Comparing Ocean Acidification Communication Strategies and Effectiveness in Marine Education Centers

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A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Marine Affairs

University of Washington

2026

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School of Marine and Environmental Affairs

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Abstract

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Ocean acidification (OA), one of the most impactful aspects of our changing oceans, significantly threatens ecosystems, industries, and communities reliant on at-risk species, such as corals and shellfish. Washington state, with its notable reliance on such species for both its economy and culture and its naturally acidified waters, is especially vulnerable. However, OA remains an under-discussed and misunderstood phenomenon, especially among the public. While many informal marine education centers such as aquariums, science centers, and marine reserves do provide communication on OA, the prevalence, type, and quality of this communication varies drastically, meaning that the public's ability to receive effective OA education varies as well. Thus, I conducted staff interviews to catalogue the prevalence of OA communication efforts at marine education centers and address barriers to effective OA outreach. I found that

while 88% of participating marine education centers discuss OA in some capacity, 81% feel restricted in their ability to talk about OA or ocean change, citing issues such as audience interest and politics. I also conducted visitor surveys at Point Defiance Zoo & Aquarium to determine how attendees' preconceived knowledge of OA's causes, impacts, and mitigation strategies changed based on provided communication and what gaps remain. While visitor knowledge of OA increased by a statistically significant amount (from 63% of visitors knowing essentially nothing about OA before the visit to 44% after; $p < 0.001$), only 49% of visitors correctly identified fossil fuel emissions as a primary cause of OA. Despite this, 97% of visitors indicated willingness to take action against OA, and nearly equivalent amounts of visitors supported individual-level vs societal-level action. Together, this research lays the groundwork for improving OA communication to the public by highlighting the importance of uplifting meaningful action, intentionally connecting with visitors through community-level and place-based impacts, and addressing staff hesitancy to discuss ocean change issues. Going forward, these recommendations will be critical in driving tangible action to address OA and protect at-risk communities and ecosystems.

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1. Introduction

1.1 Ocean Acidification:

Ocean acidification (OA), the lowering of the ocean's pH due to human-driven increases in atmospheric carbon dioxide (CO_2), is one of the most impactful aspects of our changing oceans. Not only does OA significantly threaten multiple keystone marine species, but it is a driver of large-scale environmental, economic, and societal losses in many coastal communities, particularly those reliant on at-risk ecosystems and fisheries. Worst of all, OA is expected to increase in severity as fossil fuel emissions continue to steadily rise (Jiang et al., 2023).

The global ocean is the largest sink of anthropogenic carbon dioxide on the planet, responsible for absorbing around 30% of all anthropogenic carbon emissions (Gruber et al., 2019). However, when CO_2 mixes with seawater, it initiates a series of chemical reactions that result in the lowering of pH and the consumption of freely available carbonate ions in the water.

Notably, this reduction in the availability of the carbonate ion has major detrimental effects on species that use carbonate to construct shells and skeletons, including shellfish, crabs, plankton, and corals (Kroeker et al., 2010). Due to the lower abundance of carbonate ions, calcium carbonate-dependent organisms face difficulty building and maintaining shells and skeletons, particularly in low-pH environments, making them more vulnerable to other threats (Kroeker et al., 2010). Other organisms, such as certain species of salmon, experience disruptions with neurotransmitters and olfactory receptors under higher CO_2 conditions, putting them at heightened risk of predation and starvation (Williams et al., 2018).

OA also impacts society, as many people are reliant in some way on species threatened by OA. Many coastal communities rely on organisms such as shellfish which are directly vulnerable to OA, for subsistence or commercial fisheries (Doney et al., 2020). Other at-risk

species such as salmon are additionally hugely important cultural creatures that many community members have formed strong relationships with (Haigh et al., 2015). Many indirect services are provided by threatened species as well, including corals, which act as hotspots for biodiversity, insulate shorelines from wave energy, and provide new opportunities for biomedical research (Hoegh-Guldberg et al., 2007).

A confluence of conditions puts Puget Sound at heightened risk to effects from OA. Because ocean waters entering Puget Sound from the California Current are upwelled from depth, the water already has a naturally low pH (Feely et al., 2008). This effect is amplified by the addition of lower-pH water into the system from the surrounding watershed and the bathymetry of the Puget Sound which brings low-pH water to the surface (Busch et al., 2013). Thus, as fossil fuel emissions increase the amount of anthropogenic CO_2 in the surface waters of the Puget Sound, acidification will be exacerbated. In fact, the pH of the Puget Sound has already significantly decreased, with much of the drop attributable to anthropogenic sources (PSEMP Marine Waters Workgroup, 2024).

Moreover, many members of the Puget Sound community have already been adversely impacted. Most notably, as early as 2007, shellfish growers began to experience production failures in Pacific oyster larvae, later found to be attributable to OA (Barton et al., 2015). The Washington state shellfish industry, which supports over 3,000 workers and contributes nearly $300 million to the economy, is reliant on continued awareness of and adaptation to OA to avoid severe economic loss (Barton et al., 2015).

1.2 Communicating Ocean Acidification:

Despite all of this, OA remains under-discussed and often misunderstood by many educators, industry workers, and impacted community members. Nearly 80% of the U.S. public knows little about OA, and misconceptions abound in people's understanding of OA's causes and effects (Cooke and Kim, 2018). Many barriers have contributed to a lack of public understanding of the subject, including low environmental literacy, scientific complexity, and invisibility of direct impacts (Geiger et al., 2017). Together, these factors have resulted in OA being conflated with other ocean change issues, including coral bleaching and harmful algal blooms, and few people are not aware of either the short-term or long-term ways to address OA (Danielson & Tanner, 2015). Thus, significant attention must be paid to the development and assessment of communication dedicated to OA with the intention of creating meaningful, engaging, and informative outreach to critical audiences.

A major source of this outreach occurs through aquariums and other informal marine education centers (MECs), non-academic institutions which serve as some of the most-visited locations for dedicated communication about the marine environment and related issues (Meyer & Mott, 2014). These institutions often have dedicated programs to educate visitors and community members about environmental issues, and many have developed targeted communication around climate change issues in recent years (Fraser et al., 2010). Despite the relative complexity of issues such as climate change, nature-based museums are shown to educate and empower visitors on climate change and OA, provided that educators at these institutions are empowered and knowledgeable about how to communicate ocean change (Swim et al., 2017). Thus, organizations such as the Frameworks Institute, the National Network for Ocean and Climate Change Interpretation (NNOCCI), and Knology have invested in providing

methods and resources for educators, including those at nature-based museums, to increase their ability to communicate climate change and OA, to positive results (Swim et al., 2017).

While analyses of climate change communication at marine education centers are more prevalent given the relative increase in public awareness of the phenomenon, recent research on how OA is communicated at marine education centers is sparse. Given both the general lack of understanding of OA by the public, and its increasing threat to coastal communities, it is incredibly important to determine the state of OA education at marine education centers.

When it comes to OA specifically, the type and quality of communication varies vastly depending on the specific institution (Fauville et al., 2012). Some aquariums use place-based education to teach about OA, some mention it in passing as a small part of an exhibit, and some do not physically mention OA at all. This contrast in OA communication makes it important to determine how often OA is taught by these institutions, and under what circumstances OA communication at these institutions is "effective," a critical question given the importance of aquariums as a primary source of marine education for the public and a place where many foster their relationship with their watersheds and learn about how to take action to protect the ecosystems they rely on.

1.3 Goals:

By providing updated analysis of the state of OA communication at marine education centers, this project informs educators and communicators about the best practices in creating targeted, impactful OA education, and, optimally, inspires empowerment in the face of this oncoming threat. To do this, I conducted a two-part analysis of OA communication at marine education centers.

1.3.1 Catalog of OA Communication at Informal Marine Education Centers: Through interviews with staff at marine education centers across the United States and Canada, I cataloged if/how marine education institutions communicate OA. This included comparing and contrasting the type of information included in OA communication (i.e. whether it offers a detailed scientific explanation, whether it references local impacts), the method of communication (oral presentation, permanent exhibit, online resource, etc.), and the actions recommended (if any).

Prior to these interviews, I developed a set of hypotheses, used to analyze the state of OA education at marine education centers:

- Hypothesis 1: I predicted that OA would not be a commonly discussed environmental issue at marine education centers compared to other environmental issues.
    - This prediction is based on the idea that OA is a fairly chemically-complex issue that is not as easily explainable to the general public.
- Hypothesis 2: I predicted that at institutions that did provide communication on OA, it would focus predominantly on impacts to animals, with fewer connections to humans.
    - I predicted this because OA is an issue where impacts to humans are not directly visible in the same way as the impacts of other climate change issues, such as global warming or sea level rise.
- Hypothesis 3: I predicted that there would be a geographic disparity in the prevalence of OA education.

    - Specifically, I expected that institutions in regions more threatened by OA, such as the Pacific Northwest, would be more likely to discuss OA than those elsewhere.
- Hypothesis 4: I further predicted that there would be a geographic disparity in the type of information included in OA communications.
    - I expected that institutions in regions more threatened by OA would utilize place-based or local connections to the issue more often, leading to more interest in the issue by visitors.
- Hypothesis 5: I predicted that most institutions would promote personal, often ineffective actions as solutions to combat OA, rather than community or societal-level actions.
    - This prediction comes from patterns of ocean change communication which have centered individual action over communal action in an attempt to provide more immediately actionable solutions, even if they are less effective.
- Hypothesis 6: I predicted that most institutions would report significant limitations in their ability or willingness to communicate OA.
    - Research previously identified staff knowledge of OA and perceived audience interest as barriers preventing staff at nature-based museums from communicating about OA; I predicted that these barriers persisted, despite the increase in resources to encourage staff to communicate about these issues (Swim et al., 2017). I further predicted that the increased

politicization of climate change since Swim et al.'s data was collected would increase barriers to communicating about this issue directly.

This analysis provides both a catalog and review of current OA communication strategies across the country, which can be used to determine the most common communication strategies at informal education centers across North America and to identify shortcomings in communication.

1.3.2 Point Defiance Zoo & Aquarium Case Study: Furthermore, I performed a case study at the Point Defiance Zoo & Aquarium (PDZA), surveying visitors to PDZA to measure their understanding of OA, its local impacts, and possible responsive actions. The survey intended to determine how visitor knowledge changed after exploring an exhibit containing information on the local impacts of OA. In contrast to previous studies of visitor response to OA communication at nature-based museums, which utilized direct interventions, this case study attempted to investigate how visitor knowledge and empowerment changes during a passive exploration of exhibits discussing OA. This was done to more closely emulate a visitor's experience at a marine education center.

Going into the case study, I developed three hypotheses:

- Hypothesis 7: I expected visitors to have a relatively low level of awareness and understanding of OA.
    - I predicted that this would be true, despite visitors being in a region where OA's impacts are comparatively more prominent, based on the relative lack of understanding of this issue by the public.

- Hypothesis 8: I predicted that visitors' understanding of OA's causes, local environmental impacts, and impacts to humans would increase following their visit.
    - I expected this to occur due to the availability of OA education in the exhibit.
- Hypothesis 9: I predicted that visitors with place-based ties to the region would be more likely to engage in long-term, community-based actions to combat OA,
    - I predicted this due to an expectation that visitors would be motivated by their elevated level of risk and their heightened connection to the region.

This qualitative research provides for specific analysis of the prevalence and effectiveness of OA communication in the Salish Sea region, identifies levels of public understanding, and informs future conservation and management practices regarding OA to be in line with public perception and values. Developing this understanding of OA communication in the Puget Sound is essential in driving urgently-needed, community-informed action against threats to coastal ecosystems and peoples.

1.3.3 Outcomes: Ultimately, this research addresses several important goals. First, this research helps to showcase how members of the public perceive, understand, and want to address OA. By determining how OA is currently being communicated and suggesting improvements, a more robust analysis of public opinion regarding ecosystem management can be accomplished. Additionally, this project underscores the connections between OA, climate change, and local communities, while revealing shortcomings in how these connections are being communicated to the public. Finally, this project provides a metric to determine the success of communication efforts around a major climate impact affecting the Puget Sound.

Through this research, I intend to produce a clearer understanding of how OA is currently being communicated at informal education centers, what strategies are particularly effective, and how communication can be tailored in the future as OA increases in impact and intensity. This understanding can then be used to inform updates to future OA communication strategies at informal education centers, particularly those in the Puget Sound. By identifying shortcomings in OA communication, new values to emphasize, and effective tools, more effective outreach can be conducted by aquariums in the region, a critical role as OA increasingly threatens the community.

Meanwhile, decision-makers including policymakers, local officials, agencies, and conservation groups can be further aware of how their communities feel about OA and related conservation management decisions. Through the increased knowledge of the public's awareness and opinions about and responsive actions, future adaptation and mitigation efforts can be better supported and implemented. The findings in this research can also inform OA communication strategies at formal education facilities (schools and universities), as well as offer a template for more effective climate and environmental communication in general.

Notably, increasing effective communication tends to facilitate representation of the voices of those in underrepresented communities. By determining where shortcomings in communication lie and where community understanding is incongruent with expert understanding, the perspectives of vulnerable communities will be uplifted and catered to in future work. This is especially true for communities that do not engage with the scientific community, but do come across informal marine education, including youth.

2. Guiding Methods

2.1 Positionality and Methodologies:

2.1.1 Positionality: Throughout this analysis, it is important to emphasize my positionality, and any biases that may influence my research. I am a Filipino-Korean man who recognizes the disproportionate impacts of ocean change on low-income communities of color. I believe that environmental justice and societal action are essential in equitably and effectively addressing the climate crisis. Notably, I am not myself reliant on fish or shellfish for cultural or economic subsistence. However, I was born and raised around Puget Sound, a region where OA-threatened species have extreme levels of cultural, economic, and subsistence value. In fact, my interest in OA stems from my connection to Puget Sound, and the heightened impacts observed around the Pacific Northwest.

Professionally, I interned at the National Oceanic and Atmospheric Administration (NOAA) Ocean Acidification Program (OAP) as a Hollings Scholar. While at OAP, I worked on several OA communication initiatives, including on a project in conjunction with the International Alliance to Combat Ocean Acidification and the Aquarium Conservation Partnership to increase place-based education on OA at aquariums. Working on this project inspired me to undertake this research into the scope and effectiveness of OA communication at marine education centers, and I acknowledge it as an influence on my work.

Furthermore, I acknowledge that my position as an early-career member of academia at the University of Washington alters my privileges and limits my perceptions. However, I am committed to ensuring that this research is made accessible to any people, organizations, and communities interested in learning about, expanding upon, or applying these findings.

While all of these factors have certainly influenced my research, I believe that I have designed and presented reasonable, data-driven analyses.

2.1.2 Methodologies: This project relies on a transformative methodology, intending to produce materials that can be used to inspire direct societal change, both in how scientists and science communicators discuss OA, and how more people from more diverse backgrounds can be motivated to take meaningful direct action against OA and its impacts.

The project is also built from constructivist roots, specifically in my experience as a science communicator on ocean acidification, a person of color, and a biological and chemical oceanographer. I have witnessed firsthand the barriers facing the communication of ocean acidification, and want to work to further develop that understanding through this project. Thus, I am focused on investigating the bridge between science and action through communication, and am coming to this analysis with the assumptions that this linkage is necessary, underemphasized, and faces barriers, especially in reaching out to non-scientists and underrepresented groups.

Transformative and constructivist methodologies are easily adaptable into producing tangible change and offering a less detached version of analysis, but are thus heavily informed by opinion and experience. Such bias is important to note. However, my analysis is supported by both qualitative and quantitative data, enabling a better understanding of both people's personal experiences and observations, as well as having statistics to back up conclusions.

3. Catalog of OA Communication at Informal Marine Education Centers

3.1 Methods:

3.1.1 Data Collection: To create a catalog of existing ocean acidification communication at marine education centers, I conducted a series of interviews with informal marine education centers. For this study, informal marine education centers refer to non-academic institutions that offer public-facing marine education, including aquariums, science centers, museums, and visitor centers for national parks, marine sanctuaries, and reserves. It may also include some aquatic parks if they include a focus on marine education. This study was limited to institutions in the United States and Canada to encompass English-speaking audiences in North America.

I compiled an initial roster of institutions for interview requests by reviewing the list of marine institutions affiliated with the Association of Zoos and Aquariums, the Aquarium Conservation Partnership, and the NOAA Coastal Ecosystem Learning Centers (CELC) network. I additionally reached out to institutions associated with the Community Marine Centers of the Salish Sea to uplift more local institutions around the Puget Sound. Relevant institutions were narrowed by whether they had at least one prominently featured exhibit discussing marine conservation or marine life. For each institution that fit, I searched public websites to collect contact information of media, communication, or education staff when available. Otherwise, I collected general contact information or public request forms. I then emailed or called each institution individually with a request for a short interview about how the institution communicates about ocean change. CELC and NNOCCI additionally helped with outreach by directly sharing the request with their networks.

Interviews were predominantly conducted over synchronous virtual calls and were semi-structured following the guiding questions provided in Appendix A. Interviewees were

provided the guiding questions beforehand, but during the interview, I manually filled in responses to their interview questions on their behalf. However, the interview was informal and conversation was allowed to flow naturally. If follow-up questions were needed or if individuals were unable to join a call, an asynchronous digital form was provided as an alternate data collection method.

3.1.2 Data Analysis: Data was collected in Google Forms and transferred to Microsoft Excel for qualitative and quantitative analysis. Interviews were qualitatively coded for overlapping themes manually and quantitatively compared within Excel. Significance was measured when appropriate through chi-square tests for categorical data. No Large Language Model-based artificial intelligence tools were used for this analysis.

3.2 Results:

3.2.1 Overview: 34 institutions agreed to be interviewed, including 23 aquariums, eight marine science centers or museums, and three visitor centers for reserves, parks, or estuaries (Figure 1).

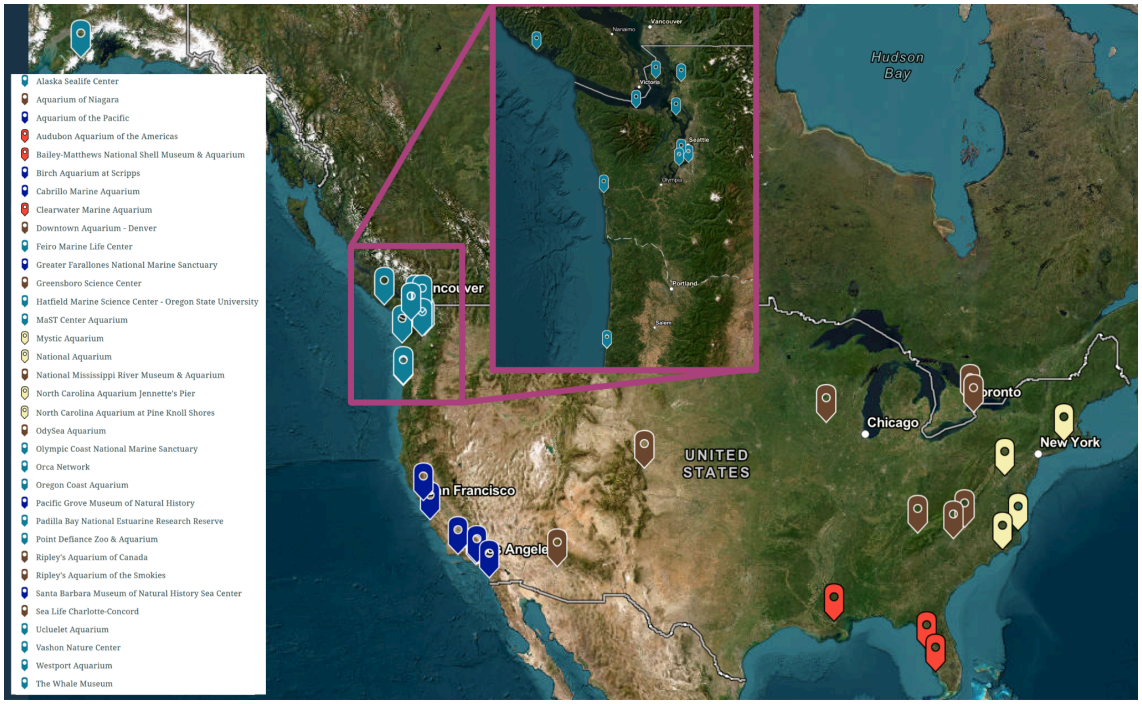

Figure 1: A map of interviewed marine education centers. A legend appears on the left with the institutions sorted alphabetically, and an inset bordered in pink shows the Pacific Northwest in more detail. MEC locations are represented by pins with colors corresponding to their geographic categorization. Aquamarine represents PNW institutions, blue represents other West Coast institutions, red represents Gulf Coast institutions, yellow represents East Coast institutions, and brown represents landlocked institutions.

A full list of participating institutions is in Appendix B. Note that while some MECs are identified with a numerical tag in the following pages, these numbers do not correspond to any public list or ranking, including alphabetical. Each MEC was categorized geographically into one of five mutually-exclusive regions:

1. Pacific Northwest (PNW): institutions within 100 miles of the coast between Northern Oregon and Alaska;

2. West Coast: institutions within 100 miles of the coast between Southern Oregon and California;
3. Gulf Coast: institutions within 100 miles of the Gulf Coast;
4. East Coast: institutions within 100 miles of the U.S. East Coast;
5. Landlocked: institutions not within 100 miles of any coast

Interviewees had the option of declining to answer questions for any reasons, meaning that sample size per question varies. Most interviewees worked in the education department for their respective institution, but other interviewees came from the engagement, communication, exhibit design departments, as well as a few executive directors of the institution.

3.2.2 OA in Broader Context: When asked to describe "what topics related to ocean change, if any, does your institution talk about," MECs responses varied widely.

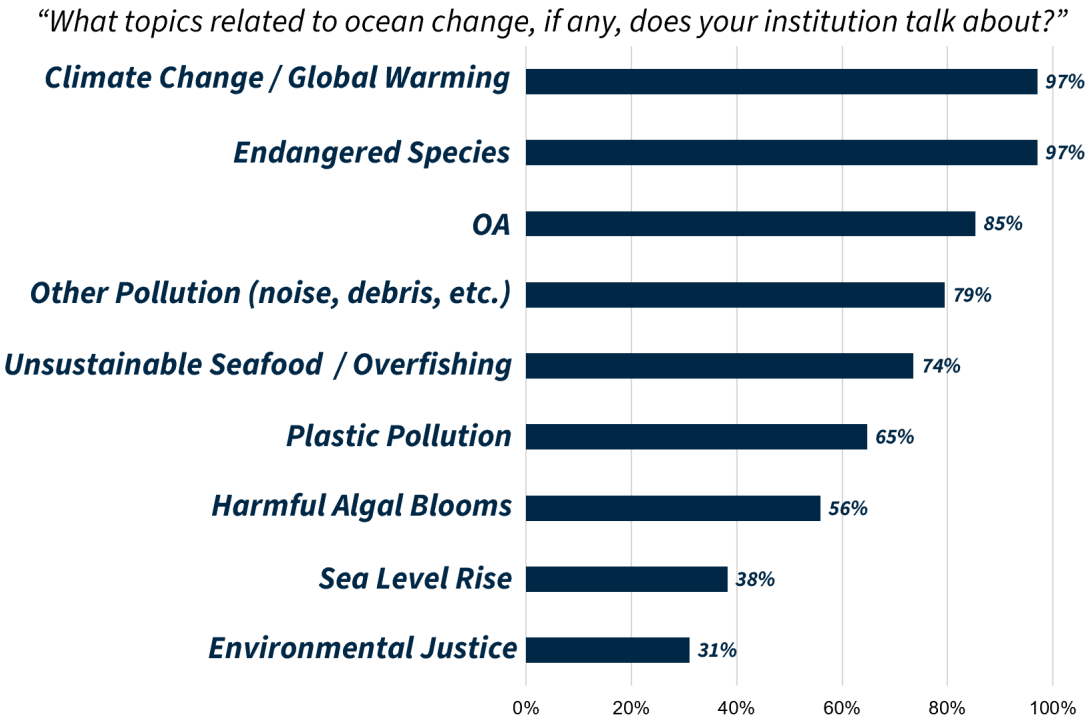

Figure 2: A bar chart displaying what percent of interviewed MECs (n = 34) discuss specific ocean change issues. Interviewees were asked "What topics related to ocean, if

any, does your institution talk about?" and answers were sorted by the interviewer into the above nine categories, which were chosen based on prior assumptions of the most commonly-discussed ocean change issues. Percentage on the x-axis.

Of these nine ocean change issues identified by the interviewer as the most prominent, "Climate change / global warming" and "Threats to endangered species" were tied as the issue mentioned at the most MECs, both being represented at 33 out of the 34 MECs (Figure 2). "OA" was the next most prevalent ocean change issue, being mentioned at 29 MECs, followed by "Non-plastic pollution" such as chemical pollution or noise pollution (27 of 34), "Overfishing / unsustainable seafood" (25 of 34), "Plastic pollution" (22 of 34), "Harmful algal blooms" (19 of 34), and "Sea level rise" (13 of 34) (Figure 2). All of these issues, except "Environmental justice" (EJ) and "Sea level rise" were mentioned at over 50% of MECs (Figure 2).

"Environmental justice" as a broad concept was the least discussed ocean change issue, being brought up at only 31% of MECs (9 of 29) (Figure 2). One interviewee explained that their communicators at their institution have "wrestled with EJ but have not figured it out" (*MEC 11*). Notably, several interviewees emphasized that there was a desire for EJ to become more of a focus going forward, given its importance and lack of visibility outside of one-on-one discussions. One interviewee described how "you might not see it evidently in the exhibits" even though "environmental justice is built in" to their organization (*MEC 15*). Even at an organization currently including external-facing programs about EJ in their communications, educators "don't always use the term" (*MEC 14*). When EJ was mentioned, it often related to disproportionate impacts of ocean change on coastal or Tribal communities.

However, others mentioned that environmental justice messaging is scaled back due to fear of political retaliation. One interviewee who noted that "[t]here is a strong push (not just at

this institution, but in most I've seen) to convey all things in a positive, non-critical light. I have seen a remarkable shift, too, in the last 15 months away from EJ and climate with the current federal regime. Institutions are scared of backlash, scared of loss of funding prospects, and perhaps are taking the easier route to just not address DEI/EJ at all" (*MEC 24*).

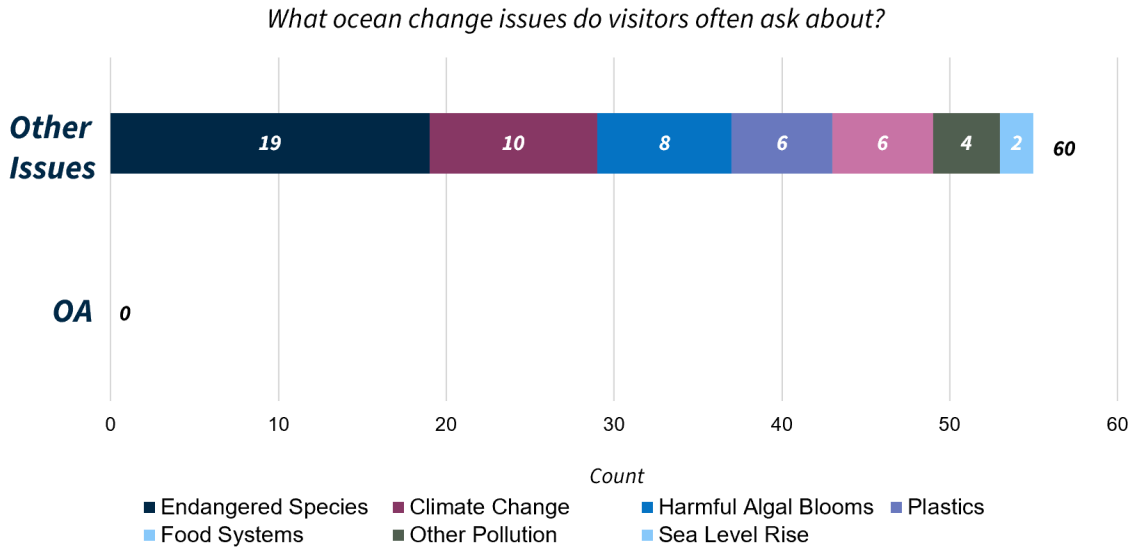

Figure 3: A stacked bar chart showcasing interviewee (n = 34) responses to the question "What ocean change issues do visitors often ask about?" Counts are on the x-axis. Answers mentioning "OA" are compared to mentions of all other issues. A legend is included at the bottom of the graph.

When interviewees were asked "Do visitors ever express interest in learning more about ocean change? Which specific topics?," "Threats to endangered species" was the most common response, being mentioned by 56% of respondents (19 of 34) (Figure 3). One interviewee theorized questions were prompted by the idea of "charismatic megafauna" (*MEC 2*) or the "animals they can visually see" in the exhibits (*MEC 3*). "Climate change" and "Harmful algal

blooms" were the only other issues to be mentioned by more than 20% of respondents, at 29% (10 of 34) and 24% (8 of 34) respectively (Figure 3). Notably, OA was never listed as an issue that visitors would often ask about (Figure 3). One staff member connected this to the fact that ocean change questions were "usually about current events" such as if a harmful algal bloom was happening (*MEC 5*). Meanwhile, 21% of interviewees (7 of 34) expressed the opinion that questions related to ocean change happened so rarely to not be significant. In reference to being asked about ocean change issues, one interviewee remarked that "I've never had anybody say it unprompted" (*MEC 2*).

3.2.3 OA Communication at MECs: Most institutions reported providing some form of communication about OA. When asked if the institution provides "any public-facing communication or education about ocean acidification," 88% (30 of 34) institutions answered "yes" (Figure 4). The locations who answered "no" vary in size, geographic location, and mission, but generally ascribed the lack of extant communication to perceived audience or staff interest.

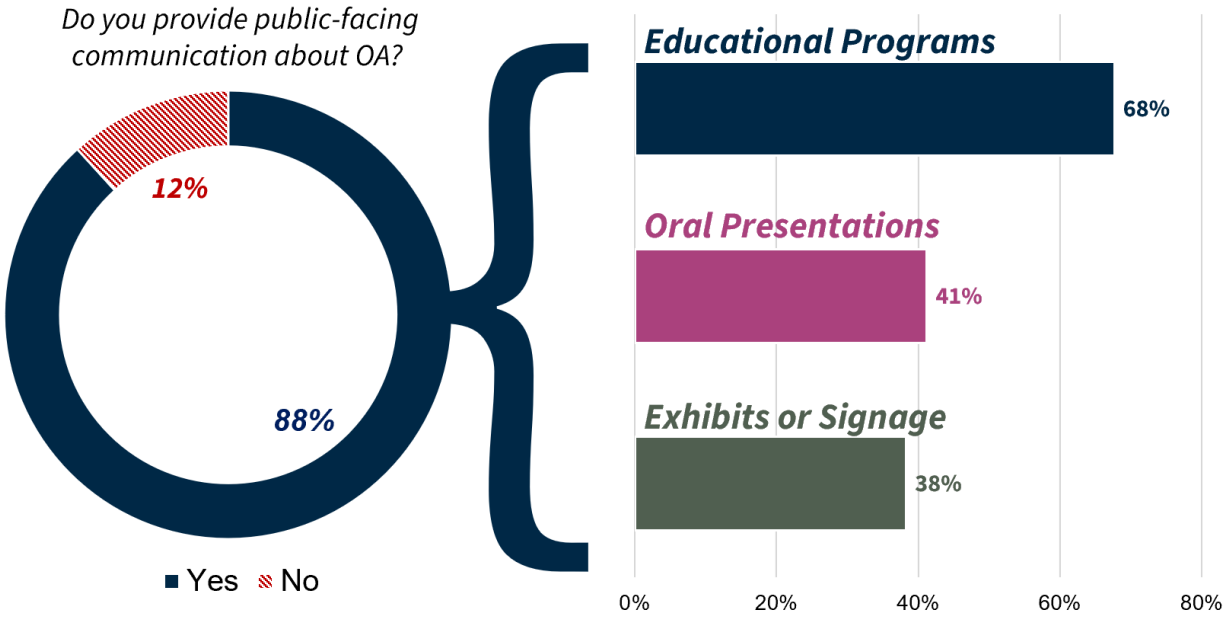

Figure 4: A combined pie chart showing interviewee responses (n = 34) to the question "Do you provide public-facing communication about OA?" and bar graph breaking down the type of communication medium by percentage of the MEC responded "yes." 36 different pieces of OA communication were analyzed in the bar chart, and percentage is on the x-axis.

Of the institutions that provided OA communication, the medium through which the communication was delivered often varied. 68% of institutions said that they provided OA communication through "Educational Programs" not limited to the facility itself such as through visits to schools (Figure 4). An example includes a "Coral workshop for young kids and high schoolers" (*MEC 3*). 41% reported providing OA communication through oral presentations or conversations at the facility, such as one institution which hosts an "ocean science lecture series which sometimes touches on OA" (*MEC 16*) (Figure 4). 38% reported discussing OA through physical signage or exhibit materials. One institution mentioned an "in person panel" which "talks about OA and how that impacts invertebrates by breaking down shells" and how that impacts charismatic megafauna (*MEC 15*) (Figure 4). Together, there were 36 different examples of OA communication, as institutions were able to provide OA-centric messaging in multiple mediums.

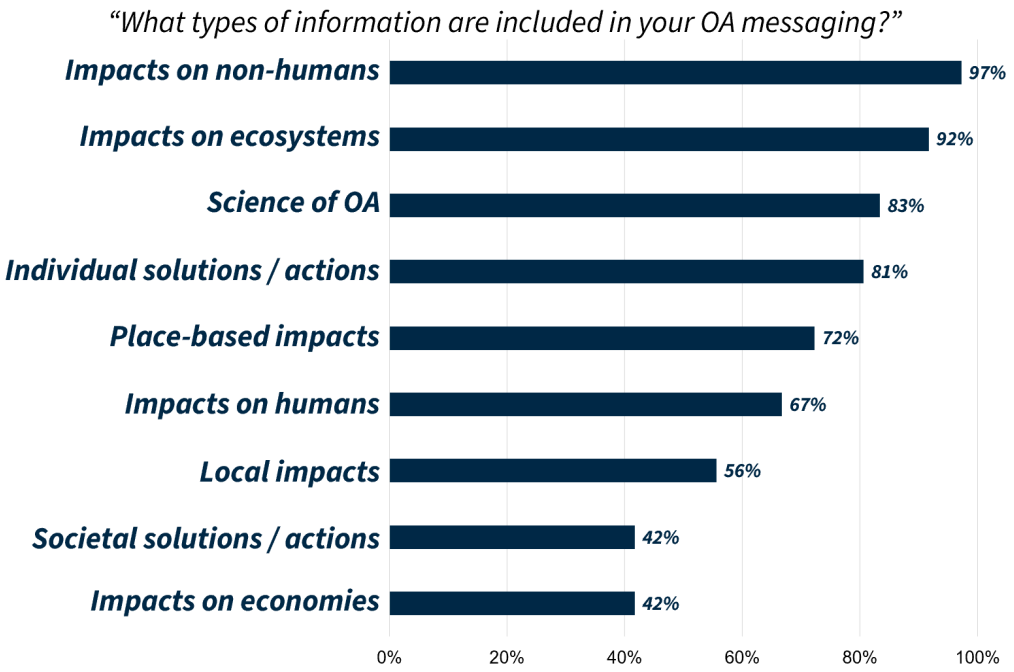

Figure 5: A bar graph showing the prevalence of certain types of information included in MEC OA messaging (n = 36), based on interviewee responses to the question "What types of information are included in your OA messaging. The percentage of communications which include each type of information is on the x-axis.

When analyzing the 36 examples of OA communication collectively, 97% included information about the impacts of OA on "non-humans" including animals, plants, and the environment (Figure 5). Corals and shelled organisms were the most commonly cited specific non-humans mentioned. 92% included information on ecosystem impacts, or how impacts to specific species could cause cascading impacts on other non-human organisms (Figure 5). 83% of communications included some information on the actual science of OA, although usually limited to the basics of the process (Figure 5).

72% of communications used place-based case studies as part of their strategies, and 56% of communications further included local impacts of OA in their education (Figure 5). An

example of how one institution provides this information is intentional discussion of how local fishers are being impacted, and "if that is impacting you, how does that impact the community, and how does that impact businesses reliant on those fisheries as well" (*MEC 20*). One institution mentioned that their communications are place-based, "but the biggest impacts…are not always local," which makes it " hard to do advocacy" (*MEC 15*).

67% of communications mentioned impacts on humans and 42% mentioned economic impacts specifically (Figure 5). One interviewee emphasized that they "try to connect everything to human impact" including by discussing how impacts to specific local species affect the "major fishing fleets" in the area (*MEC 20*). In contrast, another reflected on how this disparity in discussion of impacts on human societies was an intentional choice: "Economics are talked about sometimes," they said, "but almost never first go to," as usually it is just focused on "ocean change broadly" (*MEC 14*).

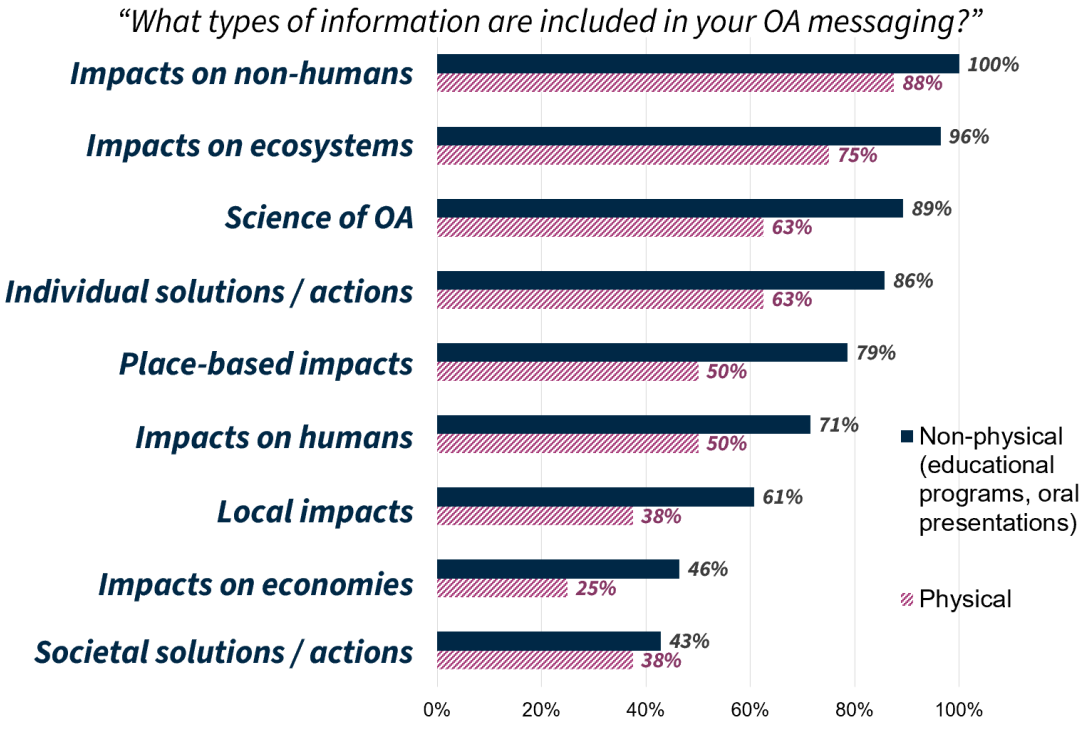

Figure 6: A bar graph comparing the prevalence of certain types of information included in MEC OA messaging in different communication mediums, based on interviewee responses to the question "What types of information are included in your OA messaging. The percentage of communications which include each type of information is on the x-axis. Non-physical communication (n = 28) is shown in solid blue and physical communication (n = 7) is shown in striped pink.

Notably, non-physical communication pieces (n = 28) were routinely more likely to provide information than physical communication (n = 7) across all categories analyzed (Figure 6). For instance, the "Science of OA" was discussed in 89% of non-physical OA communication examples, compared to only 63% of physical communications, a 26% gap (Figure 6). "Place-based impacts" had a similar disparity, being discussed in 79% of non-physical and 50% of physical communications. "Impacts on economies" dropped by nearly half, from 43% in non-physical messaging to 25% in physical.

The geographic location of the MEC led to disparities in the inclusion of certain information. MECs were grouped into five regions: Pacific Northwest (including Alaska) (n = 13), West Coast (non-PNW) (n = 6), Gulf Coast (n = 3), East Coast (n = 4), and Inland (defined as greater than 100 miles from the ocean) (n = 8). The small sample size of most of these categories must be noted when considering the following analysis. MECs in the PNW and West Coast were collectively analyzed as MECs in areas "Threatened" by OA while MECs found on the Gulf Coast, East Coast, or Inland were deemed as being connected to areas "Less Threatened" by OA.

There was little significant difference in whether an MEC talked about OA based on geographic location ($p > 0.8$) (Figure 7). Excluding the Gulf Coast, place-based education was

utilized at a similar rate (an average of 78%) across geographic locations (Figure 7). MECs in the PNW, East Coast, and West Coast saw the highest rates of discussing local impacts of OA at 86%, 75%, and 67% respectively (Figure 7). Local impacts were only discussed 33% of the time at Gulf Coast MECs, and 14% of the time at Inland MECs. Although not significant, PNW MECs were more likely to discuss OA ($p = 0.14$), place-based impacts ($p = 0.22$), and local impacts ($p = 0.25$) than Inland MECs (Figure 7). The difference in discussion of local impacts is 70% (Figure). MECs in "Threatened" regions appeared more than twice as likely to mention the local impacts of OA than MECs in "Less Threatened" areas, although this finding is not statistically significant ($p = 0.49$) (Figure 7).

Geographic Comparison of the Prevalence of OA Communication, Place-based Messaging, and Local Messaging

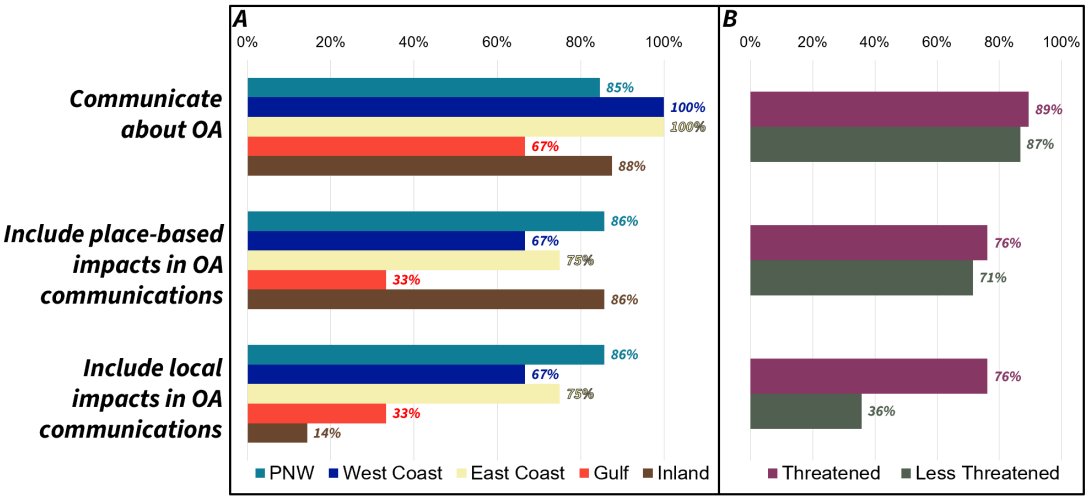

Figure 7: Bar graphs showing the percentage of MECs that reported including OA communication, place-based messaging in OA communications, and messaging about local impacts in OA communications, broken down by geographic location of the MEC. Percentage is on the x-axis. A: Geographic breakdown according to five regions, with PNW in aquamarine (n = 13), West Coast in blue (n = 6), East Coast in yellow (n = 4), Gulf Coast in red (n = 3), and Inland in brown (n = 8). B: Geographic breakdown

according to whether the MEC is in a region "Threatened" by OA (PNW and West Coast) in pink (n = 19) or in a "Less Threatened" region (Gulf Coast, East Coast, and Inland) in green (n = 15).

3.2.4 Recommended Solutions: Broadly, solutions were categorized into two categories: "Individual solutions/actions" and "Societal solutions/actions." "Individual solutions/actions" encompassed recommendations focused on change at the level of an individual. Commonly cited examples by interviewees included reducing personal waste, reducing personal emissions, and talking to others about OA or climate change. Individual solutions were provided as part of messaging 81% of the time, in 29/36 pieces of communications (Figure 8).

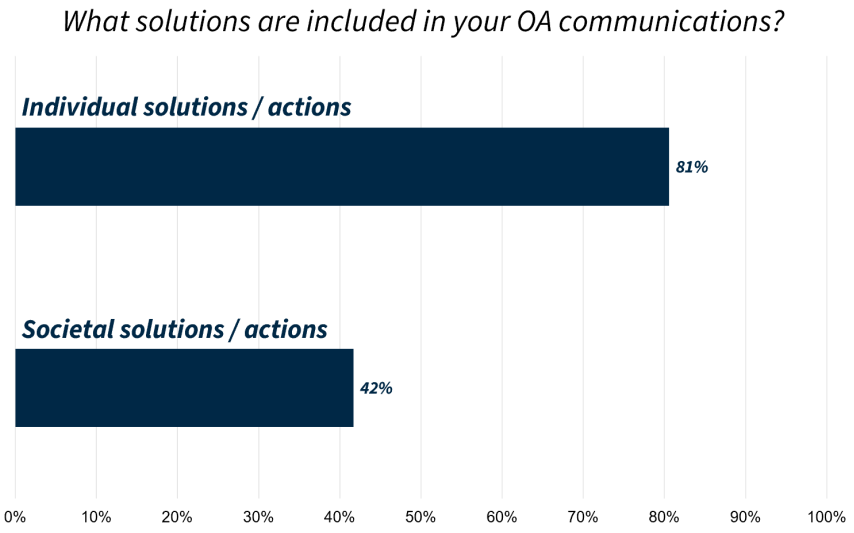

Figure 8: A bar graph comparing the prevalence of individual-level and societal-level solutions in OA communications (n = 36) at interviewed MECs. The percentage of communications mentioning each type of solution is on the x-axis.

"Societal solutions/actions" refer to recommendations intended to explicitly create change at a level greater than one individual, either at a community or societal level. Although

individual actions can lead to societal change, solutions in this category were meant to explicitly engage in actions that would directly impact others on a communal level, rather than on individual or household levels. Some examples which were mentioned in messaging include supporting specific pro-environment policies, supporting a transition to renewable energy, or engaging in large-scale habitat restoration. Based on this categorization, 42% (15/36) of examples of OA messaging included societal solutions, about half the amount that included individual messaging (Figure 8).

MEC staff were asked if the fossil fuel industry was cited as a "driver of emissions." Of the 23 MECs that responded to this question, only 26% stated that they explicitly cite the fossil fuel industry as a driver of emissions (Figure 9). 17% said "yes" but with caveats such as only mentioning it in conversations with certain audiences or situations (Figure 9). The majority (57%) of MECs explicitly did not cite the fossil fuel industry as a driver of emissions (Figure 9).

Do you cite the Fossil Fuel Industry as a driver of emissions?

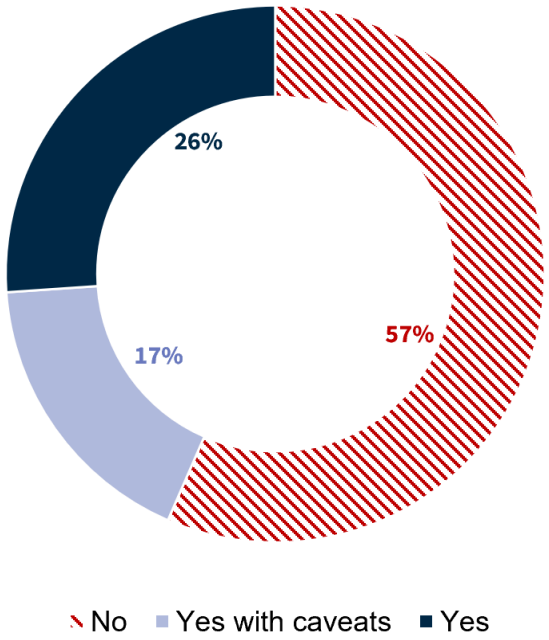

Figure 9: A pie chart showing interviewee responses (n = 23) to the question "Do you cite the Fossil Fuel Industry as a driver of emissions?" A legend appears at the bottom of the chart, explaining that "Yes" appears in blue, "Yes with caveats" appears in periwinkle, and "No" appears in striped red.

Several institutions noted a difficulty in prescribing solutions based on their audience. For example, targeting solutions at youth was repeatedly cited as something difficult, especially when combined with feelings of "doomerism" or the sense that there is no point in taking action due to the inevitability of climate disaster. Other institutions noted that OA-specific solutions were difficult due to the lack of local impacts.

3.2.5 Source of Information: 27 MECs provided an answer to the question where they "get the information needed to inform" their OA communication. The most common response, at 21 of 27 or 78%, was "Academia," including directly accessing peer-reviewed journal publications and connections with researchers. This was followed by the "Federal Government," usually NOAA, with 56% (15 of 27). 10 MECs cited "Non-profits or Non-governmental organizations" as a source of information and eight credited other aquariums or MEC networks like AZA as a source of information.

3.2.6 Staff Knowledge: Interviewees were asked several questions pertaining to staff and volunteer knowledge of OA intended to analyze how well equipped public-facing educators could explain OA to guests. Staff are generally considered to be longer-term employees of the MEC, and often receive additional training and responsibilities, while volunteers are often seasonal, less experienced, and unpaid.

Interviewees were asked if their institution "provide[s] any internal communication about OA to staff or volunteers." Of the 31 interviewees who answered this question, 23 (74%) said

"yes," and eight (26%) said "no." The internal communication ranged from one-off talks from researchers, NNOCCI trainings on how to OA and climate change communication best practices, and information included in onboarding trainings.

Interestingly, three MECs specifically noted that the interview request inspired more discussion of OA and prompted the scheduling of internal OA education for staff and volunteers. For example, a staff member at one aquarium shared that they scheduled a "lunch and learn to teach people about [OA]" because the interview request "sparked a big conversation throughout the aquarium" and revealed gaps in OA communication proficiency (*MEC 22*).

Most interviewees struggled to give a definite response to the question of "How much do you think public-facing staff/volunteers know about OA?" as the internal variance for staff and volunteer knowledge was perceived as too high to give a single estimate. When asked to estimate "What % of staff can explain OA well? What % of volunteers?" responses varied wildly. Of the 19 interviewees to provide an answer for this question, seven estimated that 100% of public-facing staff would be able to communicate OA "well." All of the institutions with this estimate are located in either the Pacific Northwest or the East Coast. In contrast, another seven estimated that the percentage of staff that could communicate OA "well" was 50% or less. The geographic distribution of these MECs ranged included PNW, East Coast, Gulf Coast, landlocked, and West Coast institutions. Other interviewees chose qualitative estimates including "a good percentage" (*MEC 14*) and "most" (*MEC 13*). All estimates for the proportion of volunteers that could explain OA "well" were below 33%.

Interviewees tended to define being able to communicate OA "well" as being able to describe the cause and the impacts on species and the ecosystem to a general audience, but not the chemistry. One interviewee emphasized that they "do not ask that anyone memorize exact

chemistry, more that people can conceptualize what is going on, since you aren't talking chemistry with the guests" (*MEC 14*).

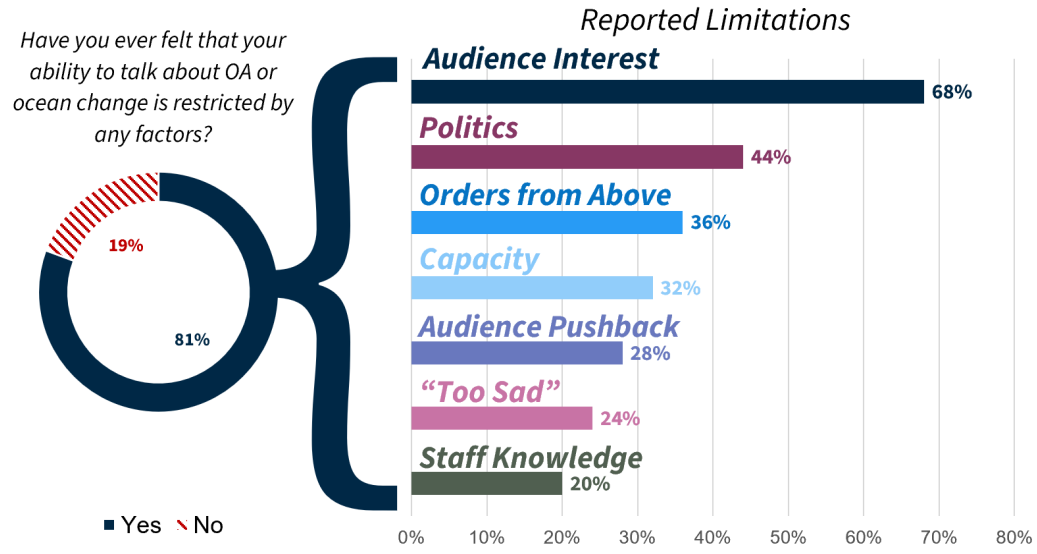

Figure 10: A combined pie chart showing interviewee responses (n = 31) to the question "Have you ever felt that your ability to talk about OA or ocean change is restricted by any factors?" and bar graph breaking down the reported limitations of the MECs who responded "yes" (n =22). The percentage of interviewees who mentioned each limitation is on the x-axis.

3.2.7 Communication Restrictions and Limitations: 31 interviewees answered the question "Have you ever felt that your ability to talk about OA or ocean change is restricted by any factors?" 22 interviewees explicitly said that "yes" they had felt restricted in some way. An additional three did not explicitly say that they felt restricted, but went on to describe ways they felt restricted or limited in their ability to communicate OA or ocean change. Thus, 25 of 31 interviewees, or 81% of interviewees, described feeling restricted in their ability to communicate

OA or ocean change, compared to only 19% (6 of 31) not feeling restricted in some way (Figure 10).

Perceived audience interest was the most commonly reported barrier to discussing OA or ocean change (Figure 10). 17 different interviewees mentioned that they limited their discussion of ocean change due to a belief that visitors to their institution were there to have a fun time rather than to learn or that visitors simply did not have the attention span to learn about ocean change. As one interviewee put it, many communication decisions were informed by the belief that "sometimes people are just here to see animals in an aquarium," which impacts whether topics such as ocean change or OA are brought up (*MEC 3*). Another interviewee explained that "we want people to feel welcomed and not lectured to, so there is some hesitancy to bring things up," (*MEC 21*). This is exacerbated by the fact that there is only a limited time to engage guests and topics like OA or ocean change take a bit longer to fully explain.

Specifically, 24% of interviewees (6 of 25) mentioned that they tended to avoid discussion of OA or ocean change because it felt too gloomy and they wanted to present a message of hope that felt incongruent with the state of OA (Figure 10). One interviewee said that they "personally feel like priorities to talk about ocean change have fallen off because it became really hard to not be doom and gloom" (*MEC 9*). Another interviewee, one of the six who reported not feeling limited or restricted in their ability to communicate ocean change, noted that because "kids have lots of climate anxiety" their institution has done a lot to "try to emphasize hope" (*MEC 17*). Because they believe that "kids feel more hopeful when out doing the work," and they need to "realize there is a future in this work, they have worked to balance being honest about environmental change with offering opportunities for uplifting tangible, place-based work (*MEC 17*).

Furthermore, seven interviewees cited audience pushback as a factor limiting their ocean change communication (Figure 10). This differs from audience interest in that it stems from a fear of direct confrontation, rather than an assumption of general uninterest. Some interviewees reflected on specific demographics that had pushed back in the past, including *MEC 6* explaining that there had been "pushback from the fishing community a little bit," and *MEC 7* noting that "guests have been combative," as they "may work for the oil and gas industry" which is a big presence in the area.

An interviewee affiliated with *MEC 14* mentioned that "some staff have felt intimidated to talk about climate change" as they were "spooked by the potential audience reaction, especially under the [Trump] administration." This overlaps with the second-most common reported limitation: politics. 44% of interviewees (11 of 25) mentioned some form of political pressure as something that limited their ability to discuss ocean change as freely (Figure 10). This includes federal funding cuts, limitations on accepted messaging from the federal government, and restrictions from state governments. One interviewee highlighted how they were being forced to operate "with a lot of caution because of political pressure" (*MEC 5*) while another pointed more to how "institutional change" at both the state and local level is "getting worse rather than better due to budget cuts" (*MEC 6*). Six institutions specifically mentioned changing language around climate and ocean change topics to avoid retribution from the Trump Administration. *MEC 8* shared how "new restrictions on language" have "trickled down a little bit," and "people have tried to get ahead of [the Trump Administration] by preemptively changing language."

36% of interviewees (9 of 25) mentioned that orders from bosses or funders were limiting their ability to discuss ocean change freely (Figure 10). *MEC 18* noted that ocean change

communication had been reduced over “Management’s trepidation over entering into topics people find unpalatable” including the “climate change conversation” which had been deemed “a political positioning.” When it comes to funding, institutions were asked “How much does your institution’s funding source influence exhibits?” and over 40% of responding interviewees (13 of 25) indicated no meaningful influence. Only two interviewees implied complete control. However, several interviewees described how funding sources could influence their educational material. For example, *MEC 2* said that they don’t mention climate change in their exhibits because they “have to walk a fine line to avoid upsetting donors,” and “don’t want a donor to come by and say ‘hey, this is attacking my business.’”

32% of interviewees (8 of 25) listed capacity issues, including time, funding, and staff, as limiting their ability to discuss OA or ocean change more (Figure 10). One MEC emphasized that the biggest limitations to talking more about OA were “space, time, and money, not intentional exclusion” (*MEC 1*). This sentiment was especially prevalent as an impact to smaller institutions. Finally, 20% of interviewees (5 of 25) emphasized staff knowledge as a factor restricting communication of OA (Figure 10). *MEC 3* cited “training for staff/volunteers needing the knowledge to properly talk about it” as something that was currently missing, and *MEC 6* said that their key issue to overcome is that they “need more access to education for staff.”

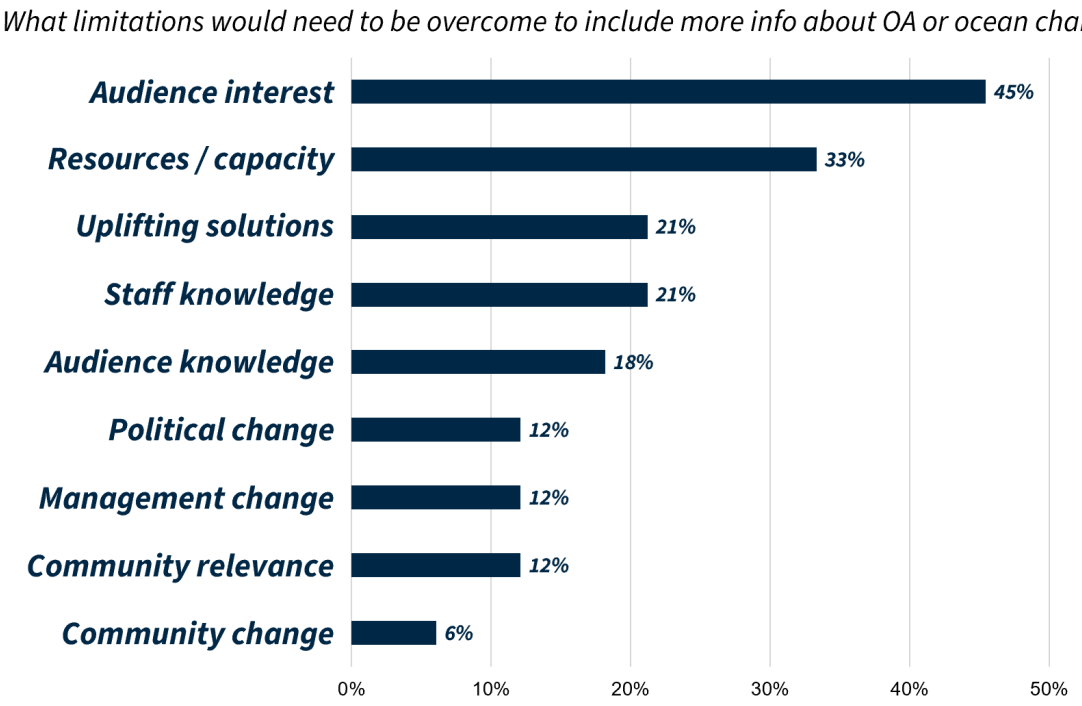

Figure 11: A bar graph breaking down interviewee responses to the question "What limitations would need to be overcome to include more info about OA or ocean change" by how often each limitation was mentioned. The percentage of interviewees who mentioned each topic is on the x-axis.

When asked "What is the key barrier to overcome to include more OA/ocean change comms?," the most common response was expressing the need for a change in perceived audience interest, being mentioned as a critical issue by 45% (15 of 33) of respondents (Figure 11). One interviewee mentioned the difficulty in "trying to frame it in a way to convince people to care" and questioned how to balance providing information with preserving hope (*MEC 15*).

33% of interviewees (11 of 33) said that the key issue to overcome is a lack of resources, such as "space, time, money" (*MEC 1),* "internal bandwidth" (*MEC 14*) or "space for signage" (*MEC 21*) (Figure 11).

Increasing staff knowledge and uplifting solutions were each cited by 21% of respondents (7 of 33) (Figure 11). One interviewee stated that "the only limitation is volunteer and staff knowledge level" (*MEC 15*). Another respondent mentioned how "pairing problems with solutions and giving people opportunities for action is important" to combat the "fear that guests don't want to hear about hard stuff" (*MEC 16*). In both cases, staff reported feeling ill-equipped to provide the necessary information.

18% of interviewees mentioned a need for audience knowledge to increase (Figure 11). While this often included discussion of how to communicate the pH scale, it was not just in terms of OA. Several respondents, including *MEC 11*, said that "our science education system K-12 across the country, however, is pretty abysmal and people are not getting a good science education" which is inhibiting their ability to comprehend the processes driving ocean change and OA. Finally, a need for political change, change in management, and increased community connection to OA were each mentioned by 12% of respondents (4 of 33) (Figure 11).

4. Point Defiance Zoo & Aquarium Case Study

4.1 Methods:

4.1.1 Data Collection: To collect information on visitor knowledge of OA in response to OA communication, I collected surveys from visitors at the Point Defiance Zoo & Aquarium (PDZA). PDZA was selected as a candidate for this case study based on size, popularity, relevant exhibits, and aligned research goals. Other candidates included Seattle Aquarium and Vancouver Aquarium, but both declined to participate. The aim of these surveys was to capture how much people have passively learned during trips to local aquaria about a critical ocean issue to the region, ocean acidification, in order to improve how OA is communicated to the public.

Survey design occurred with support from the UW Center for Statistics and the Social Sciences. The survey was designed to be completed in less than 10 minutes, and predominantly used likert scale, checkbox, or short answer responses. Any questions where participants could select from multiple options in a list were randomized to avoid bias, except “Unsure,” “None,” and “Other: [Fill in your own]” always appeared as the final options when included. The full survey is available in Appendix C.

To do this, I conducted exit surveys inside the PDZA’s Pacific Seas Aquarium exhibit. Survey-takers were compensated with a $10 virtual gift card to encourage broader participation. The Pacific Seas Aquarium was recommended for this study based on the relevance of educational material within the exhibits. Notably, the Pacific Seas Aquarium includes a digital touch screen which displays several stories related to blue carbon, including a story entitled “Oyster Acid Trip” which details what OA is and how it impacts local communities, especially those dependent on oysters. Photos of the display are included in Appendix D. OA is also

reportedly a topic of discussion by some touchpool exhibit volunteers, as several species within the touchpool, including Pacific mussels, are impacted by OA.

While stationed at an intersection before the primary exit to the aquarium, but after the exhibits in which OA is discussed, I set up a table from which I asked visitors if they were willing to complete a short, anonymous survey about their knowledge of ocean change and what they learned at the aquarium. A script for my ask is also available in Appendix C. Visitors were offered a $10 virtual gift card for survey completion, which was shared over email. If visitors agreed to complete a survey, they were offered the choice to take it virtually on their own device using a provided QR code, complete a paper copy of the survey, or have me conduct the survey orally. The survey was not timed, and did not require visitors to stay in one place during survey completion, as long as I could verify that each participant only filled out the survey once. No identifying data was connected to specific surveys.

Demographic data was collected by asking respondents if they "belong to any of the following communities:"

- Educator
- Student
- Fishing community
- Tribal / First Nation / Indigenous communities
- Tourist
- Local to the area
- Youth (under 18)

Survey-takers were allowed to select multiple demographics. These demographics were selected partially based on demographics of interest from the NOAA Ocean Acidification Program

Stakeholder listening sessions which were meant to inform the NOAA Ocean Acidification Education Implementation Plan (Perotti, 2023). Surveys were only permitted to be taken by visitors above the age of 18. “Youth (under 18)” was included as an option when asking about demographics as an additional check for compliance with Institutional Review Board requirements for all survey-takers to be adults. Any surveys with the “Youth” demographic selected were discounted and destroyed.

Data collection happened from Thursday, March 26, 2026 to Sunday, March 29, 2026, meaning that data was collected on two weekdays and two weekends.

4.1.2 Data Analysis: Data was digitized into Google Forms and transferred to Microsoft Excel for qualitative and quantitative analysis. Identifying data was not collected in connection to survey results. Unless otherwise stated, questions left blank were discounted from the analysis, meaning that survey size per question varies. Answers indicating “unsure” in some way were included in the analysis. Qualitative survey questions were coded for overlapping themes manually and quantitative questions were directly analyzed all within Excel. Significance was measured when needed through chi-square tests and a Wilcoxon Signed-Rank Test. No Large Language Model-based artificial intelligence tools were used for this analysis.

4.2 Results:

4.2.1 Overview: 149 visitors filled out the survey over the course of four days, with 118 respondents opting for the paper option and 31 opting for the digital option. The largest demographic was “Local to the area” (n = 91), followed by “Student” (n = 35), “Educator” (n = 21), “Tourist” (n = 21), “Fishing community” (n = 4), and “Tribal / First Nation / Indigenous

communities" (n = 1). During data analysis, all survey-takers who did not select "Local to the area" were compiled to create a comparison group of "Non-locals" (n = 58).

Broadly, there were no significant differences between demographics, possibly due to the high variance in sample size between groups and the especially low sample size for most demographics. Thus, the following analysis generally consolidates all survey data across demographic differences, unless explicitly stated.

4.2.2 Most Concerning Ocean Change Issues: 137 respondents are included in the analysis of the question "What do you see as the top ocean change issues?," as blanks and surveys with more than three answers selected were excluded. "Plastic pollution" was the most commonly cited issue, being mentioned by 70% of survey-takers (96 of 137) with "Global warming / Climate change" being ranked second at 57% (78 of 137) (Figure 12). 18% of respondents (25 of 137 mentioned "Ocean acidification" as one of their top three issues, making it the 6th-most commonly cited issue out of nine (Figure 12). The disparity between these proportions was found to be statistically significant according to chi-squared expected frequency analysis ($p < 0.001$).

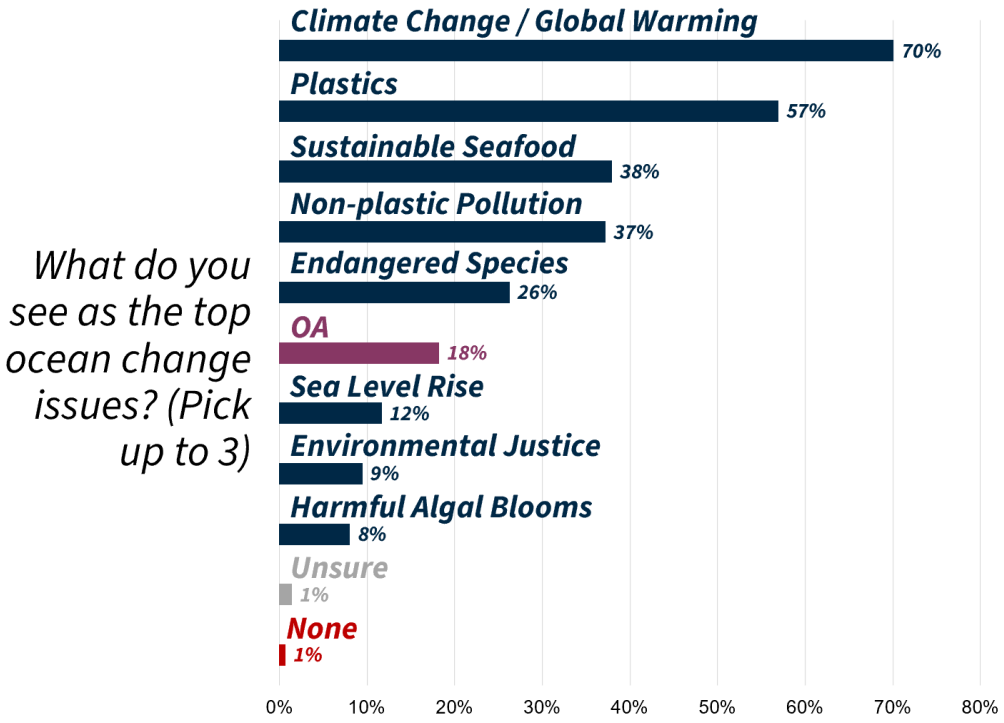

Figure 12: A bar graph breaking down survey responses to the question "What do you see as the top ocean change issues? (Pick up to 3)." Percentages on the x-axis indicate how often each issue was selected by one of the respondents (n = 137). "OA" is highlighted in pink, "Unsure" is in gray, and "None" is in red.

4.2.3 Understanding of Ocean Acidification: When asked "Which of the following do you see as a primary cause of ocean acidification" to test if survey-takers understood that the primary cause of OA is fossil fuel emissions, 148 respondents answered.

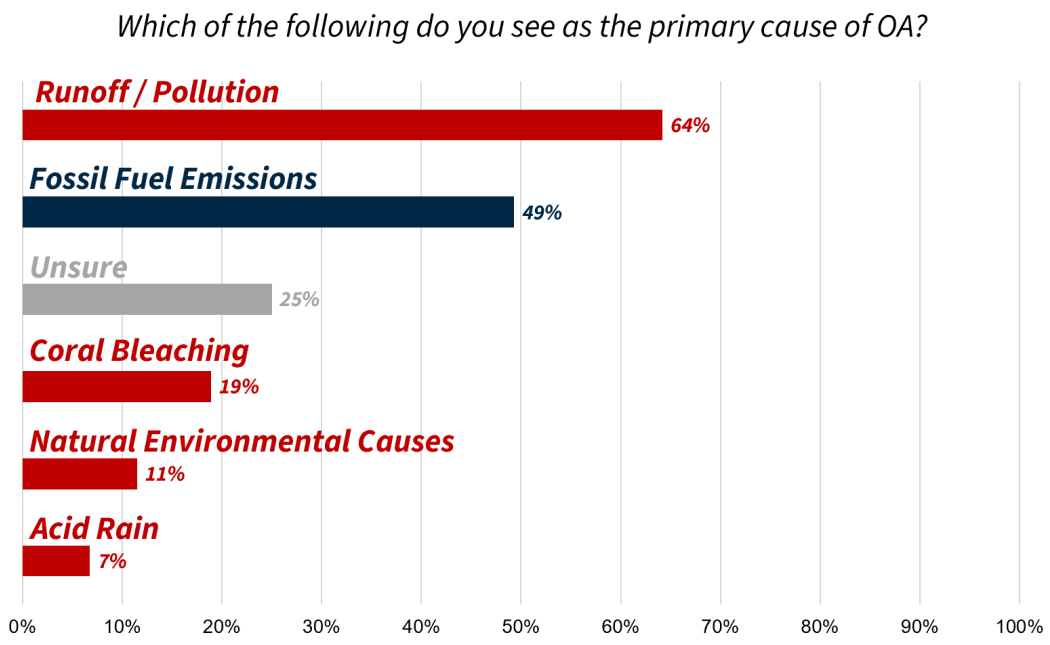

Figure 13: A bar graph displaying survey responses to the question "Which of the following do you see as a primary cause of ocean acidification?," broken down by percent of respondents (n = 148) who chose each answer on the x-axis. Incorrect answers are displayed in red, "Fossil Fuel Emissions" (the most correct answer) is in blue, and "Unsure" is in gray. Note that respondents could select multiple answers.

The most commonly selected answer was "Pollution / runoff," which was chosen as an answer by 64% of respondents (95 of 148) (Figure 13). "Fossil fuel emissions," the primary correct answer, was selected less than half the time (49%; 73 of 148) (Figure 13). 25% of respondents selected being "Unsure," 19% selected "Coral bleaching," 11% selected "Natural environmental causes," and 7% selected "Acid rain" (Figure 13). Of the 64 respondents who selected only one answer, 44% selected "Unsure," 28% selected "Pollution / runoff," and 22% selected "Fossil fuel emissions." In both groups, the majority of respondents failed to identify fossil fuel emissions as the primary cause of ocean acidification.

Survey-takers were further asked “How well did you understand ocean acidification (OA) **before** you visited the aquarium today?” and “How well did you understand ocean acidification (OA) **after** you visited the aquarium today?” to estimate how their understanding of OA changed due to their visit. 148 visitors answered, and selected from a qualitative likert scale with five options:

1. I've never heard of OA
2. I've heard of OA, but don't recall anything about it
3. I've learned / read about OA, but don't feel comfortable explaining it to others
4. I know some about OA, and I feel comfortable explaining the basic concept to others
5. I know a lot about OA, and feel comfortable explaining it in detail to others

Categories 1 and 2 were meant to capture those with essentially no knowledge of OA and Categories 3, 4, 5 captured varying levels of comfort with the topic.

The majority of survey-takers (63%) estimated that they fell into Categories 1 or 2 before their visit, meaning they had essentially no knowledge of OA (Figure 14). The largest group of respondents (33%) said that they had “never heard of OA” and an additional 30% of respondents said that they “don’t recall anything about [OA]” (Figure 14). 24% of respondents selected Category 3, indicating that they have learned or read about OA but don’t feel comfortable explaining it to others, while only a combined 12% felt comfortable explaining OA to others at a basic or detailed level (Figure 14).

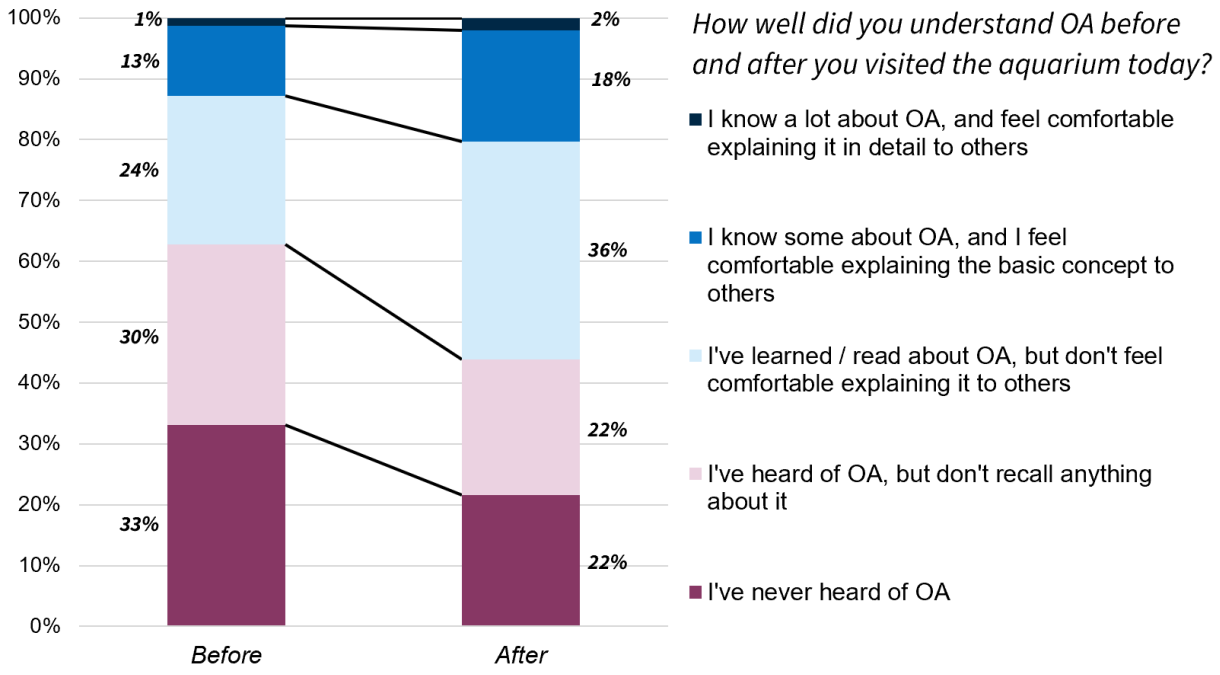

Figure 14: A stacked bar graph comparing the percentage of respondents (n = 148) who selected each option in response to the questions "How well did you understand ocean acidification (OA) **before** you visited the aquarium today?" and "How well did you understand ocean acidification (OA) **after** you visited the aquarium today?" The percentage of respondents is on the y-axis. Answers indicating low understanding are shown in pink, with darker indicating less understanding, while answers indicating more understanding are shown in progressively darker blue. The change is statistically significant according to a Wilcoxon Signed-Rank Test ($p < 0.001$).

Following the visit, only 44% of respondents fell into Categories 1 and 2, each dropping to 22% (Figure 14). Categories 3, 4, and 5 all saw increases, going to 36%, 18%, and 2% respectively (Figure 14). This also indicates that the proportion of people comfortable explaining OA to some degree increased by 8%. A Wilcoxon Signed-Rank Test reveals that the improvement in knowledge of OA following the visit to the aquarium was statistically significant

with a moderate effect size based on the probability of superiority for dependent groups test (PS_{dep}) ($p < 0.001$, z-score = 5.31, $PS_{dep} = 0.43$). Further discussion of statistical analysis is in Appendix E. However, 106 people, around 71% of respondents reported no change in their knowledge of OA.

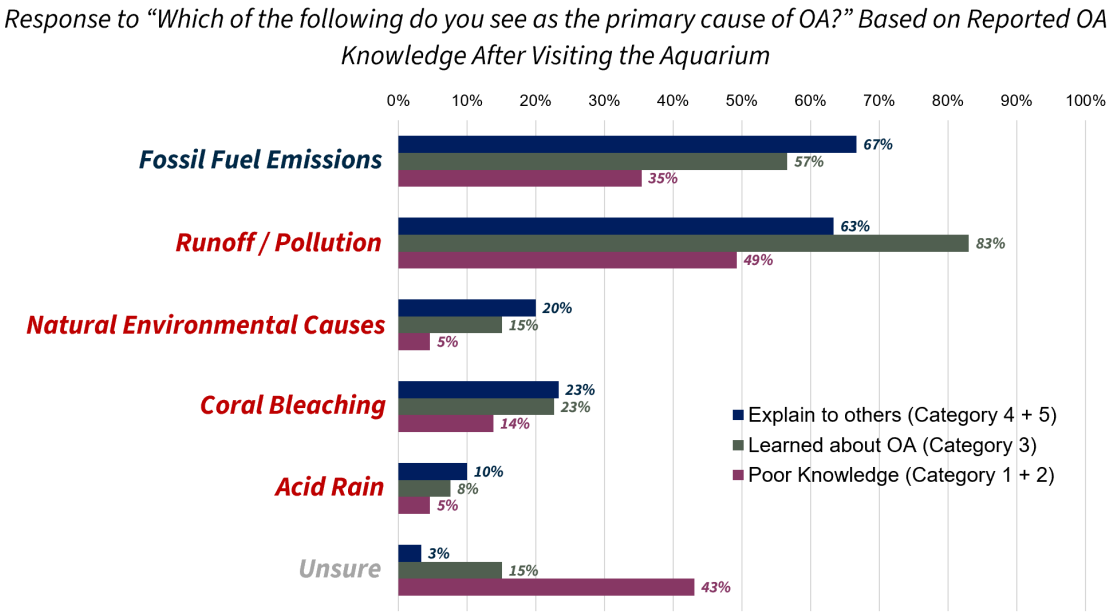

Figure 15: A bar graph breaking down survey responses to the question on "Which of the following do you see as the primary cause of OA?" based on what level of knowledge the respondent reported on the question "How well did you understand ocean acidification (OA) **after** you visited the aquarium today?" The percentage of respondents who selected each answer is on the x-axis. Incorrect answers are displayed in red, "Fossil Fuel Emissions" (the most correct answer) is shown in blue, and "Unsure" is in gray, although it should be noted that respondents could indicate multiple answers. Blue bars represent respondents in Categories 4 and 5 who indicated some level of confidence in explaining OA to other people, green bars represent respondents in Category 3 who indicated having

learned about OA but weren't confident in their ability to explain OA to others, and pink bars represent respondents in Categories 1 and 2 who have poor or no knowledge of OA.

To better verify these estimations, respondents' answers to the question about the "primary cause of ocean acidification" were analyzed based on their asserted knowledge of OA after the aquarium visit. Categories 1 and 2 were grouped together as "Poor Knowledge," Category 3 was alone, and Categories 4 and 5 were grouped as "Can Explain OA to Others." 67% of respondents in the "Can Explain OA to Others" group correctly identified "Fossil fuel emissions" as the primary cause of OA, compared to 57% of those in the "Learned about OA" group, and 35% in the "Poor Knowledge" group (Figure 15). Respondents in the "Poor Knowledge" group were 14 times more likely to indicate they were "Unsure" about the primary cause of OA than those in the "Can Explain OA to Others" group (Figure 15). These results demonstrate some level of validation in respondent's confidence rankings.

4.2.4 Local Impacts of Ocean Acidification on the Environment: In total, 94 respondents provided an answer to the question "describe any ways ocean acidification impacts the environment in this region (that you know of)," including five respondents who provided an answer equivalent to "Unsure" or "N/A."

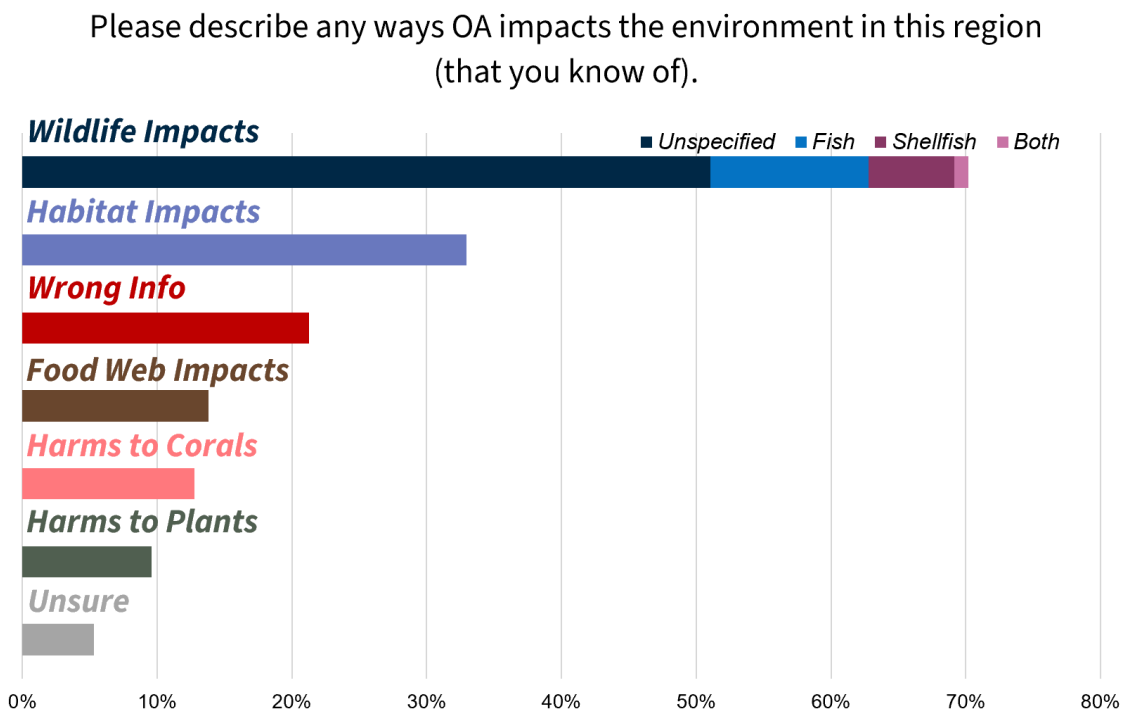

Figure 16: A bar graph breaking down survey responses (n = 94) to the question "Please describe any ways ocean acidification impacts the environment in this region (that you know of)." Count is on the x-axis. Note that respondents could indicate multiple answers. Answers mentioning impacts to "Wildlife" were further separated into a stacked bar graph to demonstrate which wildlife were mentioned, with mentions of fish being in light blue, mentions of shellfish in darker pink, and mentions of both fish and shellfish in lighter pink. Answers that did not mention specific wildlife are represented in blue. Answers mentioning impacts to the habitat are in periwinkle, answers including wrong information are in red, answers mentioning food web impacts are in brown, answers mentioning harms to corals are in coral, answers mentioning harms to plants are in green, and answers indicating "Unsure" are in gray.

The most commonly identified local environmental impact of OA was negative impacts on wildlife, being noted by 70% of respondents (Figure 16). 51% of total responses did not specify which wildlife would be impacted ("Dangers to animals and nature in this area" [*Survey 115*]), 12% specified impacts to (fin)fish ("I think it changes the food sources available for fish in the area" [*Survey 106*]), 6% specified impacts to shellfish ("Decreases oyster and other shellfish populations" [*Survey 104*]), and 1% specified both impacts to fish and shellfish (Figure 16).

Impacts to plants and corals were also tracked separately from impacts to wildlife. Harms to plants were mentioned by 10% of survey-takers ("reduction of fauna and flora in the kelp forest ecosystem" [*Survey 9*]) while harms to corals were mentioned by 13% ("animals with high calcium structures (coral, shells) cannot form as strong of structures" [*Survey 89*]).

21% of respondents included incorrect information in their response, often conflating OA with other ocean change issues such as coral bleaching, sea star wasting disease, and harmful algal blooms (Figure 16).

31 respondents (33%) mentioned impacts on the natural environment or habitat, including changes to ocean conditions more broadly (Figure 16). 13 respondents (14%) identified cascading impacts to the food web ("Impacts the food chain due to wildlife loss" [*Survey 34*]) (Figure 16). Not including the 55 visitors who left the question blank, five visitors indicated an answer equivalent to "unsure" (Figure 16).

4.2.5 Local Impacts of Ocean Acidification on People: 91 respondents described "any ways ocean acidification impacts **people** in this region (that you know of)," including six respondents who said an answer equivalent to "Unsure" or "N/A."

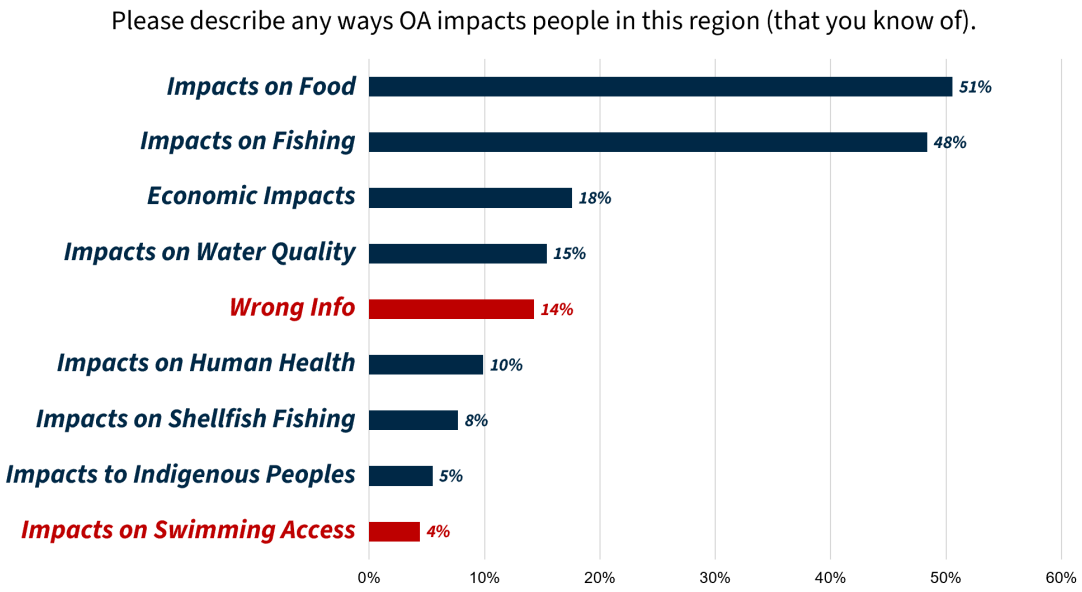

Figure 17: A bar graph breaking down survey responses (n = 91) to the question "Please describe any ways ocean acidification impacts people in this region (that you know of)." Percentage is on the x-axis. Note that respondents could indicate multiple answers. Answers mentioning incorrect assumptions of impacts are shown in red.

The majority (51%) of respondents mentioned impacts on seafood, ranging from noting how acidification is "reducing the amount of various food sources people rely on" (*Survey 109*) to the incorrect assumption that "Seafood can be dangerous to eat" (*Survey 75*) (Figure 17). 48% of respondents mentioned fishing or fisheries,and 8% mentioned shellfish specifically, such as how *Survey 16* mentioned that "It could impact fishing by decreasing the number of viable shellfish" (Figure 17). 5% of respondents mentioned impacts to Tribal communities, such as *Survey 9*, which notes that "It affects the local tribes that rely on fishing for food" (Figure 17). 18% of respondents mentioned economic impacts, often connected to declines in fisheries ("Loss of oysters affects jobs for people in Puget Sound oyster industry" [*Survey 104*]).

15% of respondents mentioned impacts from changing water quality and 10% mentioned impacts to human health (Figure 17). However, many of these answers contained misconceptions, including acidification making it too dangerous to interact with the water ("Maybe we can't swim or fish if it's too acidic" [*Survey 31*] or making seafood too dangerous to eat ("Makes the water and the life inside it toxic so unsafe for us to consume" [*Survey 123*]). Altogether, 14% of answers contained some amount of incorrect information (Figure 17).

4.2.6 Personal Impacts of Ocean Acidification: 89 respondents described "any impacts of ocean acidification that you perceive as a threat to **you or your community**." This includes nine respondents who provided an answer equivalent to "Unsure" or "N/A."

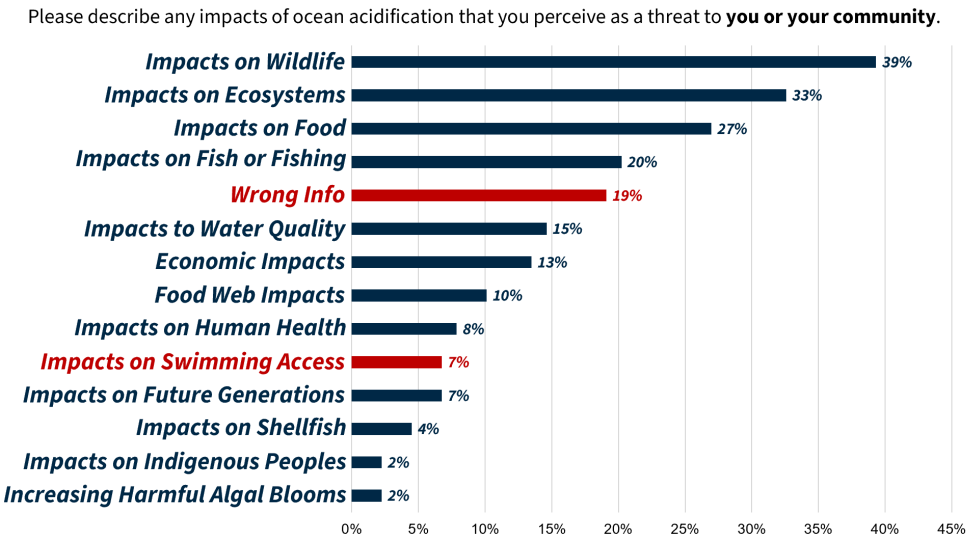

Figure 18: A bar graph breaking down survey responses (n = 89) to the question "Please describe any impacts of ocean acidification that you perceive as a threat to **you or your community**." Percentage is on the x-axis. Note that respondents could indicate multiple answers. Answers mentioning incorrect assumptions of impacts are shown in red.

The most common personal impact respondents identified were losses of wildlife (39%) or ecosystem services (33%) such as a loss of "Access to natural resources" (*Survey 94*) (Figure

18). Impacts to seafood were mentioned by 27% of respondents, 20% highlighted impacts to fishing or fishing communities, and 13% of respondents tied this to economic impacts ("Fewer fish means less food and fewer fishing jobs" [*Survey 102*]) (Figure 18). 7% of respondents also mentioned impacts on future generations or their children, such as concern that "My children may not have access to the ocean in the ways we do today" (*Survey 147*) (Figure 18).

15% of respondents mentioned water quality and 8% mentioned impacts to health (Figure 18). However, again, many of these responses contained misconceptions of the impact of OA, including "Poison food" (*Survey 93*) and "Algae makes it dangerous to swim" (*Survey 102*). 19% of all answers included incorrect information (Figure 18).

4.2.7 Combatting Ocean Acidification: 147 respondents filled out the question "which of the following actions could see yourself doing to combat the impacts of OA?"

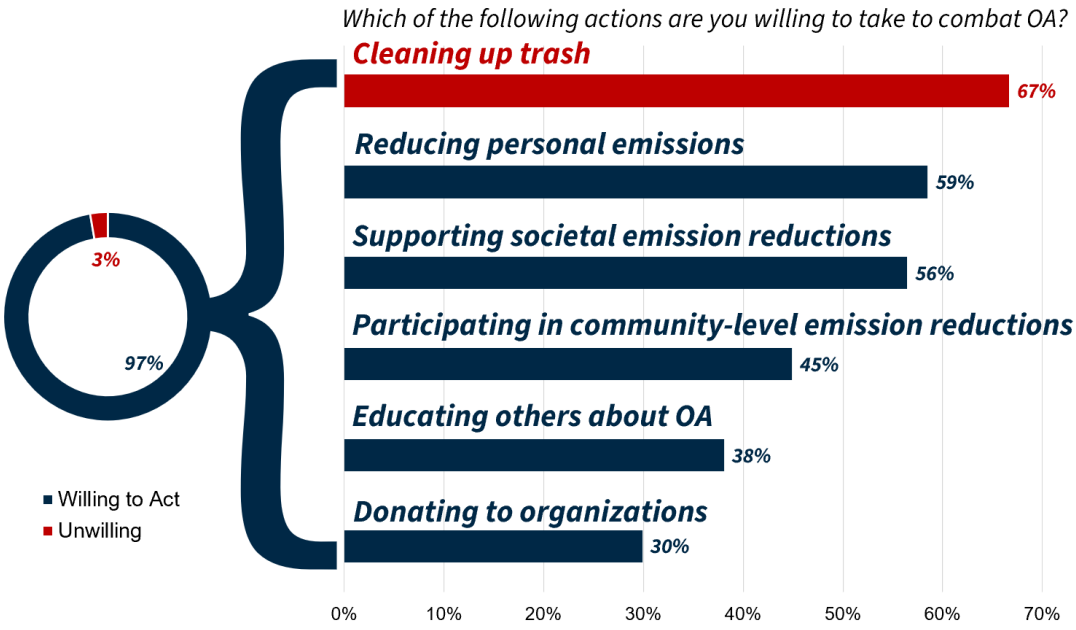

Figure 19: A combined pie chart showing survey responses (n = 147) who did **not** indicate "None" when asked "Which of the following actions are you willing to take to combat OA?" and bar graph breaking down the percentage of the respondents who

selected each answer. “Cleaning up trash” is shown in red as it does not directly impact OA.

97% of respondents (143 of 147) indicated a willingness to take at least one action, compared to only 3% (4 of 147) who answered “None” (Figure 19). The most commonly reported action that people were willing to take was “Cleaning up trash in local environment,” with 67% of respondents selecting this option (Figure 19). Notably, this action does not actually combat the impacts of OA. However, more than half of respondents also indicated a willingness to engage in “Reducing personal emissions” and “Supporting societal emission reductions” at 59% and 56% respectively (Figure 19). 45% of respondents also indicated a willingness to participate in “community-level emission reductions” such as community solar (Figure 19). 38% of respondents marked “Educating others about OA” and 30% marked “Donating to organizations” addressing OA (Figure 19).

While not statistically significant, a higher percentage of non-locals (5%) than locals (1%) answered “None” to this question (Figure 20). Meanwhile, locals were also more likely to signify willingness to engage in emissions reduction actions at all levels, as well as being more likely to signify willingness to educate others and donate to organizations addressing OA, although these results were also not statistically significant (Figure 20).

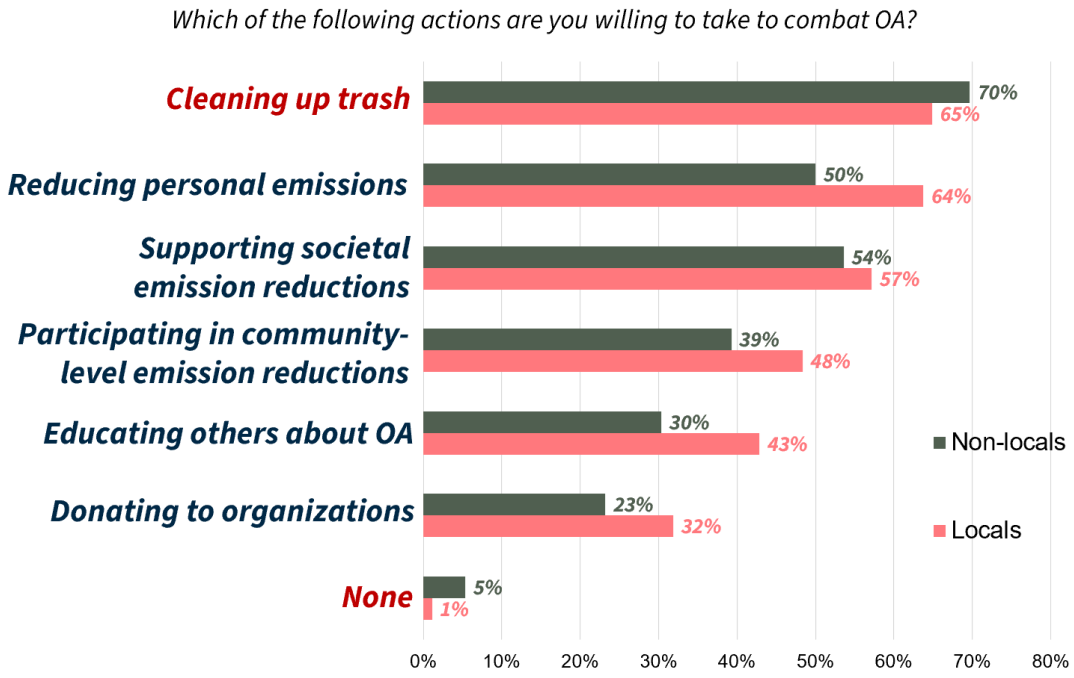

Figure 20: A bar graph showcasing survey responses (n = 148) to "Which of the following actions are you willing to take to combat OA?" broken down by whether respondents indicated they were "Local to the Area" or not. Percentage is on the x-axis. "Cleaning up trash" and "None" are shown in red as they do not address OA. Differences between non-locals and locals are not statistically significant.

4.2.8 Remaining Questions About Ocean Acidification: Respondents were provided a space to answer "What questions do you still have related to ocean acidification/ocean change?" and 88 visitors left a response.

The most common questions were variants of "What can we do?," which were asked by 23 respondents (Figure 21). Examples include "What can individuals do to combat it, and what should corporations be forced to do to combat it?" (*Survey 102*), "Is there anything I can do inside my home to help? How can kids help?" (*Survey 97*), and "Are there ways to mitigate

impacts and are there alternative options that are easy buy-in?" (*Survey 46*). Specifically, six people asked about reversing OA, such as "Is it reversible?" (*Survey 2*) and "What technologies are being created to reverse OA?" (*Survey 118*) (Figure 21).

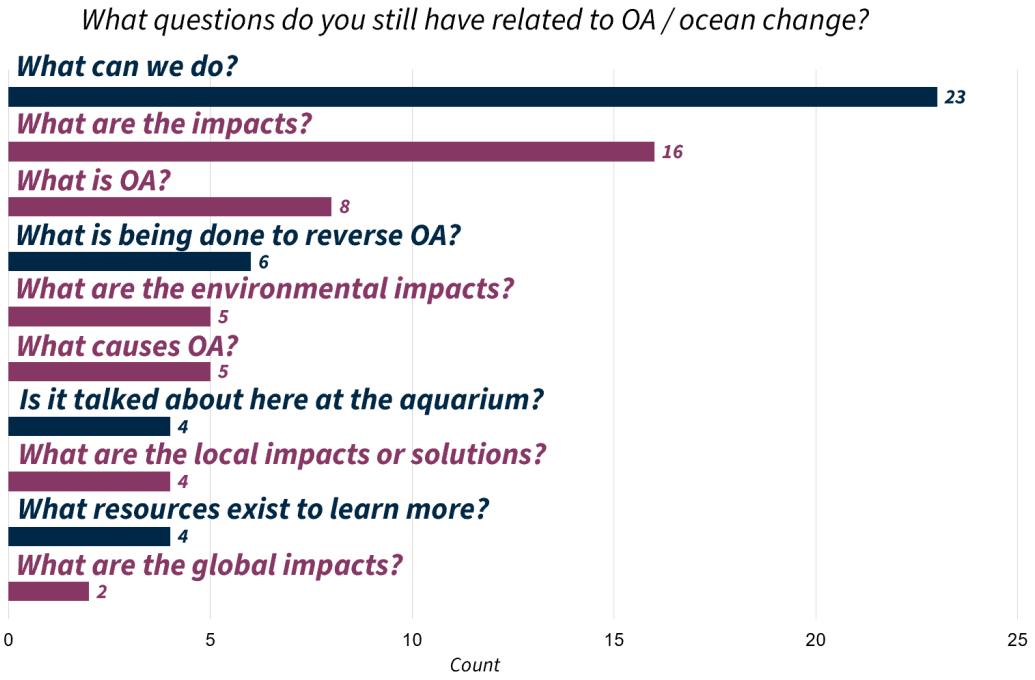

Figure 21: A bar graph showing survey respondents' (n = 88) answers to the question "What questions do you still have related to OA / ocean change?" Count is on the x-axis. Questions related to the OA's process or impacts are in pink.

16 respondents asked for further clarification on OA's impacts, either by asking broad questions like "What are its impacts or effects?" (*Survey 25*) or asking about specific impacts like "What might the long term impacts of ocean acidification be? Economic impacts from fishing or food chain impacts from species die-offs?" (*Survey 17*) (Figure 21). Five people asked specifically about environmental impacts ("What are the environmental effects? I know much more about climate change and sea level rise" [*Survey 10*]), and four asked about local aspects of

OA (“What really is impacting ocean acidification in the Seattle / Tacoma area?” (*Survey 50*) (Figure 21).

8 people asked a variant of “What is OA?” or signifying a lack of knowledge about OA (“I need to understand OA” [*Survey 85*]) (Figure 21). Five people specifically asked about what causes OA, such as *Survey 90* which says “Would like more info on causes and local effects” (Figure 21). Four respondents requested to know about resources to learn more about OA including asking “Is there a school lesson being taught” (*Survey 42*) and noting that “A documentary or seminar would be cool. A book for kids would be good. So if these sources exist, they should be widely shared.” (*Survey 72*) (Figure 21).

Finally, Four respondents asked if it would be possible to discuss OA more prominently at the aquarium, evidently having missed signage or conversations about OA (Figure 21). One respondent asked “Where in the aquarium do they discuss acidification?” (*Survey 147*), while another mentioned that “I would love to know more about ocean acidification and would be great to have signs discussing it in the aquarium!” (*Survey 92*).

5. Discussion

5.1 Discussion:

The following sections analyze whether each of the eight hypotheses are supported by my results. Sections 5.1.1-5.1.5 deal with Hypotheses 1-6, and mostly discuss data from the interviews with MEC staff. Sections 5.1.6-5.1.8 address Hypotheses 7-9 and predominantly discuss the visitor survey data.

5.1.1 Prevalence of Ocean Acidification as a Topic at Marine Education Centers (Hypothesis 1): Results from interviews with MEC staff failed to support the hypothesis that OA would not be a commonly discussed environmental issue at marine education centers. 88% of interviewees said that their institution provided some form of OA communication, and OA was one of the three most commonly discussed ocean change issues, following only "Climate change / global warming" and "Threats to endangered species." This represents a much greater proportion than expected based on public knowledge of OA (Cooke and Kim, 2018) and demonstrates the growing awareness of OA as an issue worthy of communication. I theorize that this increase in OA communication may be a product of OA becoming a higher priority from scientists, educators, and governments, exemplified for instance by the U.S. Ocean Acidification Action Plan released in 2023 (NOAA Ocean Acidification Program, 2023)..

However, the format of much of this communication is limited. Because only 26% of OA communications were in the form of physical exhibits or signage, the audience actually receiving information about OA is restricted. The predominant audience of OA communication would thus be students and school-age children through the educational programming that comprises the majority of OA communication at these MECs. Revealingly, many interviewees downplayed the prevalence of substantive OA information at the facility itself, such as describing how "with OA,

it is more here and there" rather than embedded (*MEC 12*), and that the impacts of OA are "not usually brought up as an initial talking point" in conversations with guests (*MEC 21*).

Interviewees also emphasized the difficulty in talking about OA, noting that "a challenge is abandoning the mentioning of pH or finding a way to talk about OA in a way that removes the dense details" (*MEC 19*). The complexity of communicating OA may lead to it being underdiscussed compared to other issues that are not as complex. This is reflected in the fact that, despite the prevalence of OA education, over a quarter of interviewees indicated that staff were not trained to communicate OA. Moreover, even places that did provide internal education about OA to staff did not provide them recurrently and/or make them voluntary. Thus, staff's ability to communicate OA was often limited to the basics. One interviewee reiterated this point by noting that while volunteers have enough knowledge of OA to communicate with young children, volunteers "may be uncomfortable explaining OA to anyone above fifth grade," (*MEC 10*). This reflects the disparity in who receives OA communication: targeted OA communication may be reaching schools, but aquarium guests. Some actually did note that OA is not a focus of guest communications compared to other issues. One interviewee "emphasized that part of the goal is to get people to understand the basics of climate change, so [we] haven't focused entirely on ocean acidification as a topic as much as some of the other basics of climate change" (*MEC 14*).

The apparent widespread nature of OA communication in MECs implies that MECs are building upon the opportunity to become leaders in communicating this issue (Meyer and Mott, 2014). However, it is difficult to determine if this is being received by a widespread audience. Additionally, the prevalence of OA communication at the MECs I interviewed may be inflated due to sampling bias, as institutions who discuss OA would be more willing to participate in an interview about OA. In fact, two institutions declined to participate in an interview, citing the

fact that OA is not a prominent focus of communications. Ultimately, evidence fails to support the original hypothesis of OA not being a widely discussed issue at MECs. However, rejecting this hypothesis does indicate that OA communication may be more widespread than expected.

5.1.2 Impacts on Non-Humans vs. Humans in Ocean Acidification Communication (Hypothesis 2): Interview results confirmed the hypothesis that OA communication would focus predominantly on impacts to animals, with fewer connections to humans. While 97% of OA communications explicitly contained information on impacts to non-humans only 67% mentioned impacts on humans, making non-human impacts around 1.45 times more commonly discussed. Similarly, ecosystem impacts were mentioned more than twice as often by MECs (92%) than impacts on economies (42%). These discrepancies demonstrate a focus on non-human impacts of OA, an idea underscored by one interviewee who emphasized that they were "not necessarily talking about OA in terms of foodweb and economic reliance" (*MEC 14*), another who said they were "unsure about impacts on humans or ecosystems or economies" (*MEC 21*), and a third who said they were "unaware of programs on OA that draw the line between ecosystems and people/economies" at their institution (*MEC 16*).

I theorize that this gap stems from the lack of direct impacts on most members of the public, outside of fishing communities. OA is a difficult process to tie to human impacts given that it is chemically complex and its impacts are not directly observable by the average person in the same way people can observe sea level rise, plastic pollution, HABs, or global warming. One interviewee reflected on how "a lot of people are overwhelmed by OA" as "for some people it is not tangible" (*MEC 6*). This gap may also stem from the assumption that visitors go to many MECs for the animals and do not want to necessarily learn, especially about things that are scary or depressing. Regardless, this hypothesis is supported.

5.1.3 Geographic Disparity and Place-Based Connections in Ocean Acidification Communication (Hypothesis 3 and 4): The prediction that there would be a geographic disparity in the prevalence of OA education, particularly between institutions in the Pacific Northwest and those elsewhere, was not generally supported by the results. OA was discussed fairly widely across different geographies, with no significant difference between most geographic regions. However, it should be noted that geography was cited as a reason for not focusing on OA in depth. An interviewee shared that when it comes to OA, their institution includes "nothing in physical exhibits because OA is not as big of an issue in [their region]" (*MEC 2*), and another noted that they "would need to have a very tangible thing to point to for the community to latch onto [OA]" as "there are other priority issues" (*MEC 7*). It is possible that this attitude is more widespread, but did not appear significantly in this study due to sampling bias decreasing participation from institutions that do not prominently discuss OA.

I further hypothesized that non-PNW institutions would fail to utilize place-based or local connections to the issue. There is more evidence for this aspect of the prediction, with local impacts being described in OA communications from PNW MECs more often than in Inland MECs. MECs from areas "Threatened" by OA like the PNW and the California Coast discussed local impacts twice as often as those in areas "Less Threatened" by OA. Many institutions did report effectively communicating about the ways OA impacts humans, including by focusing on local or place-based connections. One institution that utilized local impacts did it while "hoping to teach science while telling the local story of impacts" (*MEC 11*). Crucially, place-based attachment has a documented history of increasing the likelihood individuals will engage in pro-environmental behaviors, as it increases the affinity people have for their environment and encourages action to protect it (Scannell and Gifford, 2009). This concept has been applied to

increasing literacy around marine issues (Mothershed and Stilwell, 2025), including around OA in places such as the Pacific Northwest (Meyer and Mott, 2014). Place-based connections should be expanded going forward to increase general public engagement with OA communication.

Finally, I hypothesized that failing to use local or place-based connections would lead to less visitor interest in OA. This aspect of the hypothesis cannot be definitively supported. During interviews, MEC staff never reported OA as an issue visitors expressed interest in, regardless of geographic location. It seems possible that this is a reflection of the lack of knowledge members of the public have of OA in the first place (Cooke and Kim, 2018), rather than an explicit lack of belief that OA is serious, given how studies have shown that educating people about OA increases their belief that it is an issue to address (Capstick et al., 2016). As one interviewee put it: "People know about OA in practice but not in concept. But they might recognize effects in their area. We need to be more specific in examples to get things across" (*MEC 6*). However, this assumption cannot be confirmed using only my results.

5.1.4 Individual vs. Societal Solutions in Ocean Acidification Communication (Hypothesis 5): Results support the prediction that most institutions promote individual, oftentimes ineffective actions as solutions to combat OA, rather than community or societal-level actions. Many interviewees noted that OA messaging is not always connected to effective solutions or action items. Some noted that, in terms of solutions, they present "none specific to OA" (*MEC 10*). Around 40% of MECs mentioned recycling as a solution for instance, despite the fact that it has no substantial direct impact on OA. Others said that their OA messaging had "no specific actions" at all (*MEC 23*).

Because OA is driven by excess carbon emissions from the burning of fossil fuels, the most important way for people to mitigate OA is by supporting emission reductions (Jiang et al.,

2023). People can support reducing emissions on multiple scales, from individual actions (reducing personal emissions by consuming less energy or driving less), to community-level actions (contributing to community-solar projects), to societal actions (supporting a shift away from fossil fuels). MECs promoted all of these to some degree, but individual solutions were presented twice as often as communal or societal ones. Many MECs justified this disparity through an ideal of being more "tangible" (*MEC 6*) and "empowering," (*MEC 12*) especially for young audiences. However, while this is an understandable goal, communication can turn out to be disempowering if communicators are not providing honest information about what solutions are effective to combat OA. For instance, the fossil fuel industry is the source of the vast majority of carbon emissions, and has routinely engaged in attempts to push responsibility for emission reductions onto consumers. And yet, most MECs in this study did not mention the role of the fossil fuel industry in the climate crisis. If environmental communicators fail to acknowledge this fact and engage in the same work of treating the need to reduce societal and industrial emissions secondary to personal emission reductions, it risks making people feel deceived, unfairly attacked, or hopeless, while inhibiting progress in addressing key sources of emissions. This does not mean that discussion of individual actions should be abandoned, simply that they should be placed in context and built towards facilitating communal actions. Often, this is successfully done through placing an emphasis on local ways to take action as a community. This model works both for actions focused on mitigation (pushing people to vote for decarbonization rather than just turning off the lights) and adaptation (engaging in communal habitat restoration rather than just not littering). By uplifting the idea of communal change, and using individual actions as a pathway towards elevating communal consciousness, MECs can work towards balancing tangible and effective solutions. Some MECs are engaging in this type

of reframing already, choosing to emphasize that "it is important to do things in your own backyard, but more important is doing things at a community level and change" (*MEC 19*). Such a philosophy is important in empowering community members long-term.

5.1.5 Limitations to Discussing Ocean Acidification at Marine Education Centers (Hypothesis 6): My results supported the hypothesis that most institutions would report significant limitations in their ability or willingness to communicate OA. Over 80% of interviewees mentioned limitations or restrictions that impacted their ability to discuss OA or ocean change. Based on research from Swim et al. (2017), I predicted that staff knowledge of OA and perceived audience interest were major barriers preventing MECs from communicating about OA. This hypothesis was also generally supported by my research. Many interviewees mentioned utilizing resources from organizations like the Frameworks Institute or the National Network for Ocean and Climate Change Interpretation (NNOCCI) to encourage staff to communicate about these issues. However, 20% of respondents still mentioned "Staff knowledge" as a barrier to communication, indicating that there is a need to expand these resources to new staff and organizations who have not received a NNOCCI training. Meanwhile, "Perceived audience interest" remained the most commonly reported limitation to discussing OA or ocean change, being mentioned by 68% of interviewees. "There is still always going to be, because we are a public aquarium and we want people to feel welcomed and not lectured to, some hesitancy to bring things up first" reflected a staff member at *MEC 21*. However, it is important to emphasize that audience interest is only a *perceived* barrier. Research shows that visitors to nature-based museums expect and welcome conservation messaging (Ballantyne and Packer, 2016). In fact, zoos, aquariums, and other nature-based museums are seen as playing an essential and effective role in communicating around environmental change and conservation,

and tend to be especially trusted institutions among communities (Fraser and Switzer, 2021). Thus, although many environmental communicators are hesitant to discuss ocean change, evidence suggests that this has more to do with perceptions of visitors' interest, rather than reality. By providing communicators with confidence through increasing their knowledge and willingness to discuss ocean change subjects, this barrier might be addressed.

I further predicted that the increased politicization of climate change since Swim et al.'s data was collected in the mid-2010s would increase barriers to communicating about this issue directly (2017). This aspect of the hypothesis is also supported, as 44% of institutions mentioned politics as a restriction to discuss OA or ocean change, and 28% separately mentioned fear of audience pushback, due to political beliefs, as a barrier. Climate change has become increasingly politicized over the past quarter century (Ophir et al., 2024), and while OA was perceived as untainted by this politicization (Mott and Meyer, 2014), clearly communicators perceive it as a risk to discuss.

The Trump Administration has likely increased this perception. Six interviewees mentioned altering or removing language related to climate change or environmental justice, and the Trump Administration was explicitly named as driving that trend in three interviews. Loss of funding over political change was also commonly cited as a fear, sometimes in connection to changing language. For instance, one interviewee said that they "had to change 'climate' to 'environment' and 'underrepresented' to 'community'" because of the risk of losing funding (*MEC 19*). That representative underscored that "the science has been hijacked and politicized, so it is hard to discuss" topics related to ocean change, but in response, "the strategy has been thinking about the common values" such as "stewarding the land" (*MEC 19*). It is natural for educators at MECs to want to avoid political topics, especially in a funding environment where

becoming a political target could lead to an institution being unable to fulfill its mission. However, educators should also not shy away from discussion of ocean change due to politicization, especially because the underlying science is clear. Honest conversations about ocean change are essential in creating the social change necessary to preserve ecosystems and communities.

5.1.6 Visitor Awareness and Understanding of Ocean Acidification (Hypothesis 7): I expected visitors to have a relatively low level of awareness and understanding of OA, even in the PNW where its impacts are more prevalent. Previous studies highlighted a widespread lack of public understanding of OA (Cooke and Kim, 2018), so I expected this trend to be replicated in my results. When asked to estimate their initial knowledge of OA, the 63% of respondents selected an answer indicating essentially no knowledge of OA, with 33% having never heard of OA and 30% having heard the term but not knowing anything about it. While this is a lower percentage than the 80% who indicated knowing "little about OA" in Cooke and Kim's study (2018), possibly signifying elevated knowledge due to regional salience, this may just be biased by the fact that this survey was performed at an aquarium where there may be a higher proportion of people who are aware of ocean change issues or may indicate that fact that knowledge of OA has gone up over time.

When asked about specific elements of OA's cause and impacts, respondents demonstrated gaps in knowledge. The majority of respondents failed to identify fossil fuel emissions as the primary cause of OA. Instead, 64% of respondents believed that "Pollution / runoff" was the main factor behind OA, 25% said they were "Unsure," 19% said "Coral bleaching," and 7% said "Acid rain." If the majority of people are unaware of the cause of OA, it

may be very difficult to drive effective action. For the three questions about local impacts of OA, an average of 43% of respondents left the answer blank or said something equivalent to "I don't know," and 18% of those who did answer included wrong information. Very few contained any specific information, indicating a lack of understanding of how exactly OA may impact local ecosystems and communities. This is not even accounting for the fact that around 60 respondents left these questions blank, so were excluded from analysis. While these findings cannot necessarily be generalized given the limited scope of the sample, it still demonstrates a notable lack of understanding of OA, and offers evidence for this hypothesis.

5.1.7 Impact of Ocean Acidification Communication on Visitor Understanding (Hypothesis 8): I predicted that visitors' understanding of OA's causes, local environmental impacts, and impacts to humans would increase following their visit. This hypothesis was not supported. However, visitors' self-rated understanding of OA following the visit was significantly more than their self-rated understanding before ($p < 0.001$). Furthermore, this data was validated by comparing how many respondents in each category correctly identified fossil fuel emissions as the primary cause of OA. These findings would align with previous research on OA communication conducted by Swim et al., although that study utilized direct presentation of OA communication to an audience rather than allowing visitors to passively explore the aquarium (2017).

However, sources of potential error and bias exist for these data points. Multiple confounding variables exist, including time spent at the aquarium, level of education, whether the survey taker went to the aquarium alone or with children, and prior knowledge of OA. As prior knowledge was estimated, rather than using true before-and-after surveys, responses may be skewed by respondents' incorrect evaluation of their understanding of OA prior to their visit.

Respondents may have also biased their post-visit results to ensure that they could demonstrate improvement out of fear of judgement or embarrassment. Additionally, because this survey did not collect specific before-and-after information on how understanding of the causes and impacts of OA, I am unable to determine if the aquarium visit altered people's understanding of these aspects of OA. Therefore, the hypothesis is not supported.

5.1.8 Willingness to Engage in Ocean Acidification Mitigation/Adaptation Efforts (Hypothesis 9): Finally, I predicted that visitors with place-based ties to the region would be more likely to engage in long-term, community-based actions to combat OA, given their elevated level of risk and their heightened connection to the region. This hypothesis cannot be definitively supported. Overall, both locals and non-locals were overwhelmingly willing to participate in some level of action to combat the impacts of OA. Although not statistically significant, a slightly higher proportion of locals demonstrated a willingness to take actions that would actually address the causes and impacts of OA than non-locals, including personal emissions reductions, societal emissions reductions, community-level emissions reductions, educating others, and donating. In contrast, non-locals were more likely to select "Cleaning up trash," and "None" than locals. This trend is possibly an effect of an elevated level of place-attachment or a greater sense of responsibility to protect the region's ecosystems. However, as survey data from the case study only encompassed visitors to the PNW, there is no wholly accurate point of comparison across different levels of place attachment or geographies.

Regardless of place attachment, it should be highlighted that many survey participants were eager to learn more about OA and how to take action. The fact that the most common question survey participants provided was "What can we do?" signifies that there is energy and interest in taking action to be harnessed. This is especially significant in regions where the

impacts of OA are heightened, such as the PNW, and it demonstrates the value in ensuring that solutions are included in future communications.

5.2 Limitations and Next Steps:

5.2.1 Interview Limitations: It should again be noted that statistics from the interview portion of this project are likely influenced by sampling bias, with institutions who discuss OA or ocean change being more willing to participate in the interview. Additionally, there is some level of geographic bias, both because there is a higher prevalence of discussion of OA at institutions in areas where OA is a notable threat, and because I have a broader network in this region through which to make connections for outreach. Thus, the conclusions in this study may not be fully reflected in all regions.

The sample size of government-affiliated institutions was small, despite attempts to engage National Marine Sanctuary, National and State Park, and National Estuarine Research Reserve visitor centers. It is regrettable that so few federal institutions participated in the interviews, perhaps due to staffing shortages, pressure to limit discussion of OA and ocean change, or other factors, as many other MECs reported government-affiliated programs as their primary source of information on OA.This issue was reflected to a lesser extent with small MECs, as they are harder to discover and track comprehensively. I feel confident that I contacted all the major MECs, but there exist many smaller institutions providing important communication that were overlooked in this analysis.

Pertaining to the questions themselves, several questions were designed to use the interviewee's subjective experience and opinions to characterize a broader pattern at their institution. Although the interviewees were given questions in advance and had the opportunity

to gather more opinions from colleagues, the conclusions each interviewee presents are still biased by personal experience and anecdotal evidence, and so, must be taken with some level of caution. I had little opportunity to verify most of the claims or to experience the OA communications described, which may lead to some misrepresentations.

5.2.2 Case Study Limitations: Sampling bias must be confronted with all survey research, and certainly comes into play in this study. Although I attempted to make the survey more accessible to broader demographics by providing compensation, visitors with excess time and resources are more likely to be able to set aside time to take a survey. This is especially notable in how it applies to families: parents with their children appeared less likely to stop for a survey, given the pressure put on them by children demanding their attention or wanting to move to another attraction. While I attempted to alleviate some pressure by providing children with stickers and candy, and setting up in a space where people were often loitering due to its proximity to the touchpool, this still could not be perfectly solved. Additionally, the study was carried out over only four consecutive days, making it more susceptible to other forms of sampling bias. Another limitation with the case study was the decision to ask visitors to take the survey after allowing them to explore the aquarium on their own rather than requiring them to engage with the aquarium's OA communication first. This choice was made to better measure how much OA communication the average visitor might come across as they passively explore the facility, but it allows for confounding variables. For one, there is no guarantee that each visitor received any actual OA-centric education. Engagement with the digital signage was not directly tracked, but based on observations, interviews, and survey responses, it is possible that in-depth engagement was minimal, especially as the information was only available if one clicked into the story. Additionally, prior knowledge of OA could bias results, although I

attempted to control for this by explicitly asking about prior understanding of OA. However, as previously mentioned, another limitation relates to that question. Because this was not a true before-and-after survey, and instead relied on estimations, the results of this question could be biased based on false perception of prior knowledge and a desire to show improvement on the post-question. Notably, although the survey asked survey-takers' willingness to engage in actions to combat the impacts of OA, these statistics are likely inflated, as there was no way to measure whether respondents actually changed their behavior. The timeline of this project disallowed follow-ups, so there is no choice but to caveat these results.

Broadly, the applicability of this study's findings are limited because it is a case study of a single institution in a region that is fairly exceptional when it comes to OA. As a fairly large, cost-prohibitive institution situated near an estuary, there are factors that distinguish PDZA from institutions with different missions, funders, geographies, demographics, and capacities.

5.2.4 Future Research: Future research should work to address the limitations of this study. Given that this research is biased to the United States West Coast, future research should work to spotlight other regions. Specifically, increasing partnerships with inland institutions, East Coast institutions, and institutions outside of the continental United States and Canada for both interviews and surveys would provide important alternative perspectives to the demographics that dominate this study.

Furthermore, surveys should be conducted at other MECs to allow for further comparison of OA communication effectiveness. Optimally, case studies would be performed at MECs with varying missions, sizes, geographies, and types of OA messaging to allow for more robust analysis of what makes OA communication effective or ineffective under different circumstances.

Additionally, this study chose to exclude participation from people under 18 for logistic reasons. However, youth are a key demographic, both because they will be disproportionately impacted by OA, and because MEC communication is often targeted at school-age children. Thus, future research should consider intentionally including results from youth.

Finally, the research approach used here allowed survey participants to passively explore the PDZA Pacific Seas Aquarium to better simulate the average visitor's experience, rather than direct attention to OA signage or messaging. However, to more directly analyze the effectiveness of any specific messaging, researchers should consider performing a controlled experiment studying how much people learn having been presented directly with OA communication in different mediums.

6. Conclusion

This study provides an updated investigation into the state of OA communication at marine education centers and how much understanding of OA visitors to marine education centers may have. These results suggest that while communication of OA is widespread at MECs, there is substantial room for improvement in making this information accessible and impactful to recipients of the communication. My findings identified multiple barriers experienced by MECs in discussion of OA and ocean change, including perceived audience interest, politics, and staff knowledge. Moreover, I found that visitors to an aquarium featuring OA communication still left with uncertainty over OA's cause, local impacts, and solutions. By addressing these barriers and gaps, this research can help drive an increase in effective environmental communication around OA and related subjects, and can contribute to larger-scale societal engagement, especially as my findings indicate the public is willing to take action on a societal level.

Based on my findings, I believe that OA communication at MECs can be improved through the following:

1. **Communicators should focus on making OA communication more accessible.** This of course involves ensuring that jargon and overly complex detail is avoided, as previous authors have suggested (Callwood, 2019), and that alternative strategies are used to impart complicated information, such as tested metaphors like the idea of climate change as a "heat-trapping blanket" or the head, heart, and hands model (Geiger et al., 2017; Swim et al., 2017). However, access also necessitates ensuring that more people are literally able to access communication around OA. For instance, MECs should ensure that substantive OA communication is available to both students and members of the

public. This may require emphasizing more OA communication outside of classroom programs, such as online resources, oral presentations in the facilities, or exhibit materials that are broadly visible, all of which were less prevalent in my research. This also encompasses ensuring that public-facing staff and volunteers are comfortable talking about OA and ocean change in general, a major barrier identified in my research. Foundationally, communicators must be able to accurately and effectively communicate what OA is, how it impacts non-humans and humans, and what can be done. Furthermore, communicators should understand that visitors broadly are expecting to hear about conservation messaging at MECs, and that there is an opportunity for MECs to use this expectation and the trust that has been established with the community to encourage action. While institutions should operate with tact in their communication around politicized topics, communicators should not allow fear of political pushback to fully silence important communication and advocacy, especially as the public is largely concerned about changing climates (Howe et al., 2015; Marlon et al., 2022). Of course, communication strategies and tactics may vary regionally, with more careful emphasis on empathy and shared values in locations where pushback is stronger. The difficulty is having the confidence and tact to engage in these conversations. This may require some investment in internal communication training and support, but by utilizing strategies to meet visitors where they are at, avoid talking down to people, and engage in honest conversations about what is known and what is unknown, MECs can help drive long-term change.

2. **Communicators should underscore that the source of OA is fossil fuel emissions.** My research shows that one of the largest knowledge gaps related to OA is the lack of broad

understanding that OA is driven by fossil fuel emissions. Thus, it is hard to ensure that members of the public understand how to actually mitigate OA and how to best protect vulnerable ecosystems and communities. However, there is also an opportunity for emphasizing that OA is a process where we already know the best mitigation strategies, and that engaging in these strategies can help address a plethora of other environmental and societal issues.

3. **Communicators should emphasize human, place-based, and local connections.** OA is an issue that can often appear abstract, and thus, unmotivating. Therefore, it is critical to utilize communication strategies that include clear connections to humans and their wellbeing, especially by centering local and place-based impacts, which were often absent from OA communication at MECs. People are most willing to take action when they understand how an issue will affect them, meaning that communicators cannot simply discuss OA in terms of science and pteropods. Instead, education should center impacts on people and the places people care about. This is easier for MECs with obvious local impacts, such as those situated in areas with important shellfish industries, high levels of subsistence, or cultural connections to threatened species. However, it is not limited to these geographic areas. Drawing connections to cascading impacts such as access to seafood, or focusing on building empathy through case studies using storytelling to highlight place-based impacts are good alternative strategies.
4. **Communicators should always discuss what we can do to effectively address OA.** Communicators need to remember that people are eager to learn about and support solutions because it fosters hope. OA is an issue that can appear difficult to connect to tangible actions, due to its lack of obvious observability and widespread nature. Thus, to

avoid apathy and doomerism, it is incredibly important for communications to always include information on how people can act, which was the most common question survey-takers had. Solutions or actions do not have to be groundbreaking: they can reflect other emission reduction language, or even emphasize ideas like educating others and making discussion of OA and climate change more prevalent and visible. However, solutions should include communal and societal change, rather than just individual change, and connect to people's local communities and ecosystems, as indicated by survey-takers being almost equally willing to participate in individual emissions reductions as societal emissions reductions. While change at an individual level is easy, and has a role in larger change, communicators should be more willing to explicitly emphasize the role of communal and societal progress in achieving environmental justice, and work to consider how to direct individuals to support larger goals. Additionally, by uplifting local actions, it develops pro-environmental values and increases long-term attachment and engagement with pro-environment behaviors. This idea is essential in building stronger communities, increasing connections with the natural environment, and creating informed, yet inspired members of the public. One application of this thinking is around emission reductions. MECs should be more willing to discuss the fact that the largest driver of emissions is the fossil fuel industry, and that recurrently shifting blame to individuals will only decrease motivation for action. As doomerism is already a prevalent issue, especially among younger generations, it is important that institutions continue to showcase that communal action is possible.

7. Acknowledgements

This work was completed with funding from Washington Sea Grant and the Puget Sound Partnership Puget Sound Science Research Fellowship. Additional support was provided by the Northwest Straits Foundation and the University of Washington School of Marine and Environmental Affairs. I would like to thank my thesis committee chair Dr. Kristi Straus, and the other members of my thesis committee, John Meyer and Dr. Jan Newton. I also want to thank Dr. P. Joshua Griffin as my graduate program mentor.

I want to express extreme gratitude to those who contributed to this research, including the Point Defiance Zoo & Aquarium staff and all interviewees and survey takers. I acknowledge support from the

I offer a special thanks to those who provided advice on this project, including Adam Ratner, Kait Birgenthal, Dr. Nathaniel Geiger, Dr. John Fraser, Darcy Dugan, Eleri Griffiths, Dr. Liz Perotti, Jessie Turner, and Edith Mari.

Finally, I thank all those who before me who engaged in the struggle for justice, my partners in the struggle today, and all those who will carry on the struggle into the future, until the day a just world is achieved.

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9. Appendices

9.1 Appendix A:

9.1.1 Marine Education Center Interview Request Template: Request: “My name is Isaac, and I am a graduate student at the University of Washington. I am working on a research project about how marine education centers communicate about ocean change. Disclaimer: For this project, institution names would be provided in an index. No individual's names will be listed. If we want to attribute a quote from your interview to your institution, we will request your permission in advance, unless you opt out of quotation.”

9.1.2 Marine Education Center Interview Guiding Questions:

1. Could you please introduce yourself and talk a bit about the work you do at your institution?
    a. Who is your institution’s primary audience?
2. What topics related to ocean change, if any, does your institution talk about (in any capacity)?
3. Do visitors ever express interest in learning more about ocean change? Which specific topics?
4. Does your institution provide any public-facing communication or education about ocean acidification?
    a. If yes:
        i. In what ways?
        ii. What are your institution’s goals for those communications?
        iii. What types of information are included in your materials?

iv. Where does your institution get the information needed to inform this communication?

b. If no:

i. Why not?

ii. What would you need to produce such communication?

5. Does your institution provide any internal communication about OA to staff or volunteers?
    a. How much do you think public-facing staff know about OA?
    b. How much do you think volunteers know about OA?
        i. What % of your volunteers and staff know enough about OA to explain it to kids? To adults?
6. In exhibits (or other outreach), how is information on ocean change kept current? How is it updated?
7. Have you ever felt that your ability to talk about ocean change is restricted by any factors?
    a. Does your institution's funding source influence the content you feel comfortable putting into exhibits or communications?

9.2 Appendix B:

9.2.1 List of Participating Marine Education Centers:

Note that the alphabetical order of MECs in this list does **not** correspond to the numbers attached to MEC quotes.

- Alaska Sea Life Center

- Aquarium of Niagara
- Aquarium of the Pacific
- Audubon Aquarium of the Americas
- Bailey-Matthews National Shell Museum & Aquarium
- Birch Aquarium at Scripps
- Cabrillo Marine Aquarium
- Clearwater Marine Aquarium
- Downtown Aquarium - Denver
- Feiro Marine Life Center
- Greater Farallones and Cordell Bank National Marine Sanctuary
- Greensboro Science Center
- Hatfield Marine Science Center - Oregon State University
- MaST Center Aquarium
- Mystic Aquarium
- National Aquarium
- National Mississippi River Museum & Aquarium
- North Carolina Aquarium at Jennette's Pier
- North Carolina Aquariums at Pine Knoll Shores
- OdySea Aquarium
- Olympic Coast National Marine Sanctuary
- Orca Network
- Oregon Coast Aquarium
- Pacific Grove Museum of Natural History

- Padilla Bay National Estuarine Research Reserve
- Point Defiance Zoo & Aquarium
- Ripley's Aquarium of Canada
- Ripley's Aquarium of the Smokies
- Santa Barbara Museum of Natural History Sea Center
- SEA LIFE Charlotte-Concord
- Ucluelet Aquarium
- Vashon Nature Center
- Westport Aquarium
- The Whale Museum

9.3 Appendix C:

9.3.1 Point Defiance Zoo & Aquarium Visitor Survey Request Template: Hello, my name is Isaac, and I am a student at the University of Washington. I am doing a project about how aquariums talk about how ocean change is communicated and understood by visitors to aquariums. If you have 10 minutes for a short survey about your thoughts checking out this exhibit, that would be so helpful. There is a $10 gift card compensation that I can provide after survey completion. I am happy to guide you through the questions if you would like. Disclaimer: For this project, no individual's names will be collected. All data will be anonymized.

9.3.2 Point Defiance Zoo & Aquarium Visitor Survey Questions:

Background:

1. Do you belong to any of the following demographics?

☐ Educator
☐ Student

- ☐ Youth (under 18)
- ☐ Fishing Community
- ☐ Tribal / First Nation / Indigenous Communities
- ☐ Tourist
- ☐ Local to the Area

2. How long did you spend at this **aquarium** exhibit today? (Short Answer)

_____

_____

Public Knowledge: These questions are meant to develop an understanding of the general level of knowledge of ocean acidification. Do not feel pressured to select an answer - if you are unsure, feel free to indicate that!

3. What do you see as the most concerning ocean change issues? (Pick up to 3)

- ☐ Plastic pollution
- ☐ Sea level rise
- ☐ Threats to endangered species
- ☐ Non-plastic pollution and marine debris (oil spills, chemical spills, etc)
- ☐ Environmental injustice
- ☐ Global warming / Climate change
- ☐ Ocean acidification
- ☐ Overfishing and unsustainable seafood
- ☐ Harmful algal blooms
- ☐ None
- ☐ Unsure
- ☐ Other: _____

CONTINUE TO NEXT PAGE

4. Which of the following do you see as a primary cause of ocean acidification? (Select all that apply)

- ☐ Natural environmental causes
- ☐ Pollution / runoff
- ☐ Fossil fuel emissions
- ☐ Coral bleaching
- ☐ Acid rain
- ☐ Unsure
- ☐ Other: _____

5. How well did you understand ocean acidification (OA) **before** you visited the aquarium today?

- ☐ I've never heard of OA
- ☐ I've heard of OA, but don't recall anything about it
- ☐ I've learned / read about OA, but don't feel comfortable explaining it to others
- ☐ I know some about OA, and I feel comfortable explaining the basic concept to others
- ☐ I know a lot about OA, and feel comfortable explaining it in detail to others

6. How well do you understand ocean acidification (OA) **after** your visit to the aquarium?

- ☐ I've never heard of OA
- ☐ I've heard of OA, but don't recall anything about it
- ☐ I've learned/read about OA, but don't feel comfortable explaining it to others
- ☐ I know some about OA, and I feel comfortable explaining the basic concept to others
- ☐ I know a lot about OA, and feel comfortable explaining it in detail to others

7. Please describe any ways ocean acidification impacts the **environment** in this region (that you know of). (Short Answer)

_____

_____

_____

_____

_____

CONTINUE TO NEXT PAGE

8. Please describe any ways ocean acidification impacts **people** in this region (that you know of). (Short Answer)

_____

_____

_____

_____

_____

9. Please describe any impacts of ocean acidification that you perceive as a threat to

you or your community. (Short Answer)

_____

_____

_____

_____

_____

10. Which of the following actions could see yourself doing to combat the impacts of OA? (Select all that apply)

- ☐ Participating in community-level action to reduce emissions (habitat restoration projects, community solar)
- ☐ Educating others about OA
- ☐ Cleaning up trash in local environment
- ☐ Donating to organizations mitigating/adapting to OA
- ☐ Supporting societal change to reduce emissions (renewable energy implementation)
- ☐ Reducing personal emissions (conserving energy, reducing driving, eating less meat)
- ☐ None
- ☐ Other: _____

CONTINUE TO NEXT PAGE

11. What questions do you still have related to ocean acidification/ocean change? (Short Answer)

_____

_____

_____

_____

_____

Extra Space (Please write corresponding question number):

_____

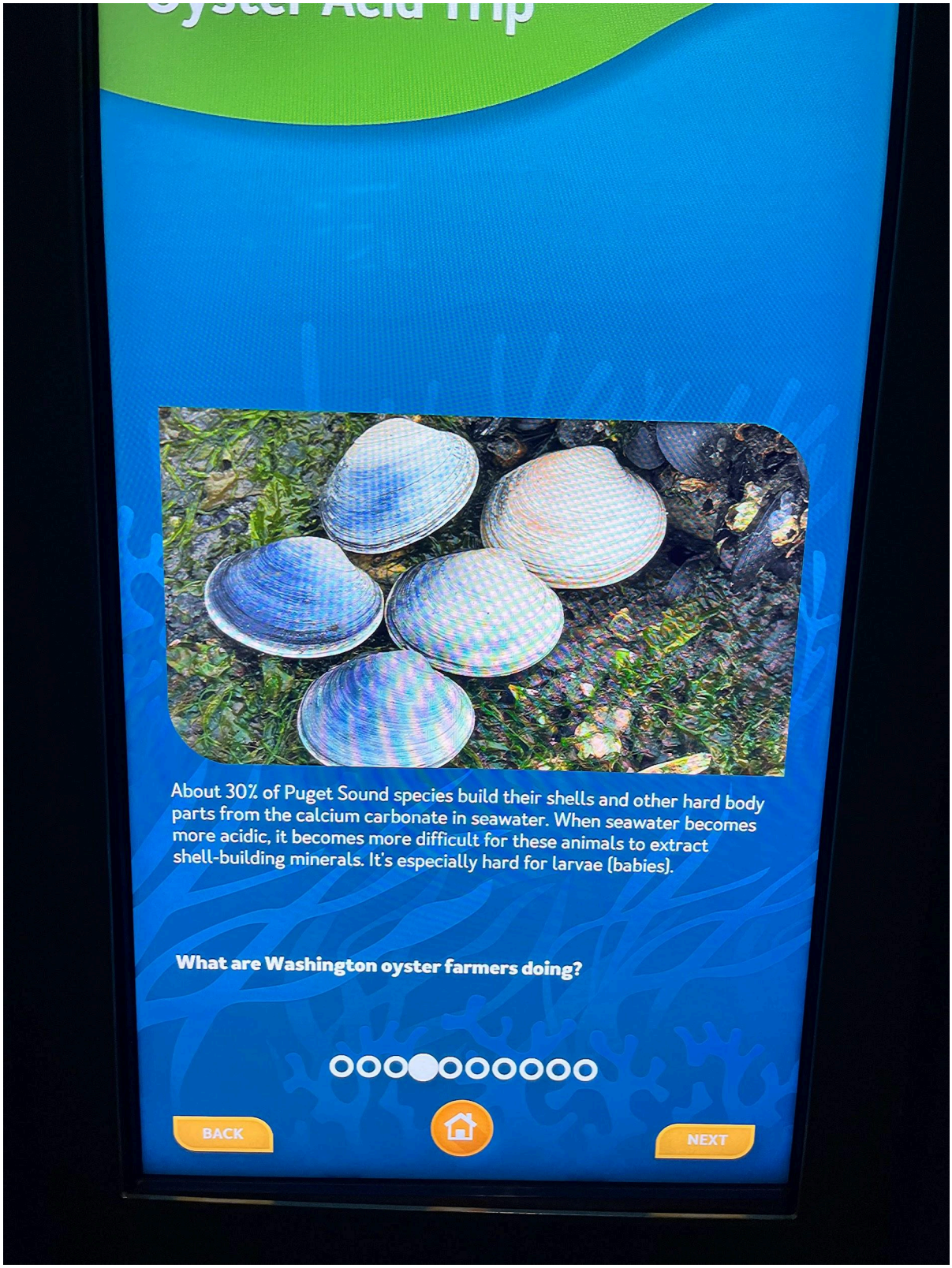
9.4 Appendix D:

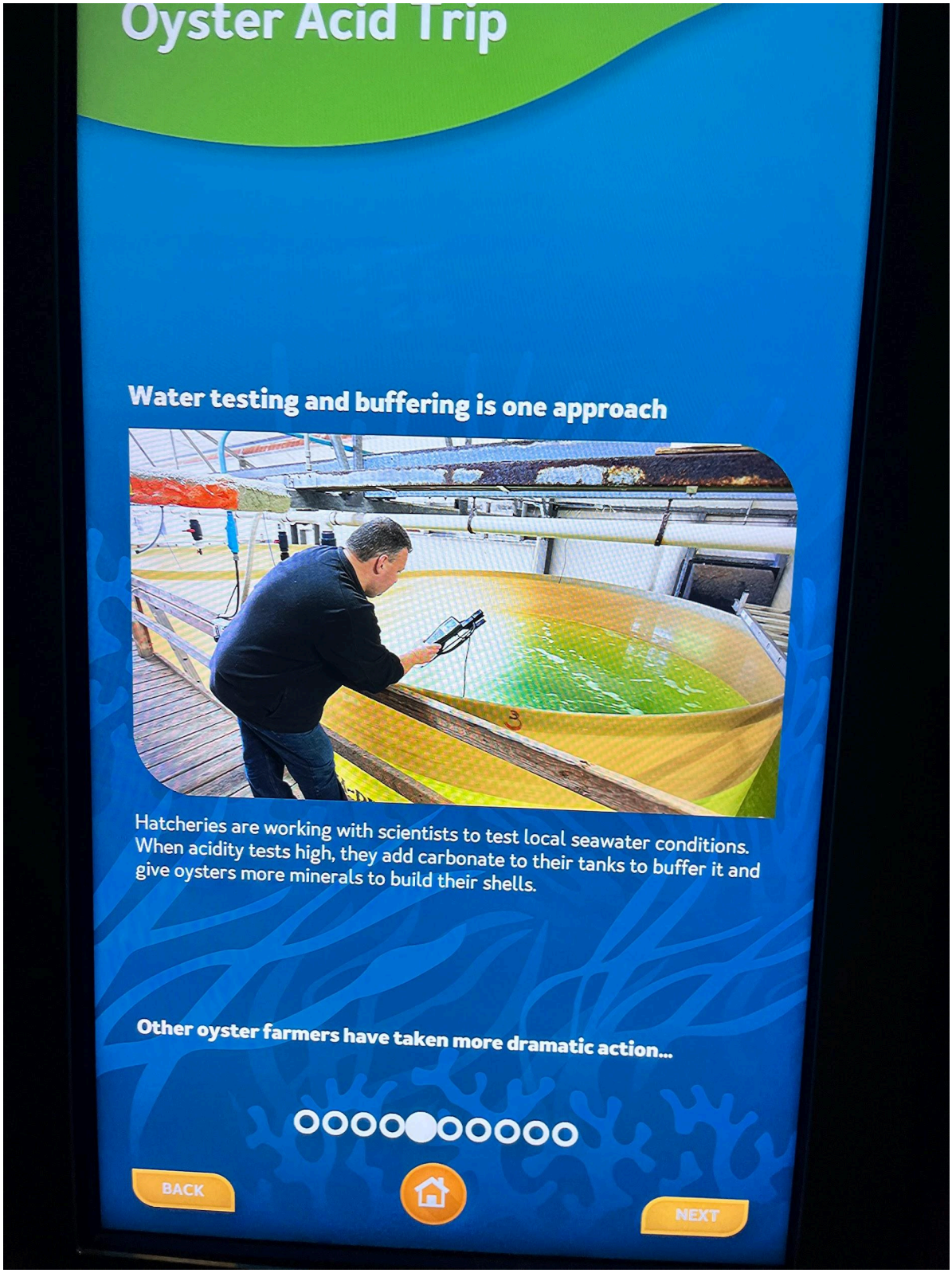
9.4.1 Oyster Acid Trip Display at Point Defiance Zoo & Aquarium:

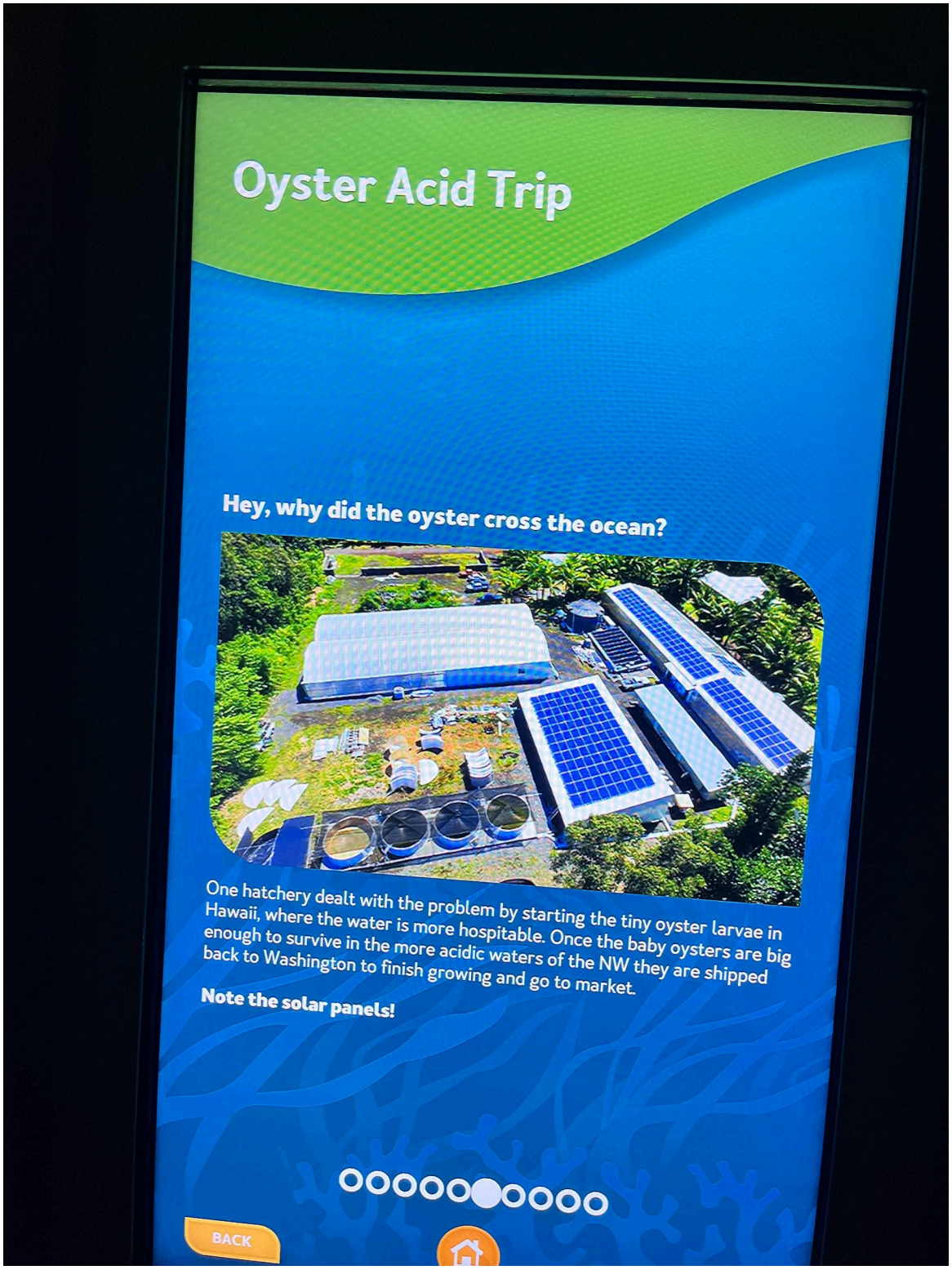
Figure 22: A nine-panel digital display from the Point Defiance Zoo & Aquarium Pacific Seas Aquarium featuring content on the local impacts of OA.


CO2 Blues Turn Green
Oyster Acid Trip
Blue Carbon
Quiz: Local Wonders
TOUCH A BUTTON TO BEGIN


Oyster Acid Trip
Real quick: a little ocean chemistry
The ocean has been mopping up much of the excess CO2 that we put into the atmosphere when we burn fossil fuels. However, it comes at a cost. When dissolved in seawater, CO2 forms carbonic acid, increasing the ocean's acidity around the globe.
Why is ocean acidification worse in the Pacific NW?
One reason is the natural upwelling of deep, CO2-laden water on the West Coast, which adds to the excess CO2 absorbed from the atmosphere. So, the problem is striking here first, providing an early warning for the rest of the world.
How does increased acidity affect oysters?
Wind
Washington Coastline
BACK
NEXT

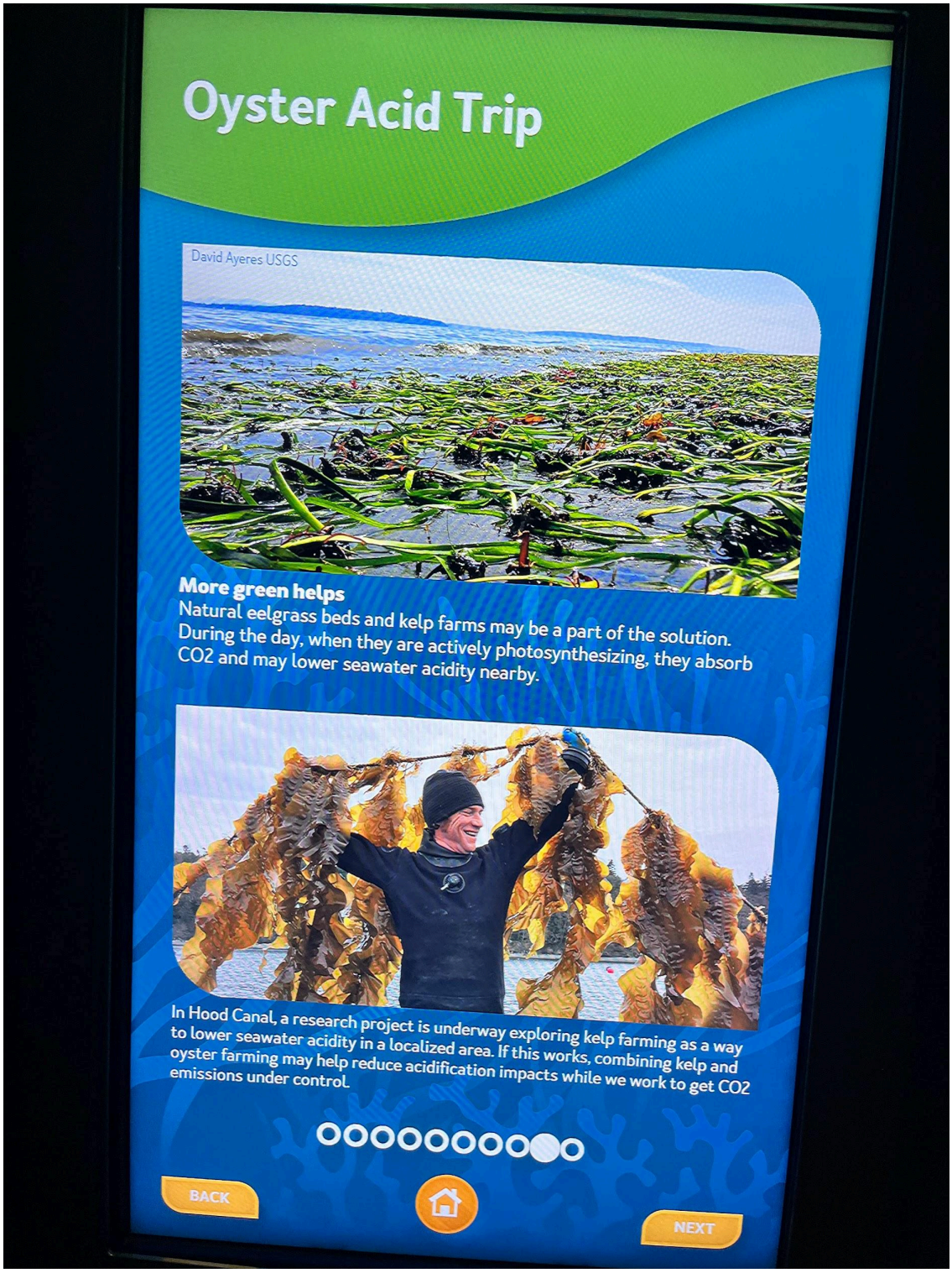

About 30% of Puget Sound species build their shells and other hard body parts from the calcium carbonate in seawater. When seawater becomes more acidic, it becomes more difficult for these animals to extract shell-building minerals. It's especially hard for larvae (babies).
What are Washington oyster farmers doing?
BACK
NEXT

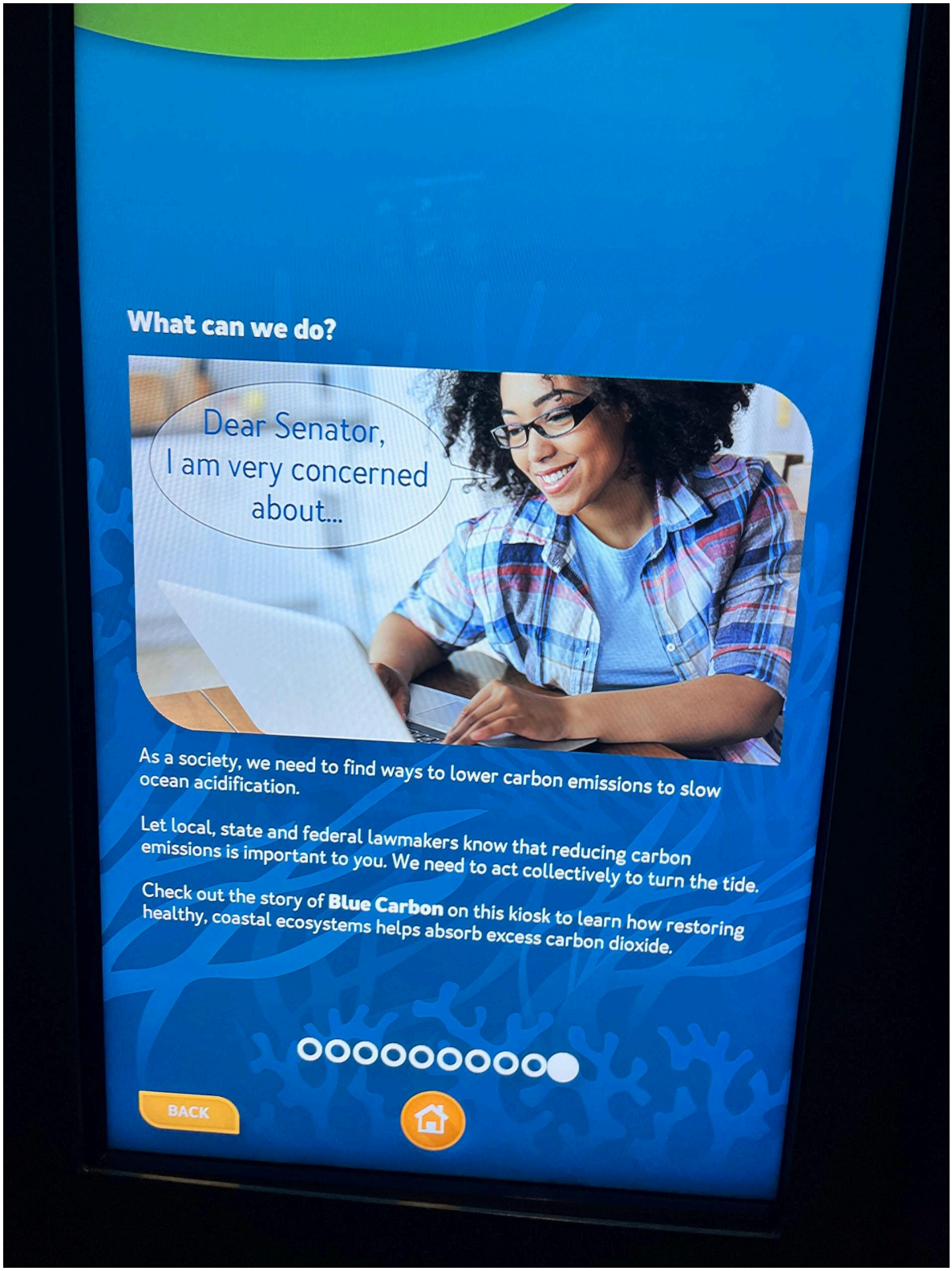

Oyster Acid Trip
Water testing and buffering is one approach
Hatcheries are working with scientists to test local seawater conditions. When acidity tests high, they add carbonate to their tanks to buffer it and give oysters more minerals to build their shells.
Other oyster farmers have taken more dramatic action...
BACK
NEXT


Oyster Acid Trip
Hey, why did the oyster cross the ocean?
One hatchery dealt with the problem by starting the tiny oyster larvae in Hawaii, where the water is more hospitable. Once the baby oysters are big enough to survive in the more acidic waters of the NW they are shipped back to Washington to finish growing and go to market.
Note the solar panels!
BACK


Oyster Acid Trip
In search of solutions for shellfish and the humans that depend on them! Washington state is our nation's top provider of farmed oysters, clams and mussels. Problems with shellfish production directly puts 3,200 jobs at risk.
In addition, Washington's tribal communities rely on healthy shellfish fisheries to support their families and cultural traditions.
So, what's being done?
BACK
NEXT


Oyster Acid Trip
In 2013, after shellfish producers sounded the alarm, the Washington legislature jumped in, providing millions of dollars to address ocean acidification.
Scientists, shellfish farmers and policy makers from federal, local and tribal governments are working together to reduce carbon dioxide emissions and respond to ocean acidification.
BACK


Oyster Acid Trip
David Ayeres USGS
More green helps
Natural eelgrass beds and kelp farms may be a part of the solution. During the day, when they are actively photosynthesizing, they absorb CO2 and may lower seawater acidity nearby.
In Hood Canal, a research project is underway exploring kelp farming as a way to lower seawater acidity in a localized area. If this works, combining kelp and oyster farming may help reduce acidification impacts while we work to get CO2 emissions under control.
BACK
NEXT


What can we do?
Dear Senator,
I am very concerned
about...
As a society, we need to find ways to lower carbon emissions to slow ocean acidification.
Let local, state and federal lawmakers know that reducing carbon emissions is important to you. We need to act collectively to turn the tide.
Check out the story of **Blue Carbon** on this kiosk to learn how restoring healthy, coastal ecosystems helps absorb excess carbon dioxide.
BACK

9.5 Appendix E:

9.5.1 Decisions Surrounding Statistical Analysis of Paired Survey Data: Based on advice from the University of Washington Center for Statistics and the Social Sciences, I conducted more descriptive analyses on the questions from the visitor surveys pertaining to respondent knowledge of OA before and after visiting the aquarium. The responses to those questions are summarized in Table 1 and Figure 23.

Table 1: A contingency table comparing respondent (n = 148) answers to the questions of "How well did you understand ocean acidification (OA) ***before*** *you visited the aquarium today?" and "How well did you understand ocean acidification (OA)* ***after*** *you visited the aquarium today?" Categories refer to the different likert scale options on those two questions:*

1. *I've never heard of OA;*
2. *I've heard of OA, but don't recall anything about it;*
3. *I've learned / read about OA, but don't feel comfortable explaining it to others;*
4. *I know some about OA, and I feel comfortable explaining the basic concept to others;*
5. *I know a lot about OA, and feel comfortable explaining it in detail to others.*

Each inner cell contains a count of how many respondents selected that pair of answers. Yellow cells represent respondents whose knowledge level did not change, green cells represent respondents whose knowledge level improved, and red cells represent respondents whose knowledge level decreased.

		Before					
	Category	*1*	*2*	*3*	*4*	*5*	*Total*
After	*1*	31	1	0	0	0	32
	2	6	27	0	0	0	33
	3	9	12	31	1	0	53
	4	3	4	5	15	0	27
	5	0	0	0	1	2	3
	Total	49	44	36	17	2	148

How well did you understand OA before and after your visit to the aquarium?

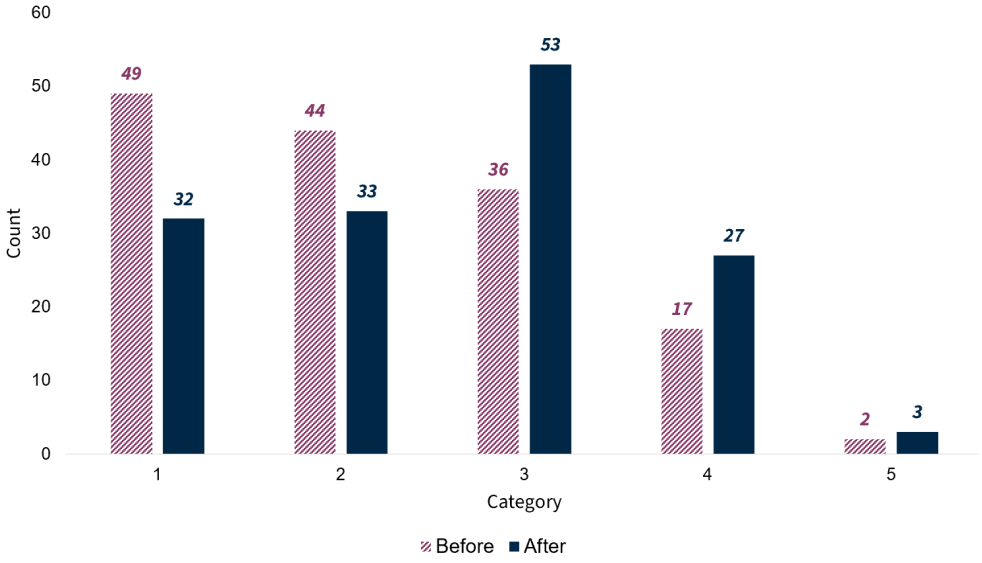


Figure 23: A histogram showing the count of respondents (n = 148) who selected each option when asked the questions “How well did you understand ocean acidification (OA) before you visited the aquarium today?” and “How well did you understand ocean

acidification (OA) after you visited the aquarium today?" "Category refers to the options provided on a likert scale:

1. I've never heard of OA;
2. I've heard of OA, but don't recall anything about it;
3. I've learned / read about OA, but don't feel comfortable explaining it to others;
4. I know some about OA, and I feel comfortable explaining the basic concept to others;
5. I know a lot about OA, and feel comfortable explaining it in detail to others.

Red shaded bars represent the "before" answers and blue solid bars represent "after."

The difference between the paired data was found to be statistically significant ($p < 0.001$) according to a Wilcoxon Signed-Rank Test. More difficult was determining the effect size of this significance. The recommended test for effect size is the matched-pairs rank-biserial correlation. According to this test, the effect size for this data is 0.94, indicating a strong correlation. However, this test does not have a simple way to control for ties within ranks, and because my data contained multiple ties, this effect size may be an inaccurate estimate. Thus, I ultimately chose to utilize the probability of superiority for dependent groups (PS_{dep}) test, which similarly provides an estimation of effect size for paired data, specifically when one expects an improvement in paired observations. For this data, $PS_{dep} = 0.43$.