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Public emotions and cognitions in response to ocean acidification

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ABSTRACT

Ecological studies on ocean acidification (OA) are abundant, but there are only a few studies examining the human dimensions (social science) of this threat to marine environments. This article explored public emotions and cognitions (attitudes, norms) toward OA, and how these concepts are related to knowledge and risk perceptions associated with this threat. Data were from a survey of residents in the coastal and most populated regions of Oregon, USA (n = 507). Respondents were grouped by their risk and knowledge, and shown four images depicting deteriorating conditions associated with OA, with questions measuring cognitions and emotions in response to each image. Knowledge about OA was quite low, and respondents perceived OA as a moderate risk to marine environments and a slight risk to themselves. As both knowledge and risk increased, awareness increased and emotions, attitudes, and norms became more negative, especially as conditions deteriorated. Implications and explanations of these findings were discussed.

1. Introduction

Ocean acidification (OA) involves a process where carbon dioxide (CO_2) is taken up by seawater and goes through chemical reactions that decrease the pH level of the water, saturation levels of calcium carbonate minerals, and concentration of carbonate ions (NOAA, 2021). These changes impede the ability of certain organisms that use calcium carbonate to build their skeletons and shells (e.g., corals, shellfish). Rising CO_2 in the atmosphere that is partially caused by human activities (e.g., burning fossil fuels, deforestation) is thought to be contributing to recent increases in OA (Doney et al., 2020). OA is expected to increase and threaten important benefits provided by marine environments (e.g., shellfish fisheries, aquaculture, shoreline protection; Doney et al., 2020; MEA, 2005). In marine areas off the coast of the State of Oregon (USA), for example, OA has progressed rapidly, with rates up to 30% higher than many other locations (Turi et al., 2016). Impacts of OA include declining populations of crabs and growth rates of oyster larvae, which threaten fisheries along the coast (Hettinger et al., 2013; UCS, 2019). According to Albright et al. (2016), the main comprehensive solution to OA is to reduce anthropogenic emissions of CO_2 and other greenhouse gasses, but there are additional actions that can be taken. For areas such as coral reefs, management decisions that support species adaptation and recovery (e.g., designate marine protected areas, reduce fishing pressure) can help to mitigate impacts associated with OA (Albright et al., 2016; Doney et al., 2020).

OA not only threatens fisheries, but also other cultural ecosystem services, which are benefits to humans provided by ecosystems such as marine environments (Fairchild et al., 2018; MEA, 2005; Rees et al., 2010). Gould and Lincoln (2017) categorized several types of cultural ecosystem services and marine environments provide many of these, including recreation (e.g., scuba diving, surfing), aesthetic (e.g., appreciate the beauty of marine areas), artistic (e.g., produce art inspired by marine areas), heritage (e.g., traditional or ancestral uses of marine areas), bequest (value marine areas for future generations), and educational (e.g., learn about marine areas) services. Given these services and benefits that marine environments provide, it is important to understand public awareness, emotions, and cognitions (e.g., attitudes, norms) regarding threats to these environments (e.g., OA). Although there have been recent studies on some of these issues in the context of OA (e.g., Capstick et al., 2016; Cooke and Kim, 2019; Danielson and Tanner, 2015; Frisch et al., 2015; Mabardy et al., 2015; Mossler et al., 2017; Schuldt et al., 2016; Spence et al., 2018), more research is needed to fully understand the human dimensions (social science) of this issue and inform both management and research. Exploring these topics in more detail is needed because it will improve understanding of what the public knows and thinks about OA, which may be useful for informing

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approaches for managing OA, educating people about this issue, and guiding future research. This article, therefore, explored public emotions and cognitions regarding OA and how these might be related to knowledge and perceptions of risk associated with this issue.

2. Conceptual foundation

2.1. Emotions

Emotions involve reactions that individuals express, especially when handling personal matters or events, with these emotions encompassing physiological (e.g., increased heart rate), behavioral (e.g., running away), physical or expressive (e.g., smiling), and experiential elements (e.g., experiencing joy; Bradley and Lang, 2000; Izard, 2007). Emotions are a part of daily human experiences that allow people to react to events or objects (Dolan, 2002). Human interactions with natural resources such as the ocean have historically invoked emotions where people developed responses to deal with situations that promoted safety and well-being (e.g., fear of drowning; Jacobs, 2009, 2012). Although many interactions with natural resources are different today and lead to a number of additional types of emotional responses (e.g., joy from watching whales or swimming in the ocean), the inherited emotional complexities are still part of humans (Jacobs, 2012). Given that many people desire experiences with marine environments (e.g., viewing marine wildlife, seeing coral reefs), studying emotional responses provides insight into human experiences with these environments (Jacobs, 2012).

Emotions are often researched by categorizing them into two perspectives. First, the discrete approach specifies that each emotion, such as fear, sadness, and anger, is qualitatively different from other emotions (Jacobs et al., 2014). This approach might adhere to the typical way that individuals identify their emotions, such as saying they are either joyful or sad. Second, the dimensional approach focuses on a smaller number of broader dimensions that encompass several emotions (Jacobs et al., 2014). Emotional valence is one important dimension of emotions, which describes the extent that emotions range from negative to positive affectivity with a midpoint that is neutral (Bradley and Lang, 2000; Briesemeister et al., 2012). Arousal is another dimension that refers to activation or deactivation (i.e., passivity) of emotions (Jacobs et al., 2014). Both valence and arousal can be used for classifying emotional dispositions (states vs. traits). Emotional traits involve the general overall tendency to respond emotionally to objects, situations, or events over time (i.e., stability), whereas emotional states are more specific feelings at one moment in time (Jacobs et al., 2014; Sponarski et al., 2015; Straka et al., 2019).

Studies have been conducted on emotions in response to locations such as coral reefs and coastal areas (e.g., Dean et al., 2018), marine diseases such as sea star wasting disease (Lu, 2015), and other issues such as OA. In the context of OA, for example, Capstick et al. (2016) found that hearing the term OA evoked a number of negative emotions (e.g., harm) among respondents. Similarly, Mabardy et al. (2015) found that some of their respondents experienced emotional impacts from OA such as feeling sad and angry when thinking about this issue.

2.2. Attitudes and norms

Human responses to marine and other natural resource issues not only consist of emotional expressions, but they also involve cognitive dispositions and processes of reasoning, evaluation, and decision-making (Manfredo, 2008; Vaske and Manfredo, 2012). Two of the most commonly studied cognitions are attitudes and norms. The cognitive component of attitudes is typically defined as an assessment of circumstances, objects, conditions, or activities with some degree of favor or disfavor (Eagly and Chaiken, 1993; Fishbein and Ajzen, 2010). One common conceptualization of norms defines them as standards that individuals use for evaluating whether activities, environments, or conditions should or should not be allowed to occur (Vaske and Whittaker, 2004). Personal norms can be aggregated to assess broader societal norms about an issue (Vaske and Whittaker, 2004). The target of an attitude or norm can be general (e.g., attitudes or norms concerning the environment or the entire ocean) or more specific (e.g., attitudes or norms concerning a specific issue such as OA; Vaske and Manfredo, 2012).

Many studies have examined public attitudes and norms toward various marine issues. Some research has even examined these cognitions in the context of OA. Capstick et al. (2016), for example, found that public attitudes toward OA were polarized, especially after linking it to climate change. Frisch et al. (2015) reported that their respondents had negative attitudes about OA and positive attitudes toward supporting more research into this issue. Gelcich et al. (2014) found that fewer than one-third of the public thought that governments should prioritize policies related to OA such as developing technologies to reduce CO_2. More recent research, however, has shown greater public support for actively reducing CO_2 to address OA (Buckley et al., 2017).

2.3. Knowledge

Attitudes, norms, and emotions may be influenced by knowledge. There are two common types of knowledge. First, self-assessed knowledge or awareness is subjective where there is no correct answer and individuals simply believe they are informed, aware, or knowledgeable about a topic (e.g., "how knowledgeable do you feel; " Perry et al., 2014; Wann and Branscombe, 1995). Second, factual knowledge is when someone either knows or does not know something that has a factually correct or incorrect answer (Perry et al., 2014; Wann and Branscombe, 1995). Factual knowledge is often measured by asking true/false or multiple-choice questions where there is one correct answer (e.g., Perry et al., 2014; Vaske et al., 2006).

Knowledge has been examined in relation to marine environments in general (e.g., "ocean literacy; " Guest et al., 2015; Steel et al., 2005) and also specific marine issues such as OA (Cooke and Kim, 2019; Spence et al., 2018) and marine reserves (Perry et al., 2014). In most studies of the general public, factual knowledge about marine issues tends to be quite low. Perry et al. (2014), for example, found that when tested on facts regarding marine reserves along the Oregon coast, 65% of the public answered half or fewer of the questions correctly. In the context of OA, almost all studies have found that public knowledge about this issue is low (Buckley et al., 2017; Capstick et al., 2016; Chilvers et al., 2014; Cooke and Kim, 2019; Danielson and Tanner, 2015; Frisch et al., 2015; Gelcich et al., 2014; Mossler et al., 2017; Spence et al., 2018; The Ocean Project, 2012). For example, among 15 different environmental issues related to marine areas, the European public reported being least informed about OA (Gelcich et al., 2014). Likewise, 80% of the British public had not previously heard of OA and only 14% knew a little about this issue (Capstick et al., 2016). Chilvers et al. (2014) found that the British public reported being least knowledgeable of OA compared to 11 other impacts of climate change on marine environments. Similarly low levels of public knowledge about OA have been found in other countries, including the USA (Danielson and Tanner, 2015; Cooke and Kim, 2019; Frisch et al., 2015; Mossler et al., 2017; The Ocean Project, 2012).

Research has shown that factual knowledge can be associated with emotions, attitudes, and norms. Jim and Xu (2002), for example, reported that the public had low knowledge about a newly established reserve, but positive attitudes toward this reserve. Wachholtz et al. (2014) found that students had negative attitudes toward climate change, but were also largely unaware of the causes and outcomes of climate change. In the context of OA, Spence et al. (2018) found that respondents who scored higher on a knowledge test about OA were more worried about this issue. Similarly, Capstick et al. (2016) found that knowledge about OA was positively related to negative attitudes and concerns about this issue. Cooke and Kim (2019) reported that public attitudes and concerns about climate change were positively related to awareness and factual knowledge about OA. Mossler et al. (2017) found that people who were more knowledgeable about OA were more likely to support policies that could reduce carbon emissions.

2.4. Perceived risk

Perceptions of risk may also be associated with attitudes, norms, and emotions. Perceived risk involves how much individuals believe that a hazard (e.g., OA) could impact or threaten themselves, other people, or something else (e.g., marine areas, the environment; Sjöberg, 2000). These risk targets, such as groups who may be impacted by a hazard, have the ability to sway an individual's risk perception (Sjöberg, 2000). Compared to objective risk assessments (i.e., actual probabilities and consequences of hazards), perceived risks are subjective evaluations of hazards (Slovic, 2010). Risk denial occurs when an individual attributes greater risk to another risk target (e.g., other people) than to themselves, and this comes from the individual's belief that they could stop or are immune to a personal threat (Sjöberg, 2000). Conversely, risk sensitivity occurs when an individual possesses a predisposition to rate most risks in life as large and believes that most risks, no matter what they are, pose serious threats (Needham et al., 2017; Sjöberg, 2004).

Risk perceptions have been studied in various contexts related to marine issues, including risks associated with marine recreation (Morgan and Stevens, 2008), climate change (Lacroix and Gifford, 2017), and species such as sharks (Gore et al., 2011). Research has also examined risk perceptions and related concerns in the context of OA. Although a few studies have found that only a small proportion of the public considers OA to be a risk (Capstick et al., 2016; Chilvers et al., 2014), most studies have reported that the majority of people are concerned about OA or consider it to be at least a moderate risk (Buckley et al., 2017; Cooke and Kim, 2019; Frisch et al., 2015; Gelcich et al., 2014; Mabardy et al., 2015; Mossler et al., 2017; Spence et al., 2018; The Ocean Project, 2012).

Research in various contexts has found that low perceived risks are often associated with normative acceptance and positive attitudes and emotions (e.g., Siegrist, 2000; Sjöberg, 2004; Vaske et al., 2004). In the context of OA, Cooke and Kim (2019) found that public attitudes and beliefs about climate change were positively related to concerns about OA. Both Capstick et al. (2016) and Spence et al. (2018) found that negative emotions and affective responses associated with OA and climate change coincided with increased risks and concerns about this issue.

2.5. Research questions

This body of research has also shown in various contexts that emotions, attitudes, norms, knowledge, and perceived risks can change as natural resource conditions improve or deteriorate (e.g., Ceurvorst and Needham, 2012; Needham et al., 2006; Vaske and Manfredo, 2012). For example, if OA is not present, the public may not be concerned, but responses may become more negative as conditions worsen. This article, therefore, explored the following research questions:

1. To what extent is the public factually knowledgeable about OA?
2. How much risk does the public perceive is associated with OA?
3. What are public emotions, attitudes, norms, and awareness in response to OA?
4. To what extent do these emotions, attitudes, norms, and awareness change as conditions related to OA deteriorate?
5. To what extent do these changes in emotions, attitudes, norms, and awareness in response to deteriorating OA conditions differ among subgroups of the public based on their factual knowledge and perceptions of risk?

3. Methods

3.1. Data collection

Data were obtained from two strata of Oregon residents. The first stratum included residents of zip codes along the Oregon coast and west of the Coast Mountain Range. These individuals live closest to the ocean (i.e., less than a 30 min drive to the Oregon coast), so are likely to be most aware of marine issues such as OA. However, data from this population are not necessarily reflective of dynamics in other regions of this state or of broader societal relationships with the ocean (Johnston et al., 2020). The second stratum, therefore, included residents of zip codes in the most heavily populated region of Oregon (i.e., cities of Portland to Ashland between the Coast and Cascade Mountain Ranges, which is a 1–2 h drive to the Oregon coast). This non-coastal population constitutes the majority of Oregon's voting population and is more socially, culturally, politically, and economically diverse compared to some other areas of this state (Johnston et al., 2020). Although this population is arguably not as aware of or directly invested in marine issues as coastal residents, this population provides insights into views held by residents of the most populous region of this state.

An online questionnaire was administered from January 5 to 19, 2021 to members of the Qualtrics Research Panel who were 18 years of age or older and resided in a zip code in these areas. Internet panels such as these consist of self-selected individuals who voluntarily join and are paid to complete online questionnaires on various topics multiple times a year. These panels can be cost effective and generate data rapidly, but there are some challenges such as accurately estimating sample representativeness and sampling error, difficulty ensuring a perfectly random sample (i.e., they usually involve nonprobability samples), and the low tolerance of some panel members to long questionnaires (Brandon et al., 2014; Vaske, 2019). Some respondents also have a tendency to skip questions or provide identical answers to all items in a set of scale questions to complete questionnaires quickly (i.e., straight-lining; Brandon et al., 2014; Vaske, 2019).

To address these challenges, the questionnaire required responses to all questions and also contained four attention filter questions that necessitated particular responses (e.g., "if you are reading this, select 'slightly support'"). A soft launch was sent to 42 individuals to check response accuracy, comprehension, and completion time. A speeding check, measured as one-half the median soft launch time (20 min), was implemented to ensure respondents were not speeding through the questionnaire and completing it in less than 10 min. Respondents who repeatedly straight-lined, answered the attention filters incorrectly, or failed the speeding check were excluded from the final dataset. The final total sample size was $n = 507$ (coast = 82, most heavily populated region = 425). The reasons for this difference in sample sizes between the coast and most heavily populated region are: (a) sampling was conducted relatively proportionate to population size (e.g., the coast has a much smaller total population), and (b) there are far fewer members of the Qualtrics Research Panel living along Oregon's coast than in its most heavily populated region. Partial responses were not recorded, so a response rate cannot be calculated and it is rare to accurately calculate response rates for internet panels (Brandon et al., 2014). A non-response bias check was not performed because other contact information of panel members (e.g., telephone numbers, addresses) is not available for most internet panels. The data were, however, weighted by demographic characteristics (e.g., male/female, education) from census information to improve sample representativeness to the population (Vaske, 2019).

3.2. Independent variables

The two independent variables were factual knowledge about OA and perceived risk associated with this issue. To measure factual knowledge, participants were asked whether they believed that five statements about OA were either true or false (or unsure). These statements are listed in Table 1 and this approach for measuring factual knowledge is identical to studies on other natural resource issues (e.g., Perry et al., 2014; Vaske et al., 2006). To measure perceived risk associated with OA, participants were asked how much they thought OA posed risks to the six different targets that are listed in Table 1. These risks were measured on eight-point scales of 1 "no risk" to 8 "high risk." This approach is consistent with other studies measuring risk perceptions (e.g., Needham et al., 2017; Petit et al., 2021).

3.3. Dependent variables

Four different scenarios were embedded in the questionnaire to measure emotions, attitudes, norms, and awareness in response to deteriorating conditions of coral reef areas impacted by OA. Images in the questionnaire depicted these deteriorating conditions (Fig. 1) with the first image showing a relatively healthy and alive coral reef, and each subsequent image showing progressively worse evidence and consequences of OA until the fourth image that showed only dead coral with a largely barren reef. Scenarios and image-based approaches such as these have been used in studies examining the human dimensions of various marine issues (e.g., Ceurvorst and Needham, 2012; Manning and Freimund, 2004; Needham et al., 2011).

Below each image were questions measuring four dependent variables in response to the conditions depicted in each image: (a) emotions, (b) attitudes, (c) norms, and (d) awareness. Five different emotions were measured after asking respondents how each image made them feel (fearful, angry, surprised, disgusted, sad) on eight-point scales of 1 "not at all" to 8 "extremely." This approach for measuring emotions is consistent with previous studies (e.g., Ekman and Friesen, 1971; Izard, 2007; Jacobs et al., 2014). Attitudes were measured with two different cognitive responses (good, like) to each image on the same eight-point scale. This method is identical to other studies measuring attitudes (e.g., Perry et al., 2017; Sponarski et al., 2015). Norms in response to each image were measured on two nine-point scales of 1 "very unacceptable" to 9 "very acceptable" and 1 "should definitely not allow" to 9 "should definitely allow." These scales are commonly used for measuring norms (e.g., Ceurvorst and Needham, 2012; Needham et al., 2011). Awareness was measured by asking respondents "do you think the conditions in this image show effects of OA" with responses of "no," "yes," and "unsure."

Table 1
Respondent factual knowledge and perceptions of risk associated with OA.

	Frequencies
Factual knowledge [a]	
Ocean acidification improves the ability of coral reefs to grow (False)	73
Ocean acidification does not impact species in Oregon's marine or coastal areas (False)	69
Human production of carbon dioxide is causing ocean acidification to increase (True)	67
Ocean acidification is no different than normal seasonal fluxes in seawater pH levels (False)	57
Some marine species can survive better under low pH levels (i.e., with a more acidic ocean) (True)	13
Total mean (*M*) 0–5 correct (standard deviation [*SD*])	2.78 (1.49)
Perceived risk – How much do you think OA poses a risk to: [b]	
Coral reef areas in particular	6.35 (1.57)
Other species living in marine areas	5.94 (1.60)
Marine areas (the ocean) in general	5.92 (1.56)
The tourism industry	5.24 (1.87)
Other humans or society in general (e.g., health, jobs)	4.53 (1.88)
Yourself (e.g., health, jobs)	4.12 (1.96)

[a] Cell entries are percent (%) who answered correctly unless specified as means (*M*) and standard deviations (*SD*) in parentheses.

[b] Cell entries are means (*M*) with standard deviations (*SD*) in parentheses on 8-point scale of 1 "no risk" to 8 "high risk."

These questionnaire items were repeated with identical wording below each of the four images.

3.4. Data analysis

Responses to the five questions measuring factual knowledge were recoded as 0 "did not answer correctly" (included "unsure") and 1 "answered correctly," summed to create a total knowledge score (0–5 correctly answered), and dichotomized into lower and higher knowledge groups based on the median split. K-Means cluster analysis of the six risk targets was used for grouping respondents into lower and higher risk groups. Combining these factual knowledge and perceived risk groups into a matrix resulted in four groups (lower risk, lower knowledge; lower risk, higher knowledge; higher risk, lower knowledge; higher risk, higher knowledge).

The multiple item indices measuring emotions, attitudes, and norms were tested for measurement reliability using Cronbach's alpha (Vaske, 2019). Impact acceptability curves (see Vaske and Whittaker, 2004 for a review) were then used for displaying and analyzing the extent that emotions, attitudes, norms, and awareness changed as conditions related to OA deteriorated across the four scenarios. These curves show how the mean emotions and cognitions change across scenarios. Another measure on the curves is crystallization, which involves the consensus or agreement among respondents. One common approach for measuring crystallization is to average the standard deviations for points comprising the curve (Ceurvorst and Needham, 2012).

Bivariate chi-square (χ^2) tests, independent samples *t*-tests, and one-way analysis of variance (ANOVA, *F*) tests with their associated effect sizes (e.g., Cramer's *V*, point-biserial correlation [r_{pb}], eta [η]) examined the extent that emotions, attitudes, norms, and awareness differed among groups based on their factual knowledge and perceptions of risk. A statistical significance level of $p \leq .01$ was adopted based on the Bonferroni correction procedure to reduce the possibility of false discoveries and multiple test bias given the four scenarios (i.e., multiple comparison problem, family-wise error; Vaske, 2019). Responses to all questions examined in this article were also tested for any differences between the two strata (coast, most heavily populated region) and only 5 of the 54 (9%) tests were statistically significant. Effect sizes ranged from 0.01 to 0.17 and averaged only 0.06. Using guidelines from Cohen (1988) and Vaske (2019), these effect sizes suggested that the strength of any differences between the strata was "small" or "minimal." Given these small effect sizes and the fact that 91% of the tests showed no statistical differences, the responses from these two strata were aggregated into a single public sample.

4. Results

Respondents correctly answered an average of only 56% of the questions measuring factual knowledge about OA (2.78/5 correct; Table 1). Respondents were most likely to know that OA does not improve the ability of coral reefs to grow (73%) and least likely to know that some marine species can survive better under low pH levels (e.g., algae, seagrasses; 13%). In total, 13% of respondents answered none of the questions correctly and only 4% answered every question correctly. The largest proportion of respondents (40%) answered four of the five questions correctly. The median split was 3, so 0–3 correct responses were categorized as lower knowledge (55%) and 4–5 correct responses were labelled as higher knowledge (45%).

Respondents felt that OA represented a slight risk to themselves and other humans, and a moderate risk to the tourism industry, marine areas, coral reefs, and other marine species (Table 1). Respondents thought that OA posed the greatest risk to coral reefs. A series of two- to six-group cluster analyses of these six risk targets showed that the two-group solution provided the best fit where respondents who rated all risks the lowest (46%) were labelled lower risk and those who rated all risks the highest (54%) were labelled as higher risk. Combining the two

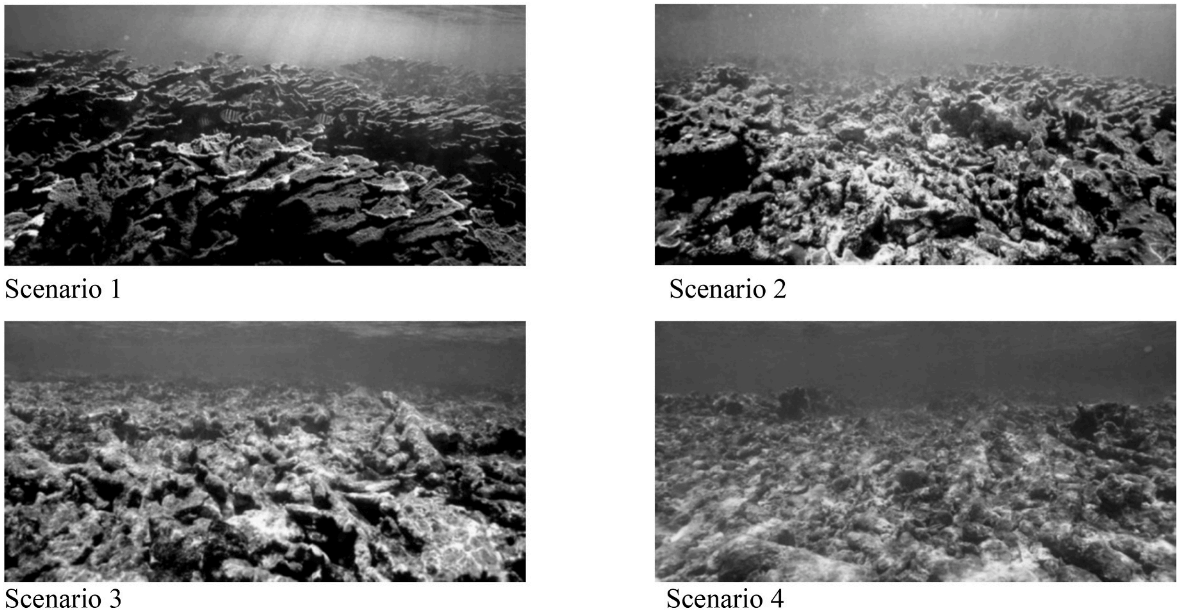


Fig. 1. Scenarios embedded in the questionnaire for measuring responses to deteriorating OA conditions. These were shown in color to respondents (images courtesy of P. Dustan and A. Haas [Haas et al., 2015] and used with permission; for these images in color, see Haas et al., 2015).

knowledge groups (lower and higher knowledge) with these two risk groups (lower and higher risk) created four possible combinations: lower risk, lower knowledge (32%); lower risk, higher knowledge (14%); higher risk, lower knowledge (23%); and higher risk, higher knowledge (31%).

There were no statistically significant relationships between knowledge about OA and both age and sex (e.g., male, female). However, more educated respondents had significantly higher knowledge about OA, $\chi^2 = 14.87$, $p = .002$, $V = 0.17$. There were no relationships between risks of OA and age, sex, and education. Personally seeing coral reefs before answering the questionnaire was also not significantly related to both knowledge and risks associated with OA.

Cronbach alpha reliability analyses were performed on the three dependent concepts measured with multiple variables on scales

Table 2
Variables and scale reliabilities for emotions, attitudes, and norms in response to the OA scenarios [a].

	Item-total correlation	Alpha if item deleted	Cronbach alpha
Emotions [b]			.89–.93
Fearful	.76–.84	.85–.90	
Angry	.83–.86	.84–.90	
Surprised	.51–.65	.89–.93	
Disgusted	.81–.85	.85–.90	
Sad	.75–.84	.87–.90	
Attitudes [c]			.88–.93
Good	.79–.87	–	
Like	.79–.87	–	
Norms			.88–.93
Acceptance scale [d]	.78–.87	–	
Should scale [e]	.78–.87	–	

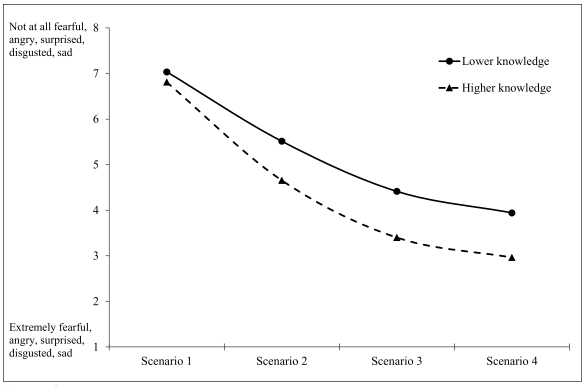
[a] Cell entries represent ranges from lowest to highest across the four OA scenarios.
[b] Measured on 8-point scales of 1 "not at all" to 8 "extremely" and these were then reverse coded for analysis so the highest number represented the most positive emotion and the lowest number represented the most negative.
[c] Measured on 8-point scales of 1 "not at all" to 8 "extremely."
[d] Measured on 9-point scale of 1 "very unacceptable" to 9 "very acceptable."
[e] Measured on 9-point scale of 1 "should definitely not allow" to 9 "should definitely allow."

(emotions, attitudes, norms) for each of the four OA scenarios (Table 2). Alphas ranged across scenarios from 0.89 to 0.93 for emotions, 0.88-0.93 for attitudes, and 0.88-0.93 for norms. These coefficients exceeded the standard of > 0.65 suggested by Vaske (2019), removing any variables did not improve reliability, and the item-total correlations ranged from 0.51 to 0.87. These results showed consistency among the variables measuring each concept and justified computing composite indices for each concept for each scenario.

As impacts from OA worsened from scenarios 1 to 4, the emotions, attitudes, and norms for respondents became more negative (Fig. 2). As impacts from OA worsened, awareness that the scenarios showed effects of OA increased. Compared to respondents with lower knowledge about OA, those with higher knowledge had more negative emotions, attitudes, and norms, especially across the scenarios showing effects of OA (scenarios 2 to 4). Respondents with higher knowledge were also more likely to be aware that the scenarios showed effects of OA. The differences in emotions between these two knowledge groups were statistically significant for scenarios 2 to 4 and the effect sizes showed that these differences were "medium" (Cohen, 1988) or "typical" (Vaske, 2019). For attitudes, the differences between the two groups were significant for scenarios 2 and 3, but the effect sizes were relatively "small" (Cohen, 1988) or "minimal" (Vaske, 2019). The differences in norms between the two groups were significant for scenarios 2 to 4, but the effect sizes were relatively "small" (Cohen, 1988) or "minimal" (Vaske, 2019). All four scenarios showed significant differences in awareness between these two groups with "small" to "medium" (Cohen, 1988) or "minimal" to "typical" (Vaske, 2019) effect sizes. The Levene's tests for homogeneity showed significant differences between groups in their crystallization or consensus for both emotions and attitudes, but not for norms. For emotions and attitudes, there was more consensus within those with higher knowledge.

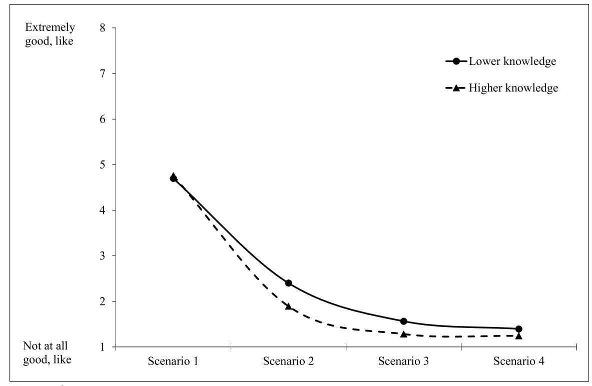
Compared to respondents who perceived lower risks from OA, those who perceived higher risks had more negative emotions, attitudes, and norms, especially across the scenarios showing effects of OA (scenarios 2 to 4; Fig. 3). Respondents perceiving higher risks were also more likely to be aware that the scenarios showed effects of OA. The differences in emotions between these two risk groups were statistically significant for all of the scenarios and the effect sizes showed that these differences ranged from "small" (Cohen, 1988) or "minimal" (Vaske, 2019) for scenario 1 to relatively "large" (Cohen, 1988) or "substantial" (Vaske,

a. Emotions



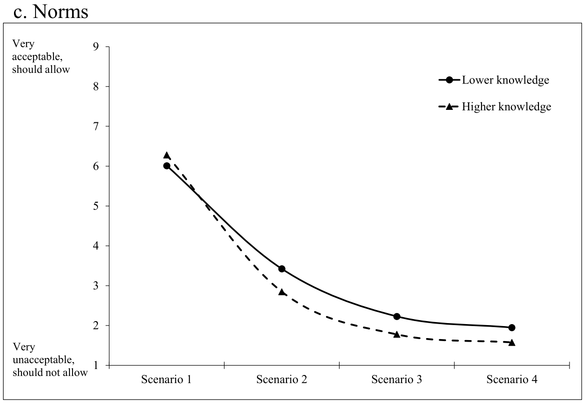
Scenario 1: $t = 1.81$, $p = .071$, $r_{pb} = .08$.
Scenario 2: $t = 5.22$, $p < .001$, $r_{pb} = .23$.
Scenario 3: $t = 6.33$, $p < .001$, $r_{pb} = .27$.
Scenario 4: $t = 6.07$, $p < .001$, $r_{pb} = .26$.
Crystallization: lower knowledge $SD = 1.81$, higher knowledge $SD = 1.60$, Levene's $F = 15.68$, $p < .001$.

b. Attitudes



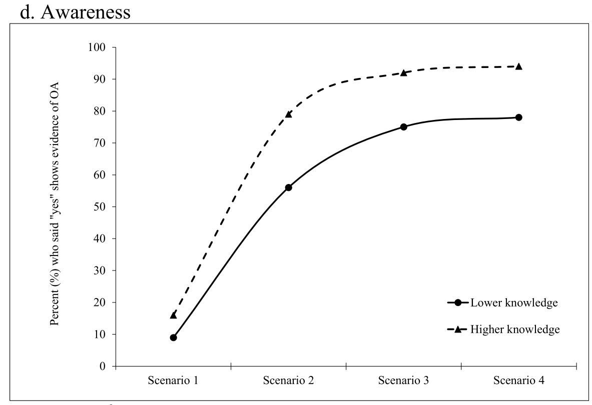
Scenario 1: $t = 0.30$, $p = .761$, $r_{pb} = .01$.
Scenario 2: $t = 3.72$, $p < .001$, $r_{pb} = .16$.
Scenario 3: $t = 3.38$, $p = .001$, $r_{pb} = .14$.
Scenario 4: $t = 1.89$, $p = .060$, $r_{pb} = .08$.
Crystallization: lower knowledge $SD = 1.56$, higher knowledge $SD = 1.23$, Levene's $F = 16.35$, $p < .001$.

c. Norms



Scenario 1: $t = 1.27$, $p = .205$, $r_{pb} = .06$.
Scenario 2: $t = 3.21$, $p = .001$, $r_{pb} = .14$.
Scenario 3: $t = 3.11$, $p = .002$, $r_{pb} = .14$.
Scenario 4: $t = 2.67$, $p = .008$, $r_{pb} = .12$.
Crystallization: lower knowledge $SD = 1.93$, higher knowledge $SD = 1.84$, Levene's $F = 6.76$, $p = .180$.

d. Awareness



Scenario 1: $\chi^2 = 11.35$, $p = .003$, $V = .15$.
Scenario 2: $\chi^2 = 29.87$, $p < .001$, $V = .24$.
Scenario 3: $\chi^2 = 33.50$, $p < .001$, $V = .25$.
Scenario 4: $\chi^2 = 22.15$, $p < .001$, $V = .20$.

Fig. 2. Emotions, attitudes, norms, and awareness in response to the OA scenarios for lower and higher knowledge groups.

2019) for scenario 3. For attitudes, the differences between groups were significant for scenarios 3 and 4, but the effect sizes were "small" (Cohen, 1988) or "minimal" (Vaske, 2019). The differences in norms between the risk groups were significant for scenarios 2 to 4, but the effect sizes were relatively "small" (Cohen, 1988) or "minimal" (Vaske, 2019). Only scenarios 2 and 3 showed significant differences in awareness between these two groups with relatively "small" (Cohen, 1988) or "minimal" (Vaske, 2019) effect sizes. The Levene's tests showed significant differences between the two groups in their crystallization or consensus for attitudes, but not for emotions or norms. For attitudes, there was more consensus within those who perceived higher risks.

For the four combined risk and knowledge groups (lower knowledge, lower risk; lower risk, higher knowledge; higher risk, lower knowledge; higher knowledge, higher risk), the lower risk and lower knowledge group had the most positive emotions, attitudes, and norms across the scenarios (Fig. 4). This group was also among the least aware that the scenarios showed effects of OA. Conversely, the higher risk and higher knowledge group was most aware that the scenarios showed effects of OA and this group also generally had the most negative emotions, attitudes, and norms across the scenarios. Responses from the other groups (lower risk, higher knowledge; higher risk, lower knowledge) generally fell in between these two groups. The differences in emotions among these four groups were statistically significant for all scenarios and the effect sizes showed these differences ranged from relatively "small" (Cohen, 1988) or "minimal" (Vaske, 2019) for scenario 1 to "large" (Cohen, 1988) or "substantial" (Vaske, 2019) for scenario 3. For attitudes, norms, and awareness, the differences among the four groups were significant for scenarios 2 to 4 and the effect sizes were between "small" and "medium" (Cohen, 1988) or "minimal" and "typical" (Vaske, 2019). The Levene's tests showed significant differences among these four groups in their crystallization or consensus for attitudes, but not for emotions or norms. For attitudes, the most consensus was within the lower risk and higher knowledge group and also within the higher risk and higher knowledge group. The least consensus was within the lower risk and lower knowledge group.

5. Discussion

5.1. Implications for managers and other practitioners

These results have implications for both practitioners and researchers. From a practitioner perspective (e.g., managing government agencies, non-governmental organizations), this sample of Oregon residents had relatively low factual knowledge about OA, suggesting a need to improve outreach and information efforts about this topic.

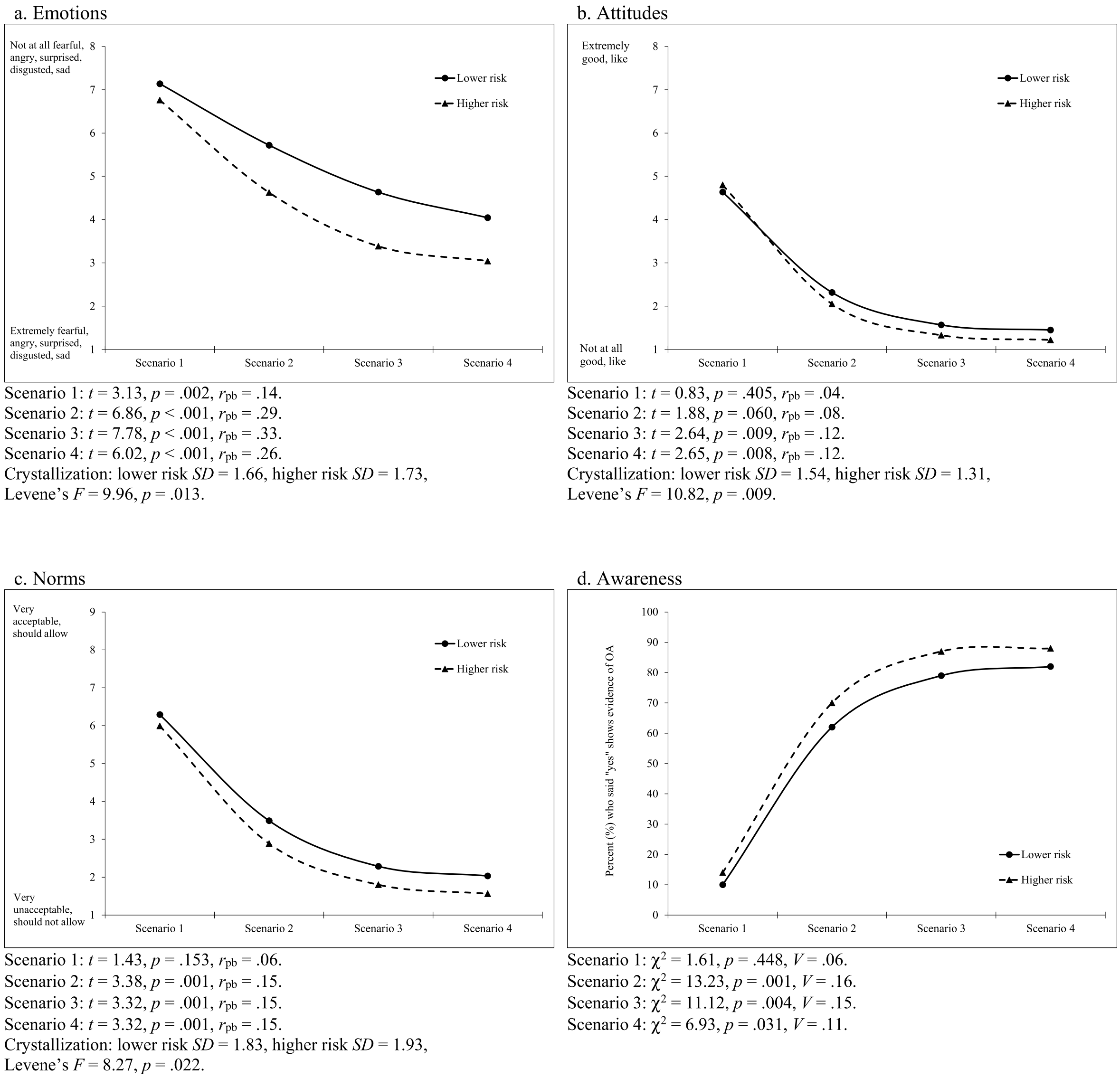


Fig. 3. Emotions, attitudes, norms, and awareness in response to the OA scenarios for lower and higher risk perception groups.

Practitioners could focus on providing more information and interpretation about OA through resources at science centers, aquariums, websites, social media sites, and other educational outlets. Targeting specific interest groups (e.g., shellfish companies, restaurants) with information about OA could also expand knowledge and provide useful information about the potential impacts of OA for those groups.

This sample was least knowledgeable of what species can survive better with OA, how OA differs from normal seasonal fluxes in seawater, and how human actions can impact OA, so information about these issues could be prioritized. That said, public knowledge about marine environments in general tends to also be quite low (e.g., "ocean literacy;" Guest et al., 2015; Steel et al., 2005) and although overall ocean literacy was not measured here, it is possible that this sample's relatively low knowledge about OA reflects a similarly low level of knowledge about marine environments in general. Therefore, providing information to the public about issues related to OA may also help to heighten knowledge about marine environments in general. This is especially important given the many cultural ecosystem services provided by marine environments (e.g., recreation, aesthetic, heritage, bequest, educational; Gould and Lincoln, 2017).

In the context of self-assessed knowledge or awareness, as impacts of OA worsened across each of the scenarios, awareness that the scenario showed effects of OA increased. This is important because it shows that respondents knew when OA became more problematic, so practitioners could perhaps reduce public information about signs of deterioration from OA and instead provide more information about specific aspects of OA such as impacts to shellfish, the science behind climate change increasing the severity of OA, and techniques for mitigating OA.

Respondents also felt that OA poses a much greater risk to marine environments and species than to themselves and other people. This suggests these residents understand that OA poses risks to the ocean, but they are not making a strong connection that risks to the ocean also pose risks to humans. OA impacts shellfish (e.g., crabs, oysters, clams) that humans consume and rely on for income. OA may also impact other ecosystem components, as it can alter organisms at the bottom of the food chain in the ocean (e.g., calcareous plankton) as well as larger megafauna such as sharks and seals (NOAA, 2021; Rosa et al., 2017). These other species provide cultural ecosystem services (e.g., whale watching) and also food for humans (Grose et al., 2020). Failing to connect risks of OA to themselves and other humans suggests there is a need for more public information about the wide-ranging effects of OA including the fact that climate change is a contributor to OA that affects people around the world. Practitioners could, therefore, emphasize how OA impacts many ecosystems and species, not just isolated examples.

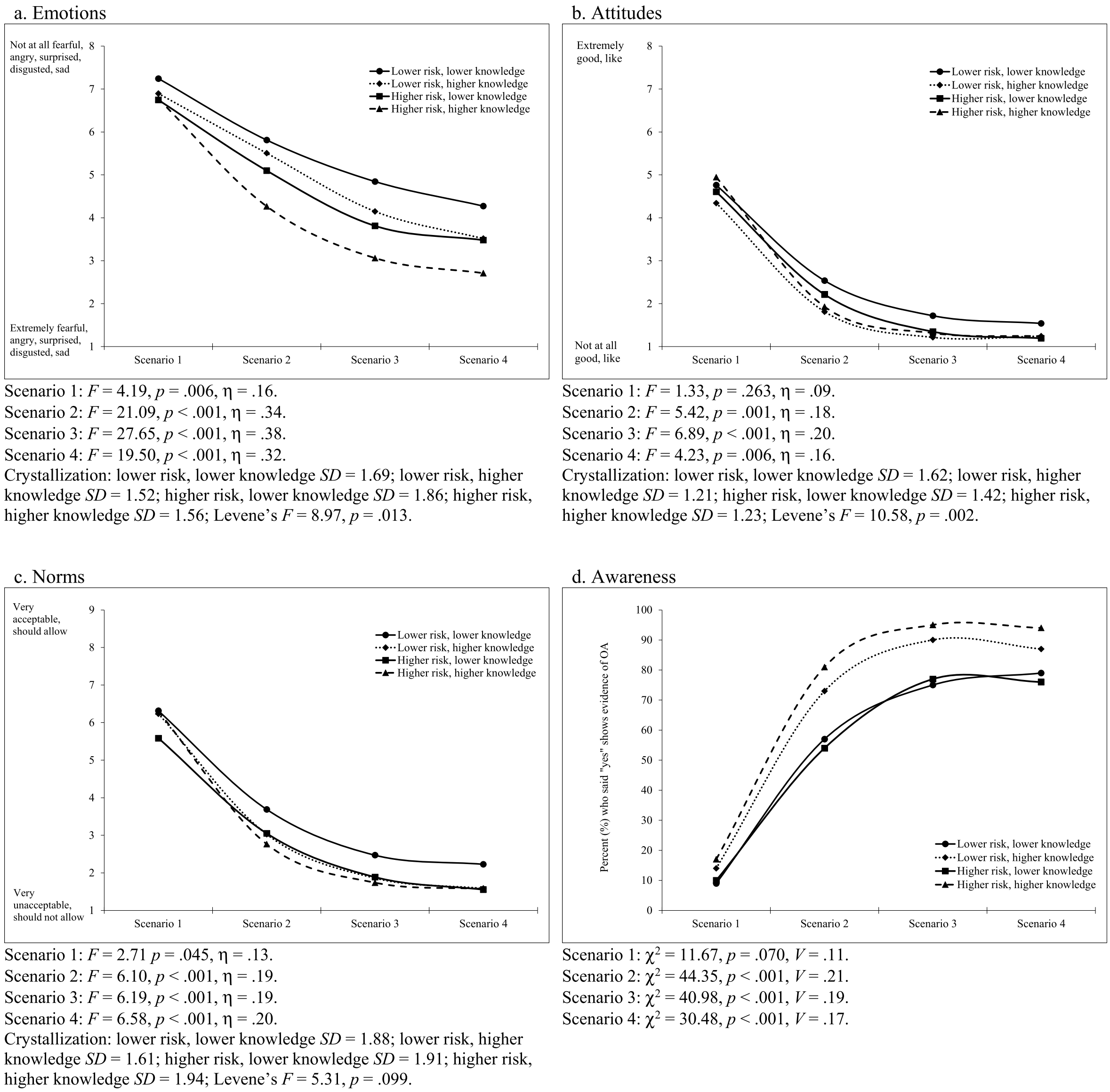


Fig. 4. Emotions, attitudes, norms, and awareness in response to the OA scenarios for the combined risk and knowledge groups.

Combining the risks and factual knowledge scores showed that the lower risk, lower knowledge (32%) and higher risk, higher knowledge (31%) groups were the two largest groups in the sample, suggesting that many respondents were polarized in their knowledge and perceptions of risk associated with OA. The largest proportions of respondents either: (a) know little and are less concerned about OA, or (b) know about OA and are concerned, leaving a gap of fewer respondents in the middle. Practitioners could use these findings to target groups with different information about OA. For example, for those with low knowledge and low risk based on their questionnaire responses, basic information that defines OA and highlights its risks would help, with the option to learn more about OA for those who are interested.

Respondents' emotions were generally more positive than their cognitions (e.g., norms, attitudes) toward OA. Even for the first scenario that showed no obvious effects of OA, their attitudes were only slightly to moderately favorable and their norms stated that conditions were only moderately acceptable or should be allowed to occur. Although speculative, these results may have occurred because coral reefs may not spark the strong cognitive responses that are often expressed for more charismatic megafauna such as dolphins, whales, and sharks (Albert et al., 2018). Cognitions involve more thought than emotional responses, but both are important for information processing and persuasion models such as the Elaboration Likelihood Model (ELM) and Heuristic-Systematic Model (HSM), which involve: (a) central or systematic routes where people are provided with detailed and cognition provoking messages, and (b) peripheral or heuristic routes that provide simple and more emotional messages, cues, and images (Eagly and Chaiken, 1993). In their science communication efforts, practitioners could consider integrating both types of messaging to target both emotional and cognitive responses associated with OA. In addition, the trend of more negative emotions and cognitions as conditions deteriorated across the scenarios suggests that respondents were concerned about the issue and do not want OA to impact reefs. As conditions deteriorated, respondents were also more likely to know that these conditions showed effects of OA. These findings suggest that many respondents already understand that OA has negative outcomes, so practitioners may be able to provide more specific and targeted forms of information when communicating about OA.

There were no substantive differences between the coastal and inland (i.e., more heavily populated area) samples in the context of responses to OA. Arguably, coastal residents should be more aware of and directly invested in marine issues due to their proximity to the ocean, but this was not the case here. Given that OA is related to climate change that is broadly acknowledged and transcends geographical locations, perhaps living in close proximity to the ocean is less important in the context of emotions and cognitions associated with OA. The inland sample also lives in relatively close proximity to the Oregon coast (e.g., just a 1–2 h drive), so many of these residents have easier access to marine environments compared to those living in the inland and landlocked states. From a practitioner perspective, this suggests that targeting different messages about OA to coastal versus inland Oregon residents may not be necessary; both groups could be targeted with similar informational and interpretive messaging. As part of this information and messaging about OA, practitioners could also consider engaging in more interactive, two-way engagements with the public, such as through community meetings and focus groups.

5.2. Implications for researchers

From a research perspective, factual knowledge about OA was quite low among this public sample, which is consistent with previous research on OA and some other topics related to marine areas (e.g., Capstick et al., 2016; Chilvers et al., 2014; Cooke and Kim, 2019; Danielson and Tanner, 2015; Frisch et al., 2015; Mossler et al., 2017; Perry et al., 2014; Spence et al., 2018). Respondents with higher knowledge about OA had more negative emotions, attitudes, and norms toward this issue, which is also consistent with past research on OA (Capstick et al., 2016; Cooke and Kim, 2019; Mossler et al., 2017; Spence et al., 2018) and other natural resource topics (Jim and Xu, 2002; Wachholtz et al., 2014). Spence et al. (2018), for example, found that respondents with higher knowledge about OA were more worried about this issue. Capstick et al. (2016) found that knowledge about OA was related to negative attitudes and concerns about this issue. Respondents with higher knowledge about OA were also more aware that conditions depicted in the scenarios showed evidence of OA, which is similar to research that has found positive relationships between factual and self-assessed knowledge (Belden et al., 1999; Perry et al., 2014; Steel et al., 2005).

In addition to knowledge about OA, Table 1 also showed that respondents felt this issue posed only slight risks to themselves, but greater risks to other targets (e.g., marine areas, reefs, other marine species), which could be evidence of some risk denial (i.e., attribute greater risk to another target than to themselves; Sjöberg, 2000). The majority of respondents also considered OA to be a moderate or higher risk overall, which is consistent with other research on this issue (Buckley et al., 2017; Cooke and Kim, 2019; Frisch et al., 2015; Gelcich et al., 2014; Mabardy et al., 2015; Mossler et al., 2017; Spence et al., 2018; The Ocean Project, 2012). In addition, those who perceived higher risks had more negative emotions, attitudes, and norms, which is consistent with previous research (Capstick et al., 2016; Cooke and Kim, 2019; Siegrist, 2000; Sjöberg, 2004; Spence et al., 2018; Vaske et al., 2004). Both Capstick et al. (2016) and Spence et al. (2018), for example, found that negative emotions and affective responses associated with OA and climate change were related to increased risks and concerns about this issue. Cooke and Kim (2019) found that public attitudes and beliefs about climate change were positively related to concerns about OA. Respondents who perceived higher risks were also more likely to be aware that the scenarios showed evidence of OA, which is consistent with research on relationships between risk and awareness or knowledge. Lee et al. (2015), for example, found that knowledge about causes of climate change was correlated with perceptions of risk about this issue. Connecting both risk and knowledge, the low risk, low knowledge and high risk, high knowledge groups were most polarized in their emotional, attitudinal, and normative responses across the scenarios. Capstick et al. (2016) found similar results where directly referencing climate change when discussing OA resulted in relatively polarized responses toward this issue.

Respondent emotions were highly positive for the first scenario that showed no obvious effects of OA, but emotions declined quickly as conditions deteriorated. This is consistent with findings from Capstick et al. (2016) and Mabardy et al. (2015) who found that OA evoked a number of negative emotions such as feeling sad and angry. From a measurement perspective, the high reliability of the emotion variables measured here demonstrated consistency with the dimensional approach to measuring emotions (i.e., smaller number of broader dimensions that encompass several discrete emotions; Jacobs et al., 2014). The discrete emotion variables (e.g., fearful, sad) combined to measure the valence dimension of emotions (i.e., from negative to positive affectivity; Bradley and Lang, 2000; Briesemeister et al., 2012) and respondents' emotional valence disposition influenced how they responded to the OA conditions depicted in the scenarios. This is consistent with previous research (e.g., Sponarski et al., 2015; Straka et al., 2019) and suggests that through measuring discrete emotional dispositions, it is possible to simultaneously measure valence dispositions as well. This idea is similar to how affective responses (e.g., emotions) can be interrelated rather than being independent (Russell, 1980). Future research should build on this study to measure more emotional dispositions toward OA. In addition, the emotions in this study generally mirror those that Natural Language Understanding and related processes (i.e., artificial intelligence, machine learning) can code for in big data and automated analyses of large datasets (Hirschberg and Manning, 2015). Examining the prevalence and patterns of emotions associated with OA in these data sources could be an extension that provides contextual and qualitative descriptions to emotions beyond the valence scales used here.

As conditions related to OA in the scenarios deteriorated, respondent emotions, norms, and attitudes became more negative. This is consistent with research in other contexts measuring responses to deteriorating natural resource conditions (Ceurvorst and Needham, 2012; Needham et al., 2006, 2011). Most of the social science research on OA, however, has only focused on OA conditions at one point in time or for a certain OA condition or level of impact. Limited social science research has varied the levels of impact or deterioration caused by OA, so this study adds a new perspective of how emotions and cognitions can change as conditions associated with OA deteriorate. Future research should consider building on this study by incorporating additional impacts and deteriorating conditions from OA when measuring how people respond to this issue.

Overall, there has been limited research on the social science or human dimensions aspects of OA, so this study contributes to the literature. There are, however, additional issues that should be considered for future studies. First, the data were obtained from a nonprobability sample, as Qualtrics Research Panel members sign up voluntarily to respond to questionnaires. Although the data were weighted by census information to be more demographically representative of the target population, nonprobability samples are not necessarily representative of larger populations. Future research should conduct random probability samples and compare results to those reported here to determine any similarities or differences. Second, the public sample of residents did not deliberately target any special interest groups (e.g., representatives of shellfish companies or members of OA councils, task forces, science panels) who likely have more knowledge and involvement associated with OA. Third, the scenarios showed coral reefs deteriorating from OA, but there are no tropical coral reefs in Oregon even though clear evidence of OA has been found in this state's marine areas (Hettinger et al., 2013; UCS, 2019). If different images were used for showing impacts from OA, such as images of crab shells deteriorating or oyster larvae unable to grow, the images might have been more salient for Oregon residents. However, 56% of respondents had seen coral reefs on the television, on the internet, in books, or in magazines, and an additional 29% had seen them in person (i.e., live). Even though tropical coral reefs are not found in Oregon, almost all respondents (85%) had seen reefs before, and impacts of OA on reefs have been widely documented (e.g., Anthony et al., 2008; Pandolfi et al., 2011). Fourth, these scenarios used images, which depict static conditions in time. Videos or other multimedia may show more dynamic and realistic conditions related to OA (Manning and Freimund, 2004). The scenarios were also presented in the questionnaire in the same order (increasing in impact) and were not randomized in their order, so research should test for potential starting point bias and order effects. Fifth, consistent with some research (see Jacobs et al., 2012 for a review), this study did not measure the arousal dimension of emotions (e.g., relaxed, energetic), so research is needed to examine if OA triggers any arousal responses (Jacobs et al., 2014). Sixth, these results are limited to this one sample of Oregon residents and the generalizability of findings to other populations and geographical areas remains a topic for further empirical investigation.

6. Conclusion

In conclusion, this study built on the limited previous research examining the human dimensions of OA by exploring public emotions and cognitions (e.g., attitudes, norms) regarding OA and how these might be related to knowledge and perceptions of risk associated with this issue. Results from a survey of residents in the coastal and most populated regions of Oregon showed that their knowledge about OA was quite low, and they perceived OA to be a moderate risk to marine environments and a slight risk to themselves. As both knowledge and risk increased, awareness increased and emotions, attitudes, and norms became more negative, especially as conditions related to OA deteriorated. These results improved understanding of what a sample of the public knows and thinks about OA, which is useful for informing approaches for managing OA, educating people about this issue, and guiding additional research. This article discussed a number of future research needs and several approaches for managing OA and informing the public about this issue.

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Ethical statement

This article was not submitted elsewhere for publication and was not under consideration for publication elsewhere. After acceptance and publication, it will not be published elsewhere.

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Each author contributed to this article, although primary authorship was the first and second authors. All authors assisted with conceptualization. The first and second authors analyzed the data.

All authors approved the final article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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