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PERCEPTION AND RESPONSE OF THE U.S. WEST COAST SHELLFISH INDUSTRY TO OCEAN ACIDIFICATION: THE VOICE OF THE CANARIES IN THE COAL MINE

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ABSTRACT In the mid-2000s the U.S. west coast oyster industry experienced several years of significant production failures. This industry has been referred to as the "canary in a coal mine" for ocean acidification (OA). Industry-led collaboration with university and government scientists identified a relationship between elevated carbon dioxide in seawater and poor oyster seed production. This multiyear production slow-down resulted in significant economic losses to the industry and spurred state and regionally led initiatives to examine the current and potential future impacts of OA. To examine the perceptions and understanding of OA by the U.S. west coast shellfish industry, a regional survey of the industry was conducted, covering oyster, mussel, clam, geoduck, and abalone producers. The web-based survey addressed four general areas: experience, understanding, concern, and adaptability. There were 86 total respondents from industry, resulting in a response rate of 46% with 96% of respondents answering all 44 questions. Seventy percent of respondents were owners or managers of a shellfish business. Findings from the survey indicate that approximately half of the industry had personally experienced a negative impact from OA. This personal experience generally led to a higher level of concern about OA; however, self-reported level of understanding of OA resulted in slightly less concordance with the level of concern. Greater than 80% of the shellfish industry noted that OA will have consequences today, approximately four times higher than the U.S. public's perception of the threat. Finally, greater than 50% of the industry felt that they would be able to somewhat or definitely adapt to OA.

KEY WORDS: ocean acidification, adaptation, survey, shellfish industry, global change

INTRODUCTION

Ocean acidification (OA) is receiving worldwide attention from researchers, media, and the public as an urgent environmental and economic issue. Accumulation of carbon dioxide (CO_2) in the atmosphere from fossil fuel combustion, land use change, and other human activities has increased the uptake of oceanic CO_2, causing average surface ocean acidity to increase approximately 30% since 1750 (Caldeira & Wickett 2003, Feely et al. 2004). The chemical reaction of CO_2 with seawater lowers pH, carbonate ion concentrations, and saturation state of calcium carbonate minerals (Caldeira & Wickett 2003, Feely et al. 2004).

As the baseline of global CO_2 is increasing, measurements and models of carbonate chemistry along the Oregon shelf and shelf break suggest that corrosive conditions are more frequent now than that before the Industrial Revolution within this highly dynamic coastal upwelling zone (Feely et al. 2008, Gruber et al. 2012, Harris et al. 2013, Hauri et al. 2013). Naturally elevated CO_2 due to respiration or other anthropogenic effects creates "OA hotspots", localized areas where acidification exceeds global changes (Kelly et al. 2011, Waldbusser & Salisbury 2014). Along the U.S. west coast, the upwelling of deep ocean water creates OA hotspots (Feely et al. 2008). Shell production and growth of shellfish are generally negatively impacted by OA (Gazeau et al. 2013, Parker et al. 2013), with larval shellfish being especially sensitive to CO_2-enriched waters during critical stages of early development (Barton et al. 2012, Waldbusser et al. 2013, Waldbusser et al. 2014).

Between 2005 and 2009, two Pacific oyster hatcheries in the Pacific Northwest experienced a significant decrease in larval production known as the "Oyster Seed Crisis" where larval mortality reached upwards of 80% (Washington State Blue Ribbon Panel Report on Ocean Acidification 2012). Production losses of larvae at the Whiskey Creek Shellfish Hatchery in Netarts Bay, OR, correlated with the intensity and timing of CO_2-enriched upwelled water (Barton et al. 2012). Limited seed supply from hatcheries combined with commercial failures of natural sets in Willapa Bay, WA, from 2005 onward (Dumbauld et al. 2011), caused economic impacts on the U.S. Pacific Northwest oyster industry (Washington Blue Ribbon Panel Report on Ocean Acidification 2012). The seed shortage resulted in reduction of oyster production from 94 million pounds ($84 M) in 2005 to 73 million pounds ($73 M) in 2009, resulting in a 22% decline in production (13% decline in gross sales) [Pacific Coast Shellfish Growers Association (PSGA) 2011]. The reduced level of seed production prompted the PSGA to identify seed scarcity as a top priority in 2009. Whereas shellfish hatcheries are adopting new strategies to sustain production, the perspectives and experiential insights of the U.S. west coast shellfish industry will prove critical in policy and governance of OA impacts on marine resources.

Social Science Frameworks to Explore Stakeholder Perspectives

Whereas studies addressing social perceptions of OA are limited, it is well documented how stakeholders worldwide perceive climate change (Wolf & Moser 2011). Social science frameworks define environmental concern by awareness of

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a problem, support for protection, and recognition of the synergistic relationship between society and the environment (Dunlap et al. 2000); however, the U.S. public concern for climate change was not necessarily determined by a clear understanding of ecological processes, the ways in which humans influence processes, or the implications of human-induced environmental change (Kempton 1991, Bord et al. 2000, Henry 2000). Instead, attention to a changing climate was motivated by beliefs formed in alignment with peers, and local and experiential knowledge of past and recent weather (Cruikshank 2001, Berman et al. 2004, Kahan et al. 2012). Alternatively, studies on commercial stakeholders found that income dependence lead to greater awareness for climate change and conservation behavior (Morgan-Brown et al. 2010, Sakurai et al. 2011).

How the shellfish industry perceives OA-related science will constitute an important component in determining domestic policy to improve adaptation strategies (Byron et al. 2011). Adaptation involves the capacity of a system to respond to a hazard, whereas maintaining everyday ''self-interest'' and is determined by a range of factors including technological options, economic resources, human and social capital, and governance (Martens et al. 2009). Adjustment or coping strategies used to adapt to immediate and hazardous environmental impacts were classified by Burton et al. (1993) as: share the loss, bear the loss, modify the event, prevent the effects, change use, or change location. Commercial fishing captains in San Diego, CA, are actively adapting to the variability of fish populations associated with climate change, even though the large majority do not believe that climate change is happening (Zhang et al. 2012). Shellfish hatcheries in the Pacific Northwest have treated water, changed timing of production, or diversified production overseas to mitigate losses from OA. The ability of the broader shellfish industry to adapt to the risk from OA and remain profitable hinges on their recognition of OA as an environmental hazard (Jackson 2005, O'Brien et al. 2006, Adger et al. 2009), and having resources to implement strategies (Barton et al. 2012, Ekstrom et al., 2015).

Shellfish hold a strong cultural identity extending beyond household income; this natural resource fosters a way of life that connects coastal communities and generational interactions. Some stakeholders may not endorse academic qualifications and scientific methodology as local knowledge is often not dependent on scientific knowledge (Weeks and Packard 1997). Climate change research shows traditional knowledge playing a critical role in understanding environmental changes and may influence future decision-making about adaptation at a local level (Leonard et al. 2013). Scientists have historically struggled to effectively communicate and bridge social gaps with stakeholders, and stakeholders are often not given the opportunity to communicate their needs or experiential knowledge (Carpenter et al. 2009). This creates obstacles when transferring information to improve scientific literacy (Weeks & Packard 1997).

Management of marine resources in recent years has shifted toward a holistic approach that integrates stakeholder insight with the implementation of coastal policy (Conway et al. 2010, Gunton et al. 2010). As policy is beginning to address OA at national, state, and local levels, the shellfish industry can help guide the process forward by sharing their insight and information needs, and forming cooperative partnerships. The shellfish industry awareness of OA is necessary when developing policy and governance strategies that hinge on support from this key stakeholder group.

Although there are multiple shellfish stakeholders (i.e., consumers, seafood processors, restaurants), for this study stakeholders are classified as commercial shellfish growers and hatcheries in Washington, Oregon, and California because this group supports the base of the extended commercial shellfish industry and is immediately affected by outcomes of OA. Whereas the term shellfish also includes crab, lobster, urchins, and sea cucumbers, this paper uses the term shellfish as shorthand for the following: oysters, clam, geoducks, mussels, and abalone. A survey of the U.S. west coast Shellfish Industry was conducted to address four objectives: (1) assess how experience with negative impacts from OA influences level of concern, (2) determine participants' perceived understanding and evaluate how understanding of OA influences level of concern, (3) investigate how the industry understanding of OA compares to other groups, and (4) investigate how the industry perceived adaptability to OA.

MATERIALS AND METHODS

Informal face-to-face interviews were conducted with shellfish growers and hatcheries at the PCSGA Conference and Tradeshow (2012) to gauge attitude regarding OA and willingness to participate in a survey. Collected data revealed stakeholder preference for Internet communication and guided the implementation of an online survey. The construction of survey questions used a modified ''tailored design method'' (Dillman 2000) and techniques for conducting an online survey within small communities (Dillman & Smyth 2007, Smyth et al. 2009). Close-ended questions allowed for evaluation of participants' opinions on a quantitative scale, whereas open-ended questions enabled the expression of strong opinions especially when the range of possible answers was unknown (Smyth et al. 2010). Questions were created and systematically organized to flow like the sequence of conversation topics, allowing respondents to feel that they were contributing to a dialogue (Schwarz 1999). Participants were provided with condensed explanations of marine concepts to potentially improve ocean literacy and reduce measurement error from inaccurate or imprecise interpretations. The survey was conducted using an online program (SurveyMonkey Inc.) that supported design options to reduce break off before survey completion by providing progress indication, the ability to skip questions, and the option to return later.

A consent statement was presented on the first page of the questionnaire explaining the research objectives and describing precautions taken to ensure confidentiality of the participants' identity. Participants were assumed to possess basic typing and information technology skills, could obtain access to a computer with Internet access, and had an E-mail account. Inaccurate E-mail addresses and phone numbers resulted in coverage error, and nonresponse error may have introduced biased results weighted by participants already engaged with OA research, and therefore more likely to respond. The survey underwent Institutional Review Board examination at Oregon State University (OSU), and was pretested by 12 nonindustry participants and revised based on the questionnaire itself (i.e., length, layout, format, sequence of questions) and specific questions (i.e., ambiguity, unfamiliar terminology) (Hunt et al. 1982). The survey contained 44 questions and was divided into four general sections that mirrored our research objectives outlined above.

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Identifying and Contacting Research Participants

State agencies and shellfish organizations along the west coast assisted in the compilation of a comprehensive industry-wide database and facilitated some communication between stakeholders and the research team. The database contained 189 commercial shellfish establishments (growers: $n = 185$, hatcheries: $n = 4$) across Washington ($n = 154$), Oregon ($n = 16$), and California ($n = 19$). One individual from each shellfish establishment was surveyed. Potential participants were initially contacted in January 2013 by E-mail. The message contained an introduction to the research team, study objectives, and a request for participation in our cooperative research. Four days later, E-mails were sent with the survey link and a unique identification code required for consent. Concurrently, shellfish organizations and state agencies emailed their respective members to encourage participation and posted notices of the survey project on their websites to reach potential participants not contacted due to faulty E-mail addresses. Two follow-up E-mails were sent to those yet to complete the survey; those who had completed the survey were sent a thank you E-mail and were requested to encourage peers' participation. The survey concluded at after being open for 7 wk.

Survey Analyses

Survey data were analyzed using nonparametric tests based on ranks of data and medians (and contingency tables where appropriate). In social science, and for the purpose of this study, Likert scale items which are commonly used to scale responses in research questionnaires are treated as continuous variables (Carifio & Perla 2007). The correlation between having personally experienced negative OA impacts and levels of concern (dichotomous and continuous variable, respectively) was tested with Fisher's exact test due to low cell values in the table. Responses of "I don't know" to having experienced negative OA impacts were excluded from the analysis (24 out of 78 total responses). The correlation between perceived understanding and level of concern (both continuous variables) was tested with Spearman's ρ. To test differences among participants in Washington, Oregon, and California for their perceived adaptability to OA (categorical and continuous) Fisher's exact test was used due to low cell frequency, as above. A post hoc analysis between industry participants' responses to the dominant timescale (hours, days, months, years, decades, centuries) that each of six processes altering carbonate chemistry (ocean currents, atmospheric CO_2, upwelling, photosynthesis, respiration, and rivers) and responses of a sample of OSU OA researchers. To test correlation in understanding drivers of carbonate chemistry, variability between survey participants and OA scientists Spearman's ρ correlations were run between the timescale frequency distribution of responses for each process. Narrative responses were categorized thematically to represent group averages and minimize researcher subjectivity (Hayes 1997).

RESULTS

U.S. West Coast Shellfish Industry Participation

A total of 86 questionnaires were collected providing a 46% overall response rate with 96% of respondents answering all 44 questions. The majority (70%) of survey participants was comprised of business owners or managers, with hatchery operations representing 5% of respondents and grow-out operations represented 95%. This distribution reflects the far larger number of shellfish growers versus hatchery operations. Respondents from Washington represented 73% of the total response, whereas Oregon and California participants represented 12% and 15%, respectively. Response rates by state were 41% in Washington, 63% in Oregon, and 69% in California. Shellfish products were represented as oyster (54%); clam (20%); geoduck (16%); mussel (5%); and abalone (5%). Participant distribution reflected the general distribution of the U.S. west coast shellfish industry, where the majority of participants were oyster growers from Washington. Furthermore, Washington participants represented all aquaculture products except abalone, Oregon participants represented oysters exclusively, and California was the only state with participants from the abalone industry.

Experience and Concern with OA

A total of 94% of respondents reported that they had heard of "ocean acidification;" 11% reported first hearing about OA 0–2 y ago, 47% reported 2–5 y *ago*, 33% reported 5–10 y ago, and 9% reported more than 10 y ago. Over half of all participants reported they have personally experienced negative impacts from OA, whereas 18% reported "No," and 31% reported "I don't know" (Fig. 1). Affirmative respondents were asked to identify the type of negative impact experienced; 97% reported financial impacts and 68% reported emotional impacts. A participant stated, "Ocean acidification kills larvae—larvae are my business. This makes me sad and angry." Participants from the geoduck industry represented the shellfish product with the fewest (36%) personal experiences with negative OA impacts (Fig. 1). Overall, however, 71% of participants knew a member of their industry who experienced negative impacts from OA.

Participants indicated their level of concern about the problem of OA where 36% were *extremely* concerned, 39% were *very* concerned, 20% were *somewhat* concerned, 4% were *not too* concerned, and 1% was *not at all* concerned. Of respondents who personally experienced negative impacts from OA, 93% were *extremely* to *very* concerned about the problem. In all, 64% of respondents who had not personally experienced negative impacts from OA were still *extremely* to *very* concerned about the problem (Fig. 2). A total of

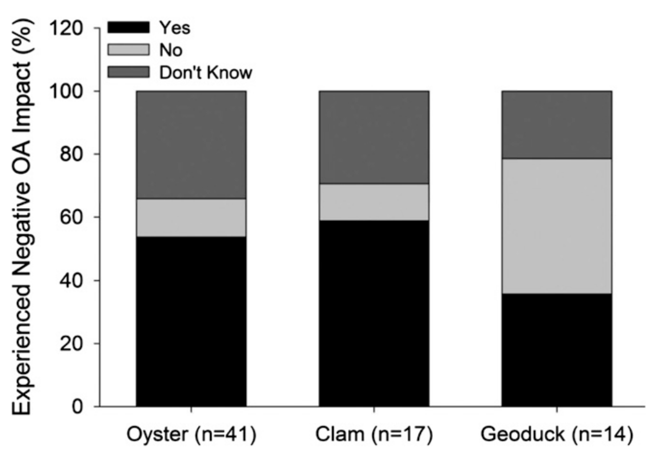

Figure 1. Response of survey participants as to whether they have personally experienced negative impacts from ocean acidification. Note that mussel and abalone responses were not reported here due to the very small sample sizes from those groups, and the specificity by state.

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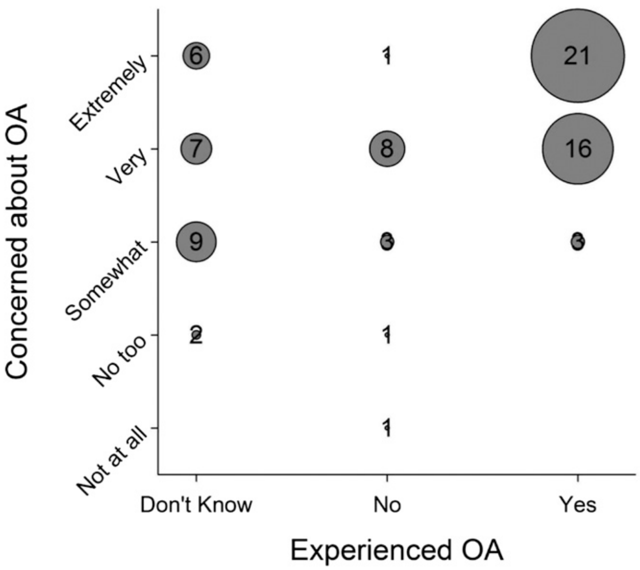

Figure 2. Relationship between experience and concern about ocean acidification. The size of the symbols and numbers correspond to the number of responses in agreement for each category along *x* and *y* axes.

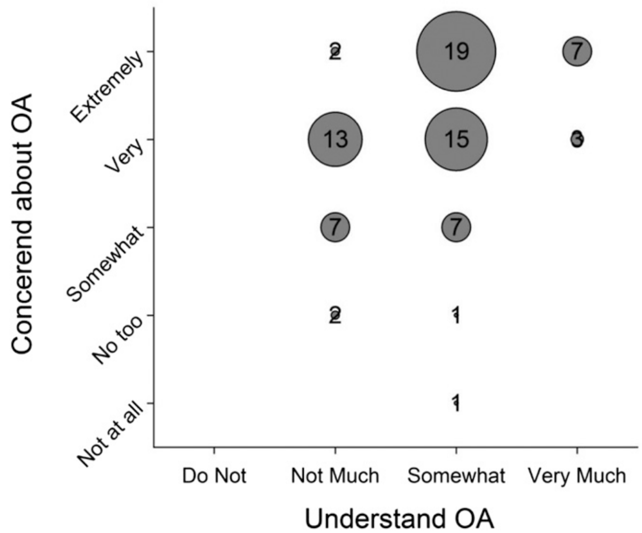

Figure 3. Relationship between self-reported understanding of ocean acidification and level of concern. As above, the size of the symbols and numbers correspond to the number of responses in agreement for each category along *x* and *y* axes.

54% of participants who did not know if they personally experienced negative impacts from OA were still *extremely* to *very* concerned about the problem. Treating clear acknowledgment (*yes* or *no* responses) as a dichotomous variable revealed a statistically significant relationship between personal experience with negative OA impacts and level of concern (Fisher's exact test, $P = 0.0026$). Overall, participants acknowledged OA and felt concerned about the problem through their beliefs, experiences with negative OA impacts, and economic losses. As stated by a respondent, "I may not understand the data but I believe it and feel concerned about it."

Perceived Understanding and Concern

Participants identified their perceived (self-reported) understanding of OA where 13% understand *very much*, 54% understand *somewhat*, 33% understand *not much*, and 0% understand *nothing* about OA. Narrative data further demonstrated participants' general understanding of OA, "We are becoming aware of the issue and its potential impact on our business, so we need to learn more about this issue as research is being done on it." Taking into consideration timescales of environmental disruptions across spatial scales and the ideas of 'carbonate climate' and 'carbonate weather' (sensu Waldbusser & Salisbury 2014), participants reported on their belief that OA is happening in three geographic domains: global, regional, and local. Most respondents were *certain it is true* or thought it *very believable* that OA is happening to the global ocean (85%), U.S. west coast (86%), and their local estuary (84%).

All participants who reported understanding OA *very much* also felt *extremely* to *very concerned* about the problem of OA. Seventy-nine percent of respondents who understand OA *somewhat* also feel *extremely* to *very* concerned about the problem of OA. Furthermore, 63% of respondents who understand OA *not much* still feel *extremely* to *very* concerned about the problem of OA (Fig. 3). Overall, 77% of participants were *extremely* to *very* concerned about OA regardless of their level of understanding. There is a significant relationship between self-reported understanding of OA and level of concern (Spearman $\rho(77) = 0.43$, P value $= 0.0002$). Results indicate however that participants' level of concern for the problem is not entirely reflected by understanding OA; as previously noted, negative experiences with economic losses appears to be a greater contributor to one's level of concern.

Participants reported their understanding of the degree that six natural processes (ocean currents, atmospheric CO_2 absorbed by the ocean, upwelling, photosynthesis, respiration, and rivers delivering freshwater) affect near-shore ecosystems and alter CO_2 concentrations. There was most agreement (76%) that ocean currents have a *great impact* on near-shore ecosystems. There was moderate agreement (46%) that CO_2 absorbed by the ocean has a *great impact* on near-shore ecosystems and that upwelling has a *great impact* on the amount of CO_2 in near-shore water. There was low agreement that photosynthesis, respiration, and rivers delivering freshwater have *great impact* on the amount of CO_2 in near-shore water (25%, 12%, and 10% respectively).

Industry Understanding and Concern Relative to Others

Whereas the industry as a whole demonstrates an advanced understanding of OA, a post hoc survey of 10 researchers with academic work relating to OA at OSU, Corvallis, OR answered identical questions about the six marine processes to affect a change in nearshore water chemistry to examine overlap and discrepancies in OA understanding. Generally, OA researchers and the shellfish industry agreed that ocean currents and atmospheric CO_2 absorbed by the ocean alter carbonate chemistry over longer timescales, upwelling and rivers delivering fresh water alter carbonate chemistry over intermediate timescales, and photosynthesis and respiration alter carbonate chemistry over shorter timescales. The overall correlation between researchers' and industry participants' responses was statistically significant (Spearman $\rho(36) = 0.81$, $P < 0.0001$); however, correlations of understanding the individual processes were not always significant (Table 1).

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TABLE 1.

Spearman's ρ correlations for relationship between industry and OA scientists on the timescales over which each process affects carbonate chemistry. There was an $n = 6$ representing the 6 possible timescales (hours, days, months, years, decades, and centuries) that each individual categorized the process as dominating the impact on marine carbonate chemistry.

Timescales of individual marine processes	r^2	*P* value
Ocean currents	0.43	0.3991
Atmospheric CO_2 absorbed by the ocean	**0.93**	**0.0084**
Upwelling	**0.93**	**0.0081**
Photosynthesis	**0.84**	**0.0361**
Respiration	0.80	0.0513
Rivers delivering freshwater	0.77	0.0763

Statistically significant correlations indicating close agreement between industry and scientists are denoted by bolded values.

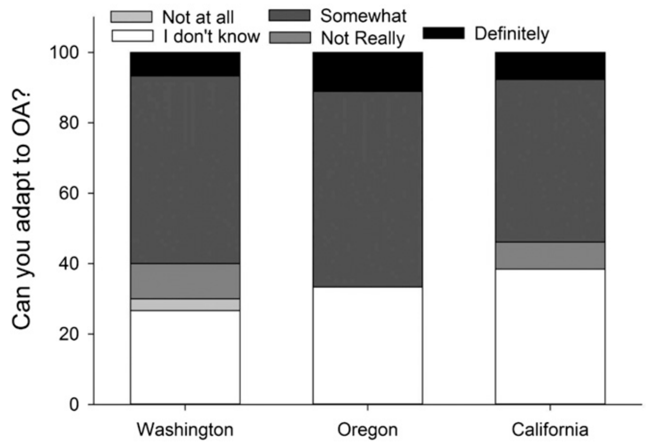

Figure 5. Perceived adaptability of the U.S. west coast shellfish industry to ocean acidification.

In addition, perspectives of the shellfish industry and the U.S. public were compared in regard to OA consequences through cooperation with Ocean Conservancy and Edge Research (2011), where three identical questions answered by the U.S. public were asked of the shellfish industry. Comparison of responses show the shellfish industry recognizes OA consequences for (1) people today, (2) people in this lifetime, and (3) future generations, to a far greater extent than the U.S. public (Fig. 4). Although the U.S. public viewed fewer consequences from OA at present, they recognized that consequences from OA would increase in future scenarios.

Industry Adaptation and Partnerships to Address OA

Participants indicated the level their shellfish business could adapt to OA, where 7% were *definitely* able to adapt, 52% were *somewhat* able to adapt, 9% were *not really able* to adapt, 3% were *not at all able* to adapt (Fig. 5). Nearly 40% acknowledged a personal experience with negative impacts from OA, yet felt that their business was *definitely* or *somewhat* able to adapt.

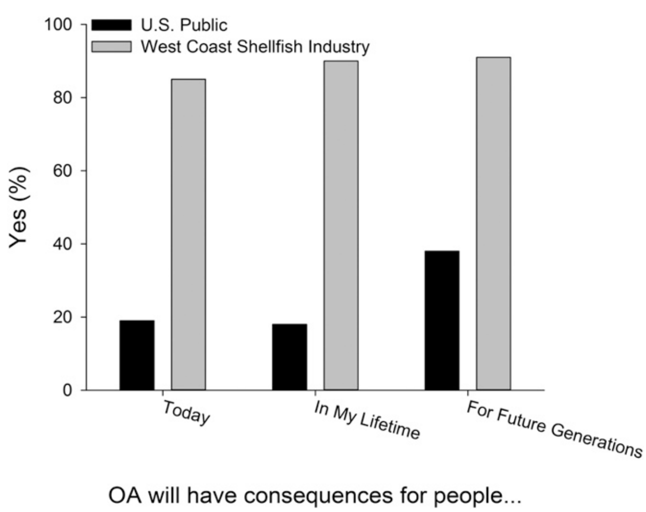

Figure 4. Comparison between national survey (see text) and U.S. west coast shellfish industry survey with regards to the immediacy of consequences of ocean acidification.

Twenty-nine percent of participants reported *I don't know* for their level of adaptation, indicating uncertainty in their future prospects. Grower participants (as opposed to hatcheries) tended to share an attitude that they operate at the whim of ''Mother Nature,'' implying that water conditions are beyond their control. Perceived adaptability to OA by state showed no evidence for differences among Washington, Oregon, and California participants (Fisher's exact test, $P = 0.9723$).

When prompted to share their perspective on acidification adaptation, participants expressed guarded optimism. ''Short term we can adapt. Long term is unknown,'' and ''We're on a pathway that will have numerous ugly outcomes in the future,'' and ''Ocean acidification, particularly in the Pacific Northwest, has already happened, and has already impacted our industry to the tune of tens of millions of dollars each year. The quicker we get this message across, the quicker we can get around to trying to salvage what's left.''

Participants next identified if the U.S. government, state government, local government, scientists, and shellfish industry should place *high priority* on addressing OA. Participants indicated greatest agreement (85%) that scientists and the shellfish industry are tasked with *high priority* to address OA. There was less agreement that governing bodies should place *high priority* on addressing OA: US government (75% agreement), state government (65% agreement), and local government (45% agreement).

DISCUSSION

Working at the interface among scientists, policy makers, and stakeholder communities is critical as management focus is shifting toward innovative adaptation strategies (Martens et al. 2009). This study on the perceptions and experiences of the shellfish industry may help to inform the ultimate effectiveness of different adaptive responses. Over half of the industry participants recognized having personally experienced negative impacts from OA and feel a heightened level of concern about consequences today and for future generation. Slight differences in experience with negative OA impacts among shellfish products (Fig. 1) may be attributed to specific biological tolerances of organisms, variation in mariculture methods, or

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the extent of social interaction within a particular shellfish trade.

It is noteworthy to acknowledge that some participants were unsure if they personally experienced negative OA impacts (Fig. 2) as this reveals ambiguity within the industry when discerning between OA impacts or other natural occurrences that disrupt shellfish production. A more lucid criterion for discerning between OA impacts and other natural events with consequential impacts on shellfish production may assist the industry in documenting future losses and returns when adaptation strategies are implemented. Continuing support for and expansion of monitoring and research to quantify the magnitude of OA impacts on the shellfish industry should help ultimately endorse the costs of implementing adaptation strategies, as they have offset a large portion of the current oyster seed losses due to OA (BRP Report 2012).

Understanding may derive from a combination of experiential knowledge, generational tradition, and scientific understanding. A study of the U.S. public's understanding of climate change (Bord et al. 2000) found that knowledge is a powerful predictor of intention to mitigate a problem. Participants' relatively advanced understanding of OA and level of concern for the issue demonstrates the importance and relevance of OA within the shellfish industry. General agreement between industry and researchers on understanding of various timescales for marine processes to alter carbonate chemistry (Table 1) is compelling. Although correlations for individual processes were not always significant, this may simply reflect more ambiguous effects of those processes, or experience with different systems. Comparable recognition of OA information can improve communication between the shellfish industry and researchers and further demonstrates how experiential and academic knowledge are both valuable contributors to understanding OA, and may align.

Concern is a measure of awareness, acknowledgment of a problem, and the potential for collective action (Potter & Oster 2008). Contrasting responses on perceived OA consequences between the U.S. public and the shellfish industry (Fig. 4) are likely driven by differences of economic investment in natural resources as shown in other industries (Morgan-Brown et al. 2010, Sakurai et al. 2011). A climate change study of how the U.S. public processes information about complex issues found that individuals generally use information that is most easily assessable, but not necessarily relevant (Zaval et al. 2014). The U.S. west coast shellfish industry advanced understanding of OA and first-hand experience with negative impacts has alerted a reaction of concern. Contrastingly, a recent study showed that fishery-dependent Alaskan residents have a limited understanding of processes that drive OA and low perception of OA risk (Frisch et al. 2015). Whereas the shellfish industry is a key stakeholder group with a highly developed recognition of OA as an environmental and economic hazard, the U.S. public's level of concern about the severity of OA may only increase substantially after personally experiencing food security issues (Cooley et al. 2011).

The U.S. west coast shellfish industry possesses unique characteristics that may promote innovative adaptations that sustain production in future climate change scenarios. Unlike other aquaculture industries, shellfish hatcheries and growers appear to share a collaborative mentality that fosters trusting relations. Differences in perspective were not significant among states, as shown in Figure 5, demonstrating how communication and community is cultivated within this industry. As supported in the literature (Jackson 2005, O'Brien et al. 2006, Adger et al. 2009), the capacity of an industry to adapt to an environmental problem hinges on their recognition of a hazard. This shellfish industry acknowledges the problem of OA as they are presently encountering change and are forced to action.

At present, several hatcheries successfully adapted to OA and this accomplishment may inspire confidence that local mitigation strategies can sustain the shellfish industry and natural resources when facing this problem. To allow more continuous operation, some hatcheries are providing refuge to larvae by monitoring PCO_2 concentrations, buffering seawater, and altering timing of production. Monitoring local water quality and measuring the variability of site-specific carbonate chemistry can also reveal "windows of opportunity" when conditions are favorable based on tidal, seasonal, and diurnal photosynthesis/respiration cycles (Barton et al. 2012, Waldbusser & Salisbury 2014, Hales et al. in review).

Global change challenges to industries will likely require partnerships with other entities to provide infrastructure, capacity, or technical guidance, and these partnerships have already been well-established in the U.S. Pacific Northwest. Ocean acidification initiatives were first established in Washington, followed by a U.S. west coast initiative (California, Oregon, Washington, and British Columbia). Participant recognition of a mutual responsibility between the shellfish industry and scientists to address OA, as shown in the findings, indicates potential for collaborative research and data monitoring as it relates to commercial production. Participants acknowledged the federal government as the governing entity most responsible for addressing OA perhaps as a result of their national funding initiatives and research to benefit the shellfish industry.

Providing information on OA can motivate interest and participation in local monitoring initiatives (Donkersloot 2012). In addition to reducing CO_2 emissions and runoff of nutrients and organic carbon, the Washington State Blue Ribbon Panel on OA (BRP Report 2012) is focused on filling knowledge gaps, engaging with stakeholders across sectors, and building awareness that promotes scientific collaboration. Opportunities are emerging for the shellfish industry to articulate the efficacy of local adaptation strategies in combating OA. Empowering stakeholders with a voice can influence and direct future policy options (Brugha & Varvasovsky 2000). Engaged stakeholders who can articulate the nature of their claims have the ability to bridge relations and participate in environmental decision-making (Reed et al. 2009).

In summary, this study explored the U.S. west coast shellfish industry perspectives and experiences regarding OA, how they perceive OA-related obstacles, and their vision of adaptation. Important findings include (1) the majority of participants have personally experienced negative impacts from OA and believe OA is happening globally, regionally and locally; (2) the industry understanding of OA and concern for the problem is fairly advanced; (3) participants and OA researchers share comparable recognition of the timescales in which natural processes change nearshore water chemistry, whereas contrasting levels of concern for OA consequences between industry and the U.S. public is likely driven by differences in economic

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investment in natural resources; and (4) respondents from all three states expressed guarded optimism on their adaptability to OA.

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