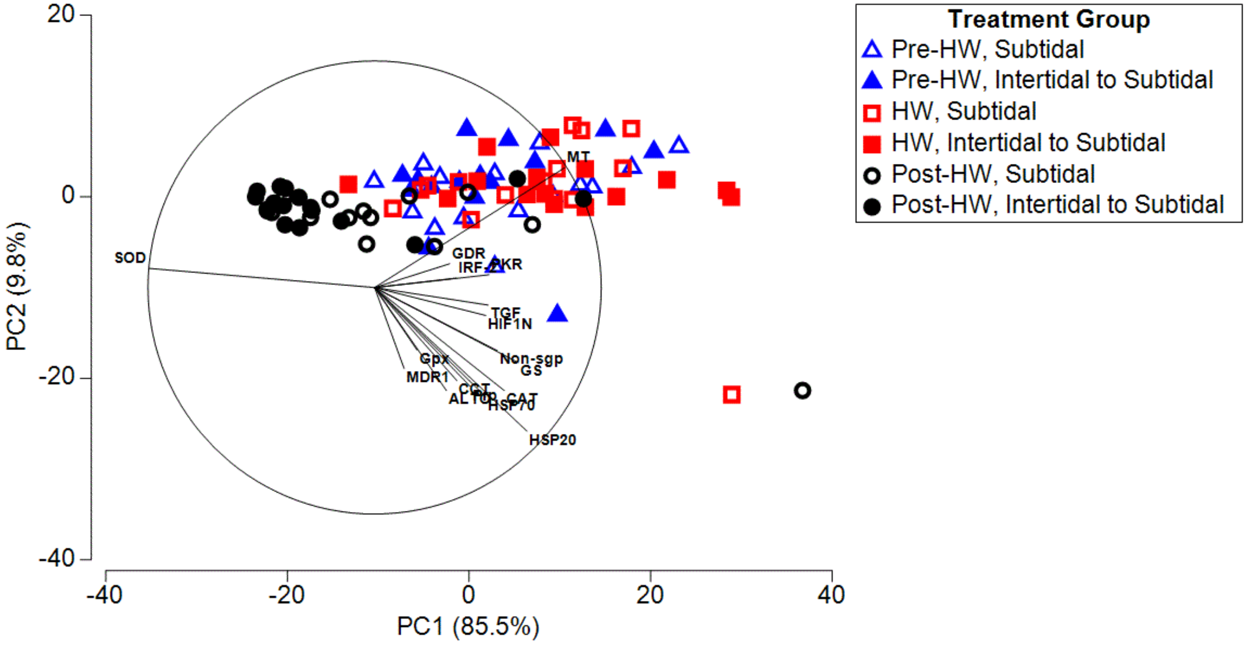
Source: Mackenzie et al. (2025)

Decrease Sensitivity/Priming

Year 2: Heatwave Comparison - Gene Expression

- **All time points/culture treatments:** Significant effect of time on GE (higher expression post-heatwave), but no difference between intertidal and subtidal treatments.

- **Post-HW timepoint:** Significant effect of culture treatment on GE; significant differences in expression of genes related to the oxidative stress response (Superoxide Dismutase (SOD) and Alternative Oxidase (AOX)).



Subtidal ≠ **Intertidal**

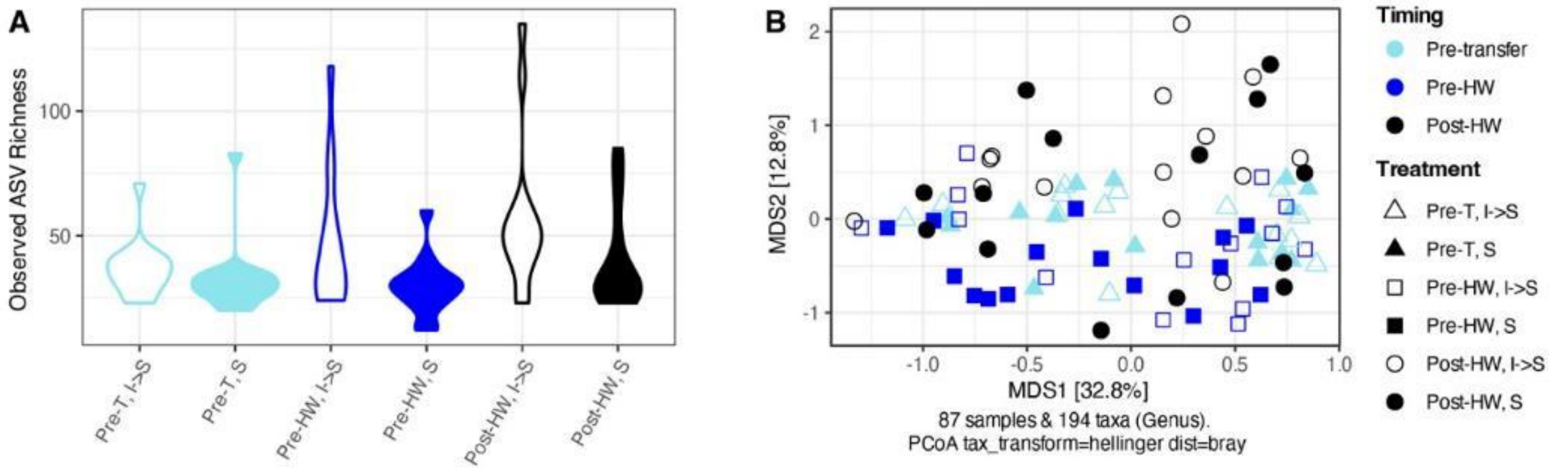
Source: Mackenzie et al. (2025)

Decrease Sensitivity/Priming

Year 2: Heatwave Comparison - Microbiome

- Treatment: MB richness was significantly higher in the gills of intertidal oysters than subtidal oysters.

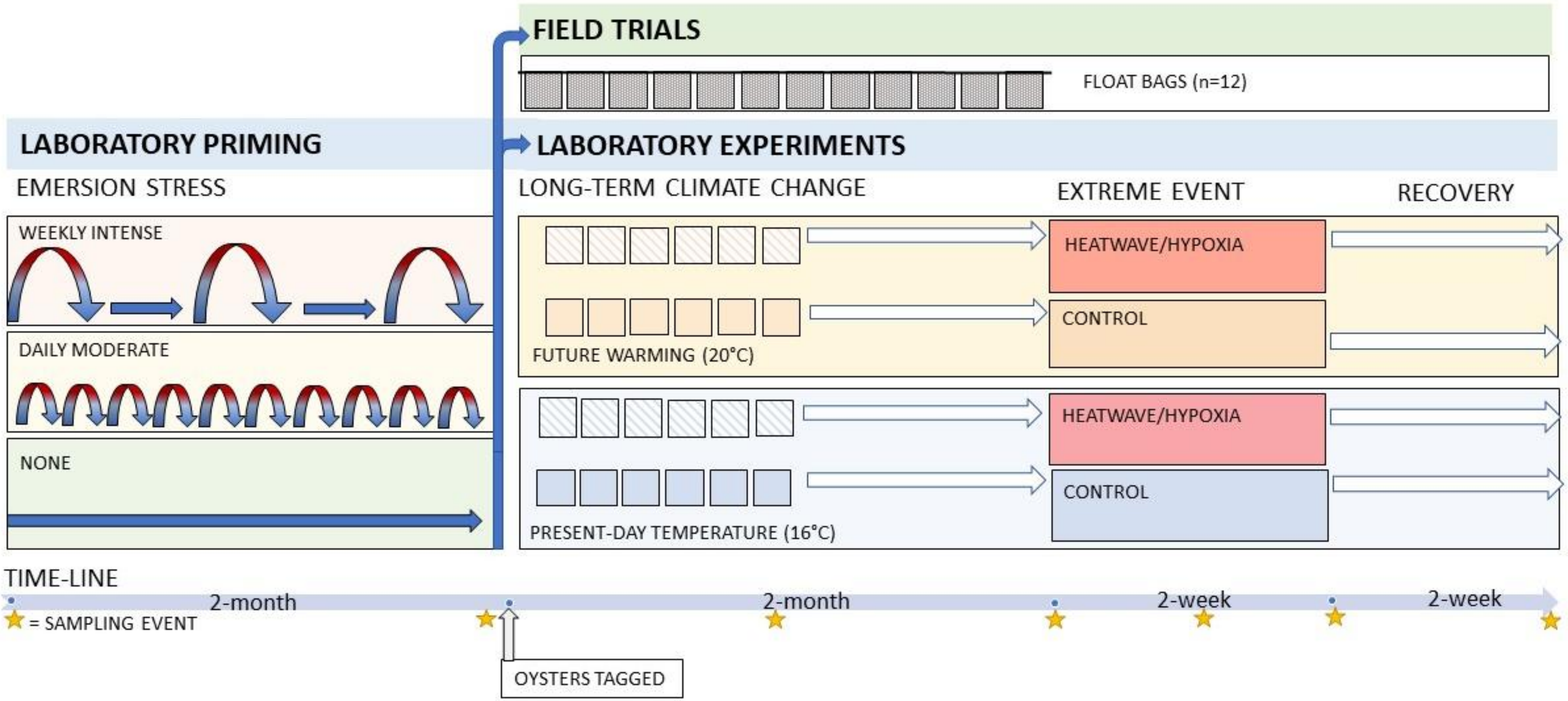
- Timepoints: MB richness significantly changed over time.



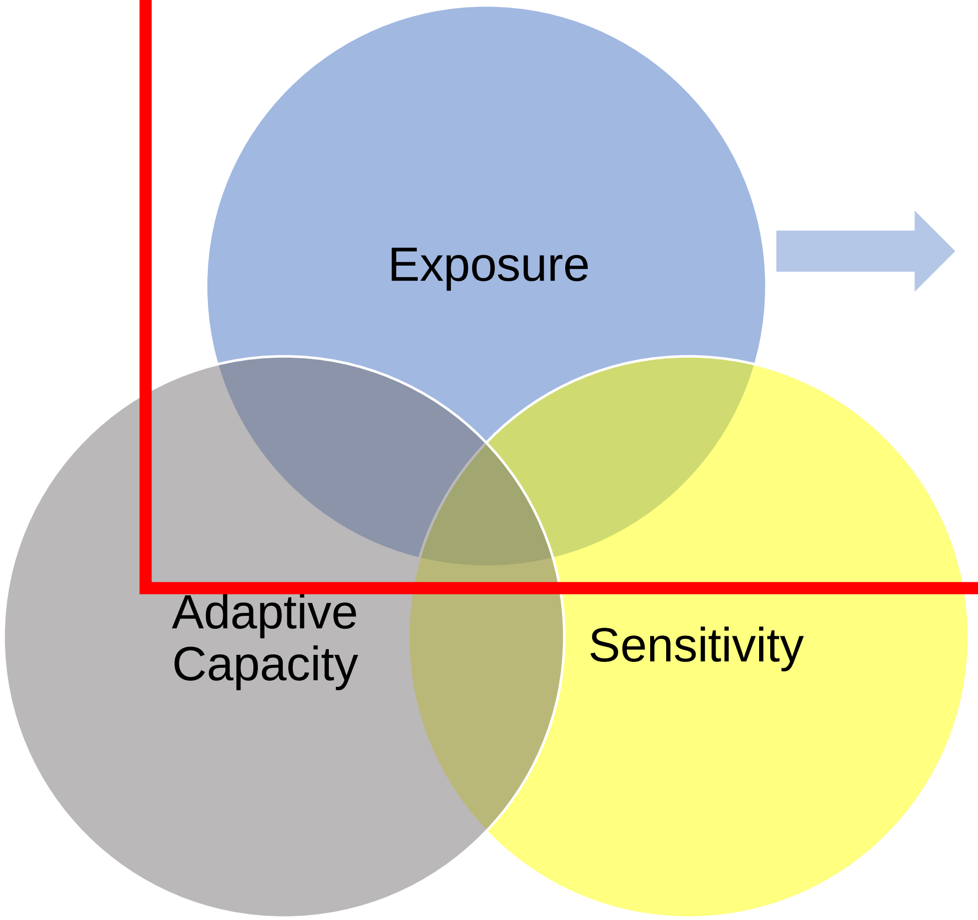
Subtidal ≠ **Intertidal**

Source: Mackenzie et al. (2025)

Decrease Sensitivity/Priming



What Determines a Species' Vulnerability versus Resilience?



Alter/alleviate exposure conditions

Reduce coinciding stressor conditions

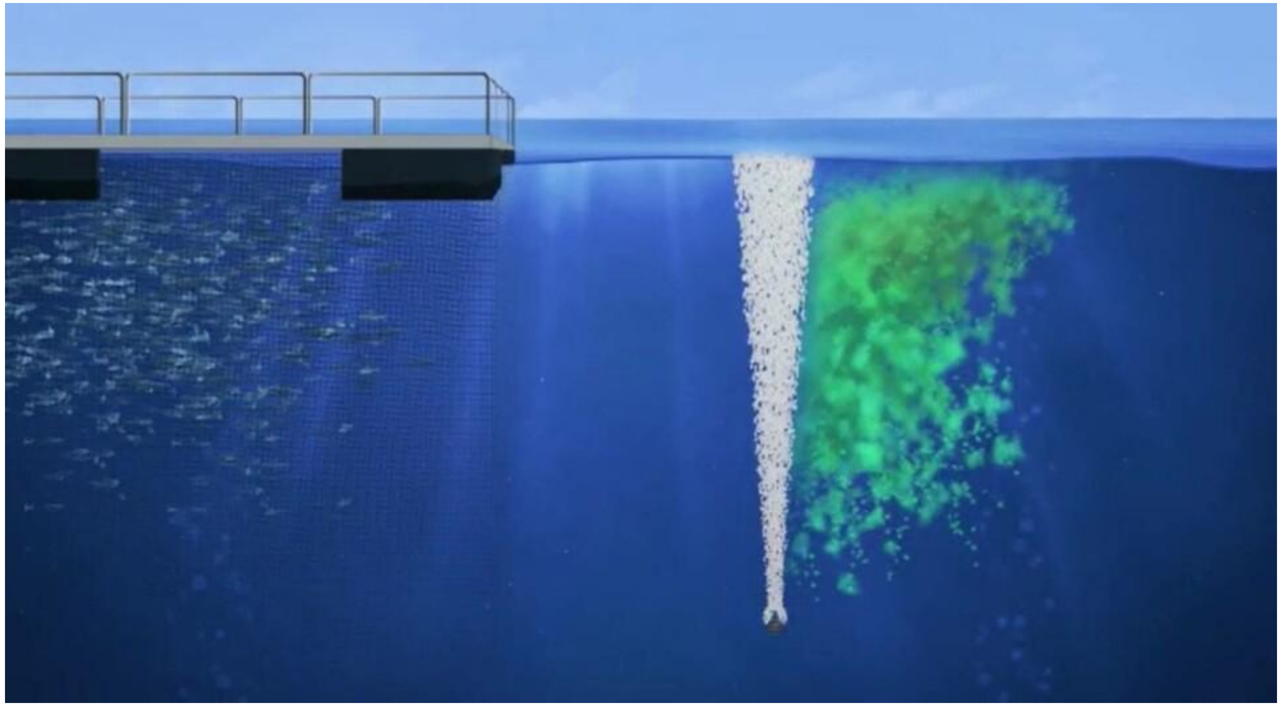
Manipulate adaptive capacity

Use of breeding programs

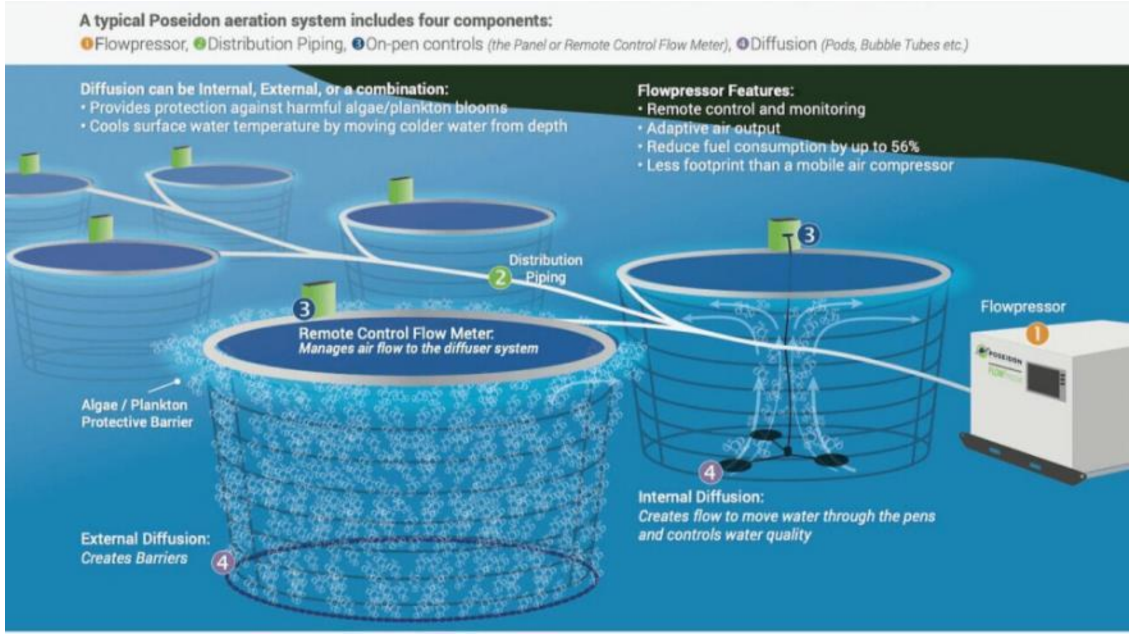
Decrease sensitivity to stressor conditions

Improve ability to respond and recover

Alter/Alleviate Exposure Conditions



Source: PSP Video (2025)



Source: Poseidon Ocean Systems (2025)

Alter/Alleviate Exposure Conditions

Bull. Jpn. Soc. Fish. Oceanogr. 78(1) 13–27, 2014 水産海洋研究

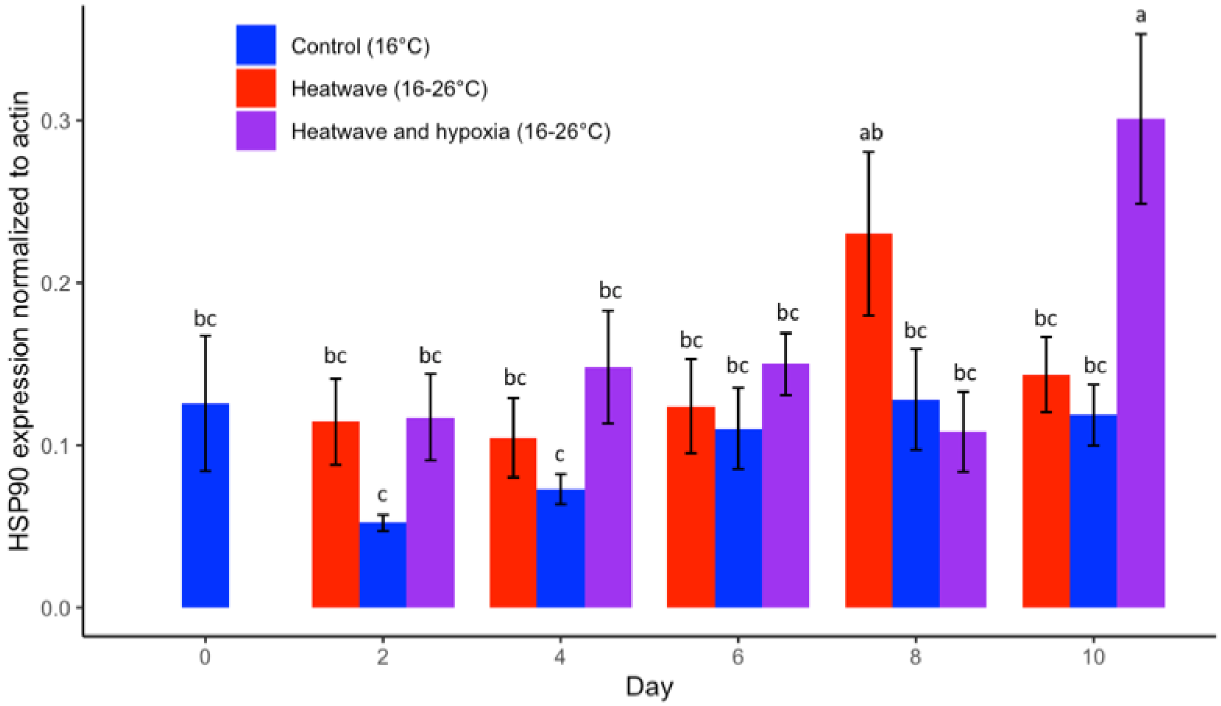
Effects of artificial upwelling on the environment and reared oyster *Crassostrea gigas* in Omura Bay, Japan

Darien Danielle MIZUTA[1†], Akihide KASAI[2], Ken-Ichiro ISHII[1],
Hitoshi YAMAGUCHI[3] and Hideaki NAKATA[4]

Artificial upwelling was tested at Seihi, Omura Bay, Nagasaki Prefecture, as a way to improve environmental conditions for Pacific oyster farming. Aeration was performed from the sea bottom during two summer seasons in 2011 and 2012. Oceanographic parameters (temperature, salinity, dissolved oxygen concentration, chlorophyll *a* concentration, and suspended solids) and oyster performance (growth, survival, condition index, and glycogen levels) were monitored monthly. Aeration was shown to be efficient in improving water conditions for oyster farming, especially in the beginning of summer, by locally lowering water temperature by approximately 1°C, redistributing nutrients, and increasing diatom biomass. Dissolved oxygen concentration increased from October, at the beginning of autumn. The condition index of oysters was negatively related to distance from the aeration point. Furthermore, a reproductive season occurring when the aeration could not overcome high temperatures and formation of hypoxic water resulted in poor oyster health (condition index and glycogen levels decreased in September). Our results indicate that aeration can improve bivalve cultures if it is performed at a rate that overcomes hypoxia formation and high water temperatures throughout the summer period.

Key words: hypoxia, enclosed bay, artificial upwelling, Pacific oyster culture, condition index

Alter/Alleviate Exposure Conditions

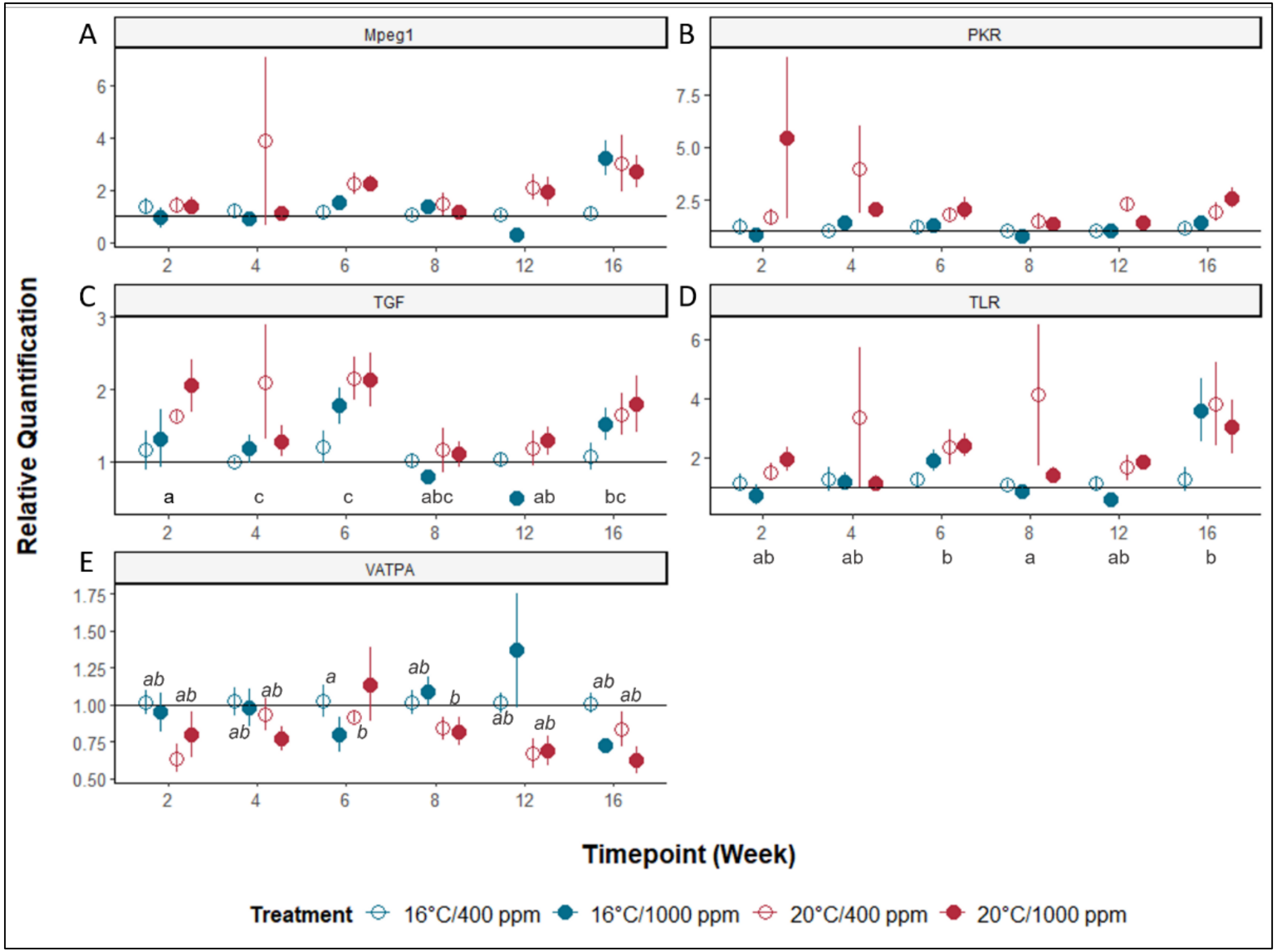


Over the 10-d experimental period, mean DO was: 7.6 ± 0.4, 6.6 ± 0.7, and 3.9 ± 1.4 mg O_2 L^{-1} for the control, heatwave, and heatwave + hypoxia treatments, respectively.

Mean relative expression ($2^{\Delta Cq}$) and standard error (n = 6) for heat shock protein 90 (HSP90) on day 0 (T0, 16°C), day 2 (T1, 18°C), day 4 (T2, 20°C), day 6 (T3, 22°C), day 8 (T4, 24°C), and day 10 (T5, 26°C) of the simulated heatwave compared to the control (16°C). Relative expression normalized to actin where $\Delta Cq = (Cq_{actin} - Cq_{HSP90})$. Letters show significant ($p < 0.05$) differences identified via post-hoc Student-Newman-Keuls (SNK) test.

Source: Bickell (2025)

Alter/Alleviate Exposure Conditions



Source: Gray (2025)

Alter/Alleviate Exposure Conditions

Larval Rearing
(Soda-ash buffered vs ambient pH)

Alter/Alleviate Exposure Conditions

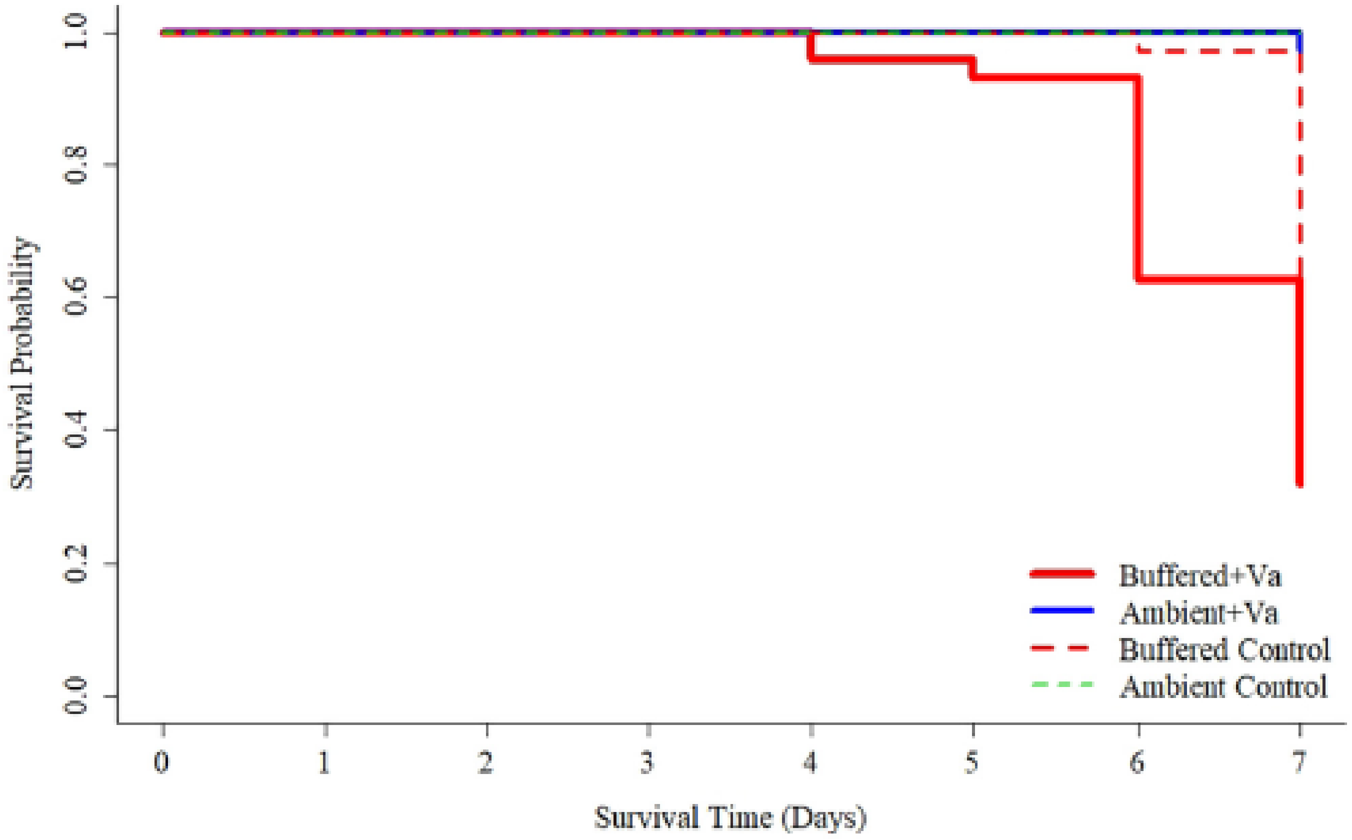


FIG 4 Kaplan-Meier survival curves of juvenile oysters reared as larvae under ambient (blue solid line) or buffered (red solid line) seawater conditions under a 7-day simulated heatwave and *Vibrio aestuarianus* exposure. Dashed lines indicate control groups not exposed to *V. aestuarianus* though are somewhat masked by the ambient treatment line.

Source: Mackenzie et al. (2022)

Alter/Alleviate Exposure Conditions

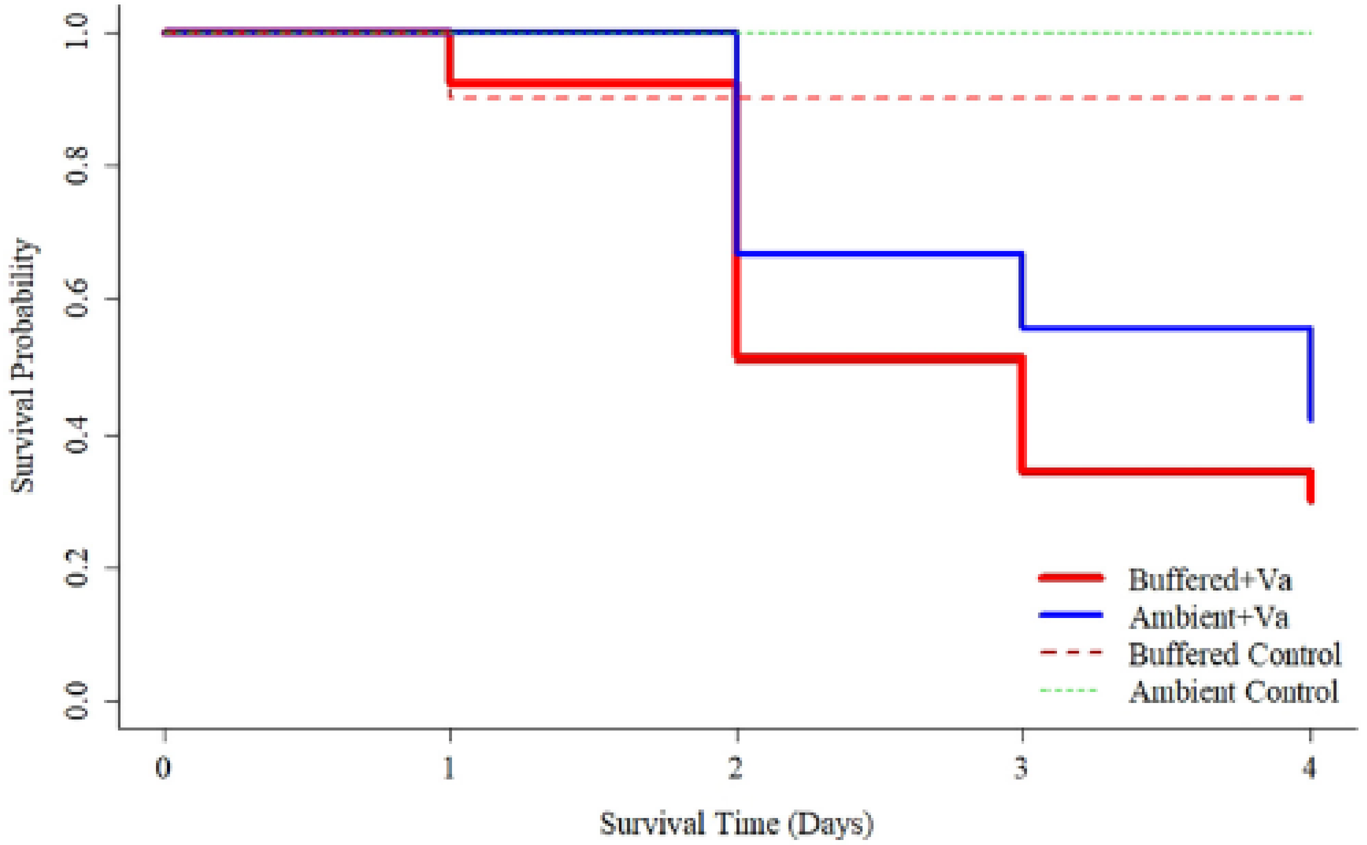


FIG 6 Kaplan-Meier survival curves of adult oysters reared as larvae under ambient (blue solid line) or buffered (red solid line) seawater conditions under a 4-day simulated heatwave and *Vibrio aestuarianus* exposure. Dashed lines indicate control groups not exposed to *V. aestuarianus*.

Source: Mackenzie et al. (2022)

Alter/Alleviate Exposure Conditions

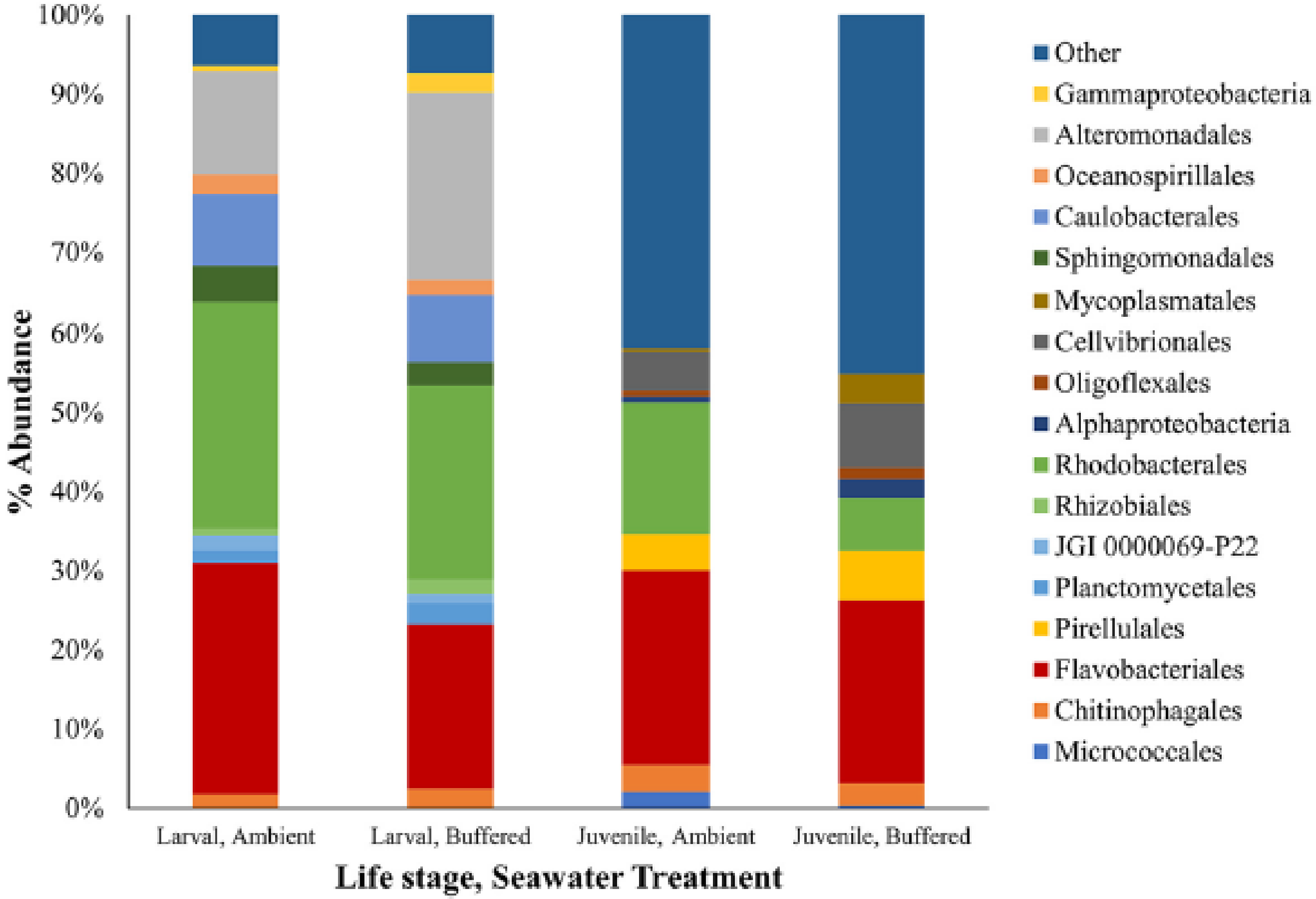


FIG 3 Proportional abundance (%) of the top 10 microbial groups contributing to dissimilarity in oyster larvae following 24 h of development under ambient or buffered seawater conditions and baseline (T0, prior to *Vibrio aestuarianus* challenge) juvenile oysters reared as larvae under ambient or buffered seawater treatment groups prior to *V. aestuarianus* challenge. All remaining microbial groups present at either life stage are shown as "Other."

Larvae: Average dissimilarity between treatments across all time points was 29.71% with top contributions from Rhodobacterales (5.24%), Flavobacteriales (3.36%), and Oceanospirillales (3.32%).

Juveniles: Average dissimilarity between treatments across all time points was 34.89% with top contributions from Vibrionales (4.03%), Mycoplasmatales (3.18%), and Flavobacteriales (2.59%).

Source: Mackenzie et al. (2022)

Conclusions

Manipulate Adaptive Capacity

- Selective breeding can produce families that are more resistant to OA and exposure to pathogenic bacteria, and which can grow better in the field, than other families.

Decrease Sensitivity to Stressor Conditions

- Growing oysters in the intertidal prior to deployment in deepwater may increase their resiliency to environmental stressor conditions (not consistent among sites though).
- Can this be replicated in the laboratory?

Alter/Alleviate Exposure Conditions

- Artificial aeration may have benefits in reducing stress response to high temperatures and/or low DO.
- More work required, especially in field (upwelling of colder, more oxygenated waters).

Acknowledgements

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- Clara Mackenzie, Chen Walker, Monique Raap, Emaline Montgomery, Sierra Gray, Andrew Bickell, Laurie Keddy, Eliah Kim, Amy Long

Fisheries and Oceans Canada   Pêches et Océans Canada

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VANCOUVER ISLAND UNIVERSITY

Taylor Shellfish Farms
- Alex Munro

SINCE TAYLOR 1890 SHELLFISH Farms

British Columbia Shellfish Growers Association
- Nico Prins, Malcolm Cowan

BC SHELLFISH GROWERS ASSOCIATION

Hakai Institute
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Hakai
Science on the Coastal Margin

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