California & Oregon Shellfish Growers' Perceptions of Adaptive Capacity in the Face of Environmental Change

KEY MESSAGES

- Shellfish growers in California and Oregon face several challenges, including a range of environmental pressures, socioeconomic factors and circumstances, and permitting restrictions. Growers are concerned about the potential impacts of OA, but they are not always able to detect if and how OA impacts their operations.
- Growers are employing or would like to employ a range of adaptive strategies that might help them respond to environmental changes. These strategies include: (1) science-based approaches (e.g., filling knowledge gaps, monitoring), (2) farm management (e.g., new or desired farm practices), and (3) policy interventions and networking (i.e., regulatory changes).
- The myriad issues growers are grappling with and the diverse strategies they propose highlight the need to bring scientists, policymakers, and aquaculture industry representatives together to collectively explore opportunities for facilitating grower's adaptation and resilience to environmental change.

Changing ocean conditions impact marine ecosystems and industries dependent on them, including shellfish aquaculture. The U.S. West Coast (California, Oregon, Washington) has an important shellfish aquaculture industry that comprises over 300 farms and 5 hatcheries worth more than $270 million, and supports two-thirds of clam, mussel, and oyster sales in the U.S.[1,2] This region of the ocean is dynamic and particularly vulnerable to climate change, with rising temperatures, decreasing oxygen concentrations, and changing ocean chemistry threatening cultivated species.[1,2] With increasing interest in expanding aquaculture, it is critical to understand the vulnerability and **adaptive capacity *(i.e., the ability to respond and adapt)*** of this industry to current and future environmental change.

Researchers from Oregon State University and San Diego State University surveyed 11 shellfish farms in California[3] and 15 farms in Oregon[4] to assess (1) **growers' awareness and perception of environmental change** and (2) **adaptive strategies that growers are already using or are interested in implementing** to respond to environmental change.

PERCEPTIONS OF ENVIRONMENTAL STRESSORS

Shellfish growers in California and Oregon identified a total of 17 environmental stressors. Growers are aware of and concerned about ocean acidification (OA), but cannot always detect its impacts on farm operations as readily as other stressors. This inability to track and detect OA can impact their vulnerability to environmental change.

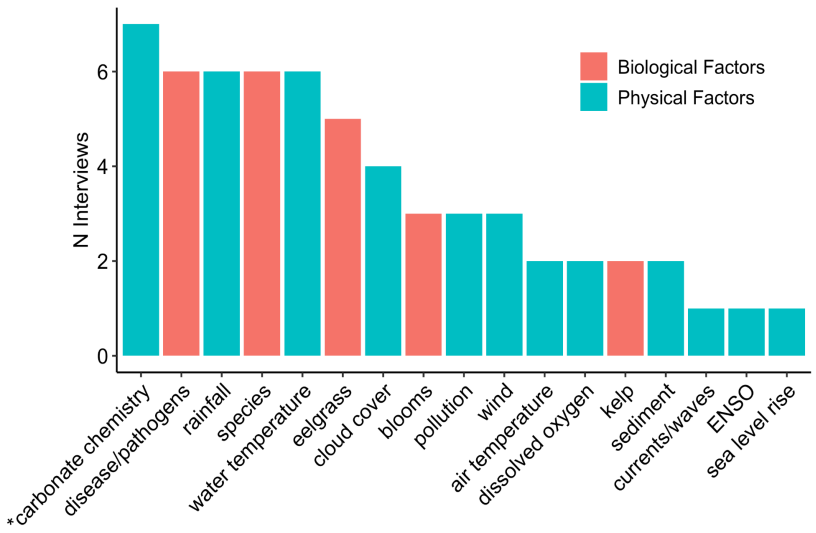

Figure 1. This figure shows the number (N) of interviews where certain biological (pink) and physical factors (blue) were identified as environmental stressors in California shellfish farms. * represents that carbonate chemistry was mentioned as a stressor only after being prompted, as opposed to interviewees identifying other stressors of their own volition (Ward et al. 2022).

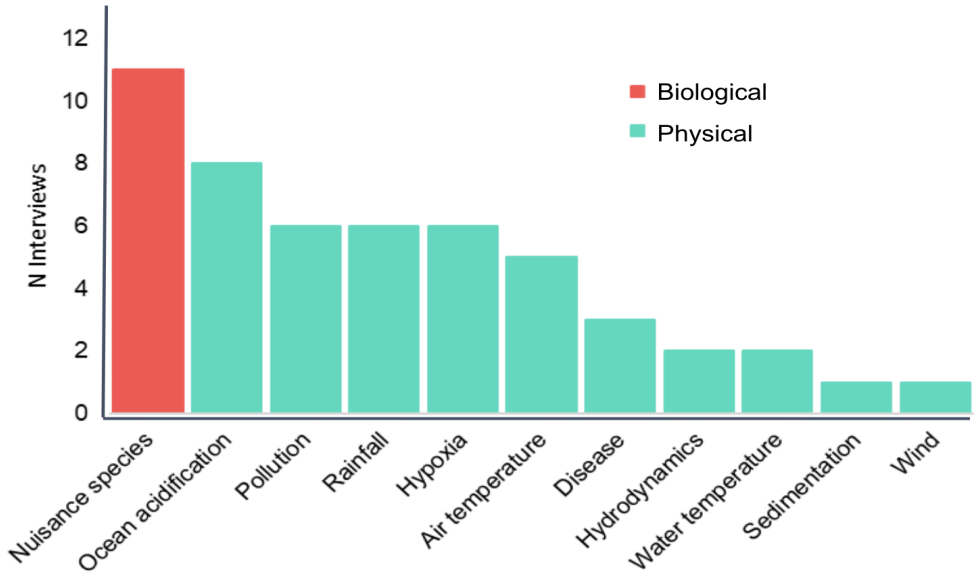

Figure 2. This figure shows the number (N) of interviews where certain biological (pink) and physical factors (blue) were identified as environmental stressors in Oregon shellfish farms (Green et al. 2023).

Although shellfish growers in both states mentioned similar environmental stressors, the prevalence of stressors differed by state. California growers emphasized *disease outbreaks* and run-off associated stressors from *pollution or rainfall*. Notably, **despite the shellfish species' demonstrated vulnerability to *OA*, many California growers did not mention it until prompted**; some growers did connect declines in pH with subsequent reductions in growth, but they did not state that OA poses a threat to operations (Figure 1).

Oregon shellfish aquaculturists' primary concern included *nuisance species* that predate on oysters, damage farm equipment, and alter seafloor terrain. **Nearly half of Oregon growers stated that *OA* is a stressor that is largely confined to hatcheries, during the oysters' earliest life stages***,* while other Oregon farmers were unable to separate its impacts from other stressors (Figure 2).

> *"We had a really heavy rainfall winter and there [were] extremely low* pH *levels that year that coincided with the heavy rainfall which also pushed the* pH *down, and we had a lot of extremely slow growth that year."*
>
> - *Anonymous California shellfish grower*
>
> *"In the hatchery, it's all early stage, when they're smaller than 130 microns … [At a] smaller size, [the oysters] have a harder time form[ing] the shell. The older oysters that the farmers are involved with are hardier and less susceptible to change or to the product … I haven't seen much effect on the commercial size oysters."*
>
> - *Anonymous Oregon shellfish grower*

In addition to environmental drivers of change, growers shared sentiments about challenging regulatory and economic circumstances. Many described the permitting process as expensive and time-consuming, which hindered their capacity to remain resilient to change. Increased labor and material costs as well as supply chain issues also adversely affected their businesses. Growers indicated that grants could help offset operation costs, but that few are available.

ADAPTIVE STRATEGIES

California and Oregon growers identified similar adaptive strategies, comprising a total of 20 strategies to respond and adapt to environmental change (Table 1). These strategies spanned three categories: **Science** (i.e., filling key knowledge gaps through scientific research or monitoring), **Farm Management** (i.e., implementing new or desired farm practices), and **Policy & Networking** (i.e., regulatory changes and networking among partners).

Overall, shellfish growers most frequently suggested changing or clarifying the permitting and regulatory landscapes as an adaptive strategy. Growers mentioned the desire to simplify or clarify the process for starting new or adjusting existing operations, reduce regulatory burdens, and increase regulatory flexibility for implementing other adaptive strategies (e.g., farm management strategies). Other common strategies included developing and leveraging networks to share information, best practices, and communicate policy and scientific needs, as well as improving knowledge on the drivers of shellfish mortality.

Table 1. Adaptive strategies identified by shellfish growers across each category (i.e., Science, Farm Management, and Policy & Networking). Note that * indicates strategies that were only suggested in California, while † indicates strategies only mentioned in Oregon.

SCIENCE	FARM MANAGEMENT	POLICY & NETWORKING
● Improve knowledge about shellfish health ● Develop broodstock with genetic resistance to environmental stressors ● Monitor OA & water quality ● Research on new methods, gear types, species* ● Study benefits and disadvantages of co-culturing shellfish with other species*	● Increase spatial & temporal flexibility for growing products in response to environmental changes ● Increase/change method/gear types used ● Alter water intake to accommodate environmental change ● Diversify customer base via retail and wholesale businesses ● Change marketing/prices to account for shifts in cost ● Culture multiple species to diversify product line† ● Culture multiple lifecycle stages in-house to avoid reliance on outside providers* ● Outplant different oyster types (diploid v. triploid) to diversify stock ● Implement intentional & proactive farm management and planning† ● Educate about and steward natural resources related to shellfish aquaculture†	● Consider changes in water quality response & regulation ● Network within and outside the aquaculture sector ● Provide funding for implementing adaptive capacity measures ● Consider permitting, licensing, & regulatory changes

IMPLICATIONS

As climate change continues to alter the ocean environment, it will be important to understand the location and timing of these shifts as well as their impact on coastal communities. As these two studies suggest, California and Oregon shellfish growers are not always able to detect if OA is affecting them or distinguish its effects from other environmental stressors, making them particularly challenging to address. Therefore, increasing growers' overall adaptive capacity using a diversity of strategies and approaches will be imperative for enhancing their resilience to future environmental change. These strategies, as identified by growers, highlight crucial opportunities for the industry, scientists, and policymakers to work together on this key issue.

Science

Science strategies help fill critical knowledge gaps and increase understanding of the impacts of OA and other environmental stressors on shellfish aquaculture, the feasibility and efficacy of certain approaches, and whether growers will continue to be exposed to future environmental change. For example, understanding drivers of shellfish mortality, investigating different culturing techniques, and exploring the efficacy of novel equipment could increase growers' options for responding to the adverse impacts of environmental change. Further investment in monitoring infrastructure in locations relevant to growers and the accessibility of those data could also improve operators' ability to plan for and respond to OA and other environmental stressors. Policymakers can play a pivotal role in advancing these science strategies, such as directing investments to address them, and developing or providing guidance.

Farm Management

Proactive management strategies and increased awareness of best practices for stewarding natural resources that support farm outputs are critical for reducing growers' vulnerability. Increasing the diversity of species grown, culturing methods used, and/or equipment deployed may increase resilience for larger operators, but will likely be prohibitive for smaller farms. Increasing farm management flexibility can provide growers with options and actions to make changes to ongoing operations while allowing them to employ best practices used by other growers. However, some of these approaches may require regulatory or policy change.

Policy & Networking

Policy responses or changes may be required to advance or implement other adaptive strategies identified by growers (e.g. investments in monitoring, implementing new farm management strategies). Policymakers can play a pivotal role by establishing reasonable expectations around potential policy changes while clarifying and clearly communicating existing permitting and regulatory processes. This will reduce the time and cost involved for growers engaging in these processes. Additionally, decision-makers can further facilitate the use of adaptive strategies by providing advice on the social, economic, and political feasibility of implementing those strategies, including identifying funding opportunities or establishing water quality regulatory responses. A forthcoming analysis will further examine the connections between existing policy and the potential adaptive strategies that growers put forth in the studies presented here.

Networking plays an important role as practical techniques are shared across farms and scientific partnerships facilitate broodstock improvement and knowledge generation. Organizations such as the Pacific Coast Shellfish Growers Association (PCSGA) provide opportunities for information exchange and represent shellfish growers in policy settings. Engagement with such interest groups could advance discussions between farmers and policymakers about current permitting and regulatory frameworks. Venues for dialogue and opportunities for sustained cross-sectoral collaborations could play an important role in facilitating adaptation. Examples of such initiatives include:

- National Oceanic and Atmospheric Administration's Regional Coastal Acidification Networks (CANs);
- Washington Sea Grant's coastwide Shellfish Aquaculture Study;
- Oregon's Scientist And Fishermen Exchange (SAFE); and
- California Ocean Protection Council's forthcoming Aquaculture Action Plan.

Overall, no single action will address the collective challenges facing the shellfish aquaculture industry. **Supporting adaptive capacity and resilience to environmental change will take a multi-pronged and multi-institutional approach that involves farmers, scientists, and policymakers.**

FUNDING

Funding for this work was provided by the California Ocean Protection Council and National Oceanic and Atmospheric Administration Ocean Acidification Program.

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