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Gauging perceptions of ocean acidification in Alaska

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ABSTRACT

While ocean acidification (OA) poses a significant threat to ocean-related ecosystems and communities reliant on marine fisheries, aquaculture, and coral reef systems, limited public understanding and awareness can prevent coastal regions from being able to adequately assess the need for OA adaptation or mitigation. This study assessed public understanding of OA and how social and demographic factors influence the public's concern for OA. The analysis was based on 311 questionnaires from full-time Alaska residents. The results showed that most Alaskans self-reported to have a basic awareness of OA, and subsequently were able to recognize that CO_2 emissions related to human activity are the dominant driver of changing ocean conditions. However, there was a low recognition of how natural variability in the marine environment affects OA, and most respondents were not very confident in their understanding of OA-related science. Moreover, even though many communities in Alaska are reliant on commercial and subsistence fishing activities, the respondents had a low awareness of fisheries-related OA risk. Given the ongoing debate associated with climate change research, evaluating CO_2 mitigation efforts through the perspective of OA could give individuals an unbiased way to assess the pros and cons of more intensive efforts to curb CO_2 emissions. Furthermore, using OA communication to enhance the understanding of how natural variability influences OA around the state and the potential economic implications for Alaska fisheries would help residents and stakeholders make informed decisions when considering fisheries management plans, food security, and job diversity as OA intensifies. Solidifying the understanding that any reduction in pH and intensification of OA can have implications for marine species that are irreversible on human timescales will reinforce not only that OA is an immediate concern, but also the importance of taking action now.

1. Introduction

Marine environments and coastal communities around Alaska have been under pressures from human-related activities, including overfishing, oil and gas development, and mining, for the past several decades. In addition, new globally emerging threats such as climate change and ocean acidification (OA) are exacerbated in Alaska where highly productive commercial and subsistence fisheries are projected to experience more rapid transitions in temperature and chemical parameters (including pH) beginning this decade e.g. [23,67,43,46,17]. While climate change could cause statewide disruptions in a number of economic sectors, OA, which is the progressive decrease in marine pH and carbonate ion concentrations driven by the uptake of anthropogenic CO_2, could have an impact on marine fisheries e.g. [43,12,13].

An expanding body of literature has shown that the biological effects of OA are predominately negative, although there is variability within certain species groups [2,35,74,39,40,14]. Throughout Alaska, many marine animals such as mollusks and other shellfish that are critical to economic viability and cultural sustainability of the State are under threat. Because of its potential implications for commercially important species, OA could cost billions of dollars and thousands of jobs for the State of Alaska. However, regions in southeast and southwest Alaska that are highly reliant on fishery harvests and have relatively lower incomes and employment alternatives likely face the highest risk [43].

OA is still emerging as a topic of interest in the public consciousness, and therefore many individuals may not have a high degree of OA literacy, or understand their associated risk. As a result, it is unclear whether communities and their decision makers have the understanding to evaluate and respond to these emerging threats. To better understand this gap in public comprehension, a statewide survey was conducted to determine the current level of understanding and concern for OA in Alaska.

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2. Background

2.1. Ocean acidification

Since the beginning of the Industrial Revolution, anthropogenic emissions have caused atmospheric CO_2 concentrations to increase by about 40% to values over 400 ppm, which is higher than at any point during the last 800,000 years [41]. The ocean has absorbed more than 25% of this CO_2 [26,61,62]. While this has offset some atmospheric warming, it has triggered fundamental changes in seawater chemistry e.g. [19,24,54]. Global surface ocean pH has already dropped by about 0.1 units since the 1850's (e.g. [9,25]), equating to a 30% increase in acidity. If growth of fossil fuel consumption continues as projected [57], this decline in pH could double or even triple by the year 2100 [19].

Carbonate (CO_3^{2-}) minerals that are naturally found in seawater partially neutralize the absorption of the accumulating CO_2 and slow the decline in pH. However, this buffering mechanism depletes the seawater of CO_3^{2-}, which makes it more difficult for many organisms that build and maintain calcium carbonate shells necessary to carry out normal lifecycles. As a result, OA-related impacts pose a significant threat for communities reliant on marine fisheries, aquaculture, or coral reef systems [43,14,13]. It is important to understand the scientific processes of this change, as well as how this puts different communities at risk, in order to have the capacity to respond [52].

2.1.1. Alaska's unique vulnerability to OA

Alaska is likely to experience detrimental acidification events before many other regions. The rate of pH change has been more pronounced in Alaska, and is accelerating due to unique ocean circulation patterns and colder water temperatures (e.g. [23,43]). In addition, the state's economy is highly reliant on a strong fisheries sector.

The addition of anthropogenic inputs of CO_2 can push CO_3^{2-} concentrations beyond critical thresholds, where waters are corrosive to carbonate minerals, especially aragonite (e.g. [44]). Additionally, acidification of Alaska's waters varies in intensity, duration, and extent due to regional processes such as sea ice decline [47] glacial runoff [22,59] and river discharge [45]. For example, the yearly discharge of large volumes of glacial melt can create conditions where aragonite is undersaturated in surface waters in inland bays and the adjacent continental shelf of the Gulf of Alaska [22]. Farther north, the subsurface waters of both the Chukchi Sea and the Bering Sea are strongly influenced by seasonal biological productivity [3,4,48,16,44], which causes an excessive buildup of CO_2 near the bottom and can cause aragonite and in some cases calcite to become undersaturated. Mooring data from the Bering Sea [46] has shown that CO_2 concentrations can remain high in bottom waters for at least four months each year, promoting prolonged periods of carbonate mineral undersaturation.

Changing carbonate chemistry in these regions may impact the ability of many species critical to Alaska's fishing industry, including crabs and pteropods, to carry out normal life cycles [39,40,6]. These changes pose a high risk potential to Alaska's commercial fishing industry, which had a wholesale value of over $4.6 billion in 2009, and is the third largest contributor to economic activity in Alaska [53]. Furthermore, these changes have implications for Alaska's subsistence fishing sector, which approximately 20% of Alaska's population relies on for food, clothing, and trade [76].

Together, the dependence on the ocean and ocean services to support individual and statewide livelihoods coupled with higher than average rates of increase for OA contribute to a high vulnerability of Alaskans to OA (e.g. [43,23]). Regional variability in OA across Alaska (e.g. [22,59,46,16]) as well as differences in local sensitivities and adaptive capacities [43] suggests that levels of concern may vary across Alaska.

2.2. Importance of public understanding and awareness of risk in climate policy

In the 1980s, when anthropogenic climate change emerged as a topic of interest in the public's awareness, so did a growing field of research on effective climate change communication [52,15,55,8,36]. This research focuses on evaluating how communicating science can shape understanding and awareness of climate-related risk [15,55,8]. Understanding and awareness of risk influence the ability of political, economic, and social actions to reduce risk, both through increasing support for the creation of mitigation policies, and developing strategies that allow specific communities to adapt. Climate change communication works to develop or improve public understanding of various aspects of climate-related risk [52]. This includes understanding drivers, scientific processes, and personal risk. The goal is that over time, these efforts will transition the way individuals behave so that climate safe actions such as reducing one's carbon footprint become more common [52].

Although Alaska's oceans have been some of the first to be exposed to prolonged acidification events (e.g. [46]), to date there has not been a study to evaluate the current understanding and awareness of OA risk in Alaska. Thus, public perceptions of OA are not fully understood, which has hampered the ability to effectively communicate OA-related research.

2.2.1. Public understanding of oceans and ocean acidification

Few studies have examined public understanding of ocean processes and issues including OA, though public understanding of climate change is well documented for various stakeholder groups across the world (for a review, see [75]). Public understanding of climate change is influenced by a range of factors including source of information on ocean health, issue immediacy, preexisting environmental beliefs, and issue salience [68,29,66,73]. Knowledge alone does not drive behavioral change [30]. Decisions and preferences are influenced by several additional factors including values, ideologies, political environments, perceptions of risk, and trust [42,31]. Furthermore, misperceptions of climate drivers, such as perceived connections between climate change and the ozone hole, can influence policy support just as much as an actual understanding of climate processes [70].

The limited body of research on the public understanding of the ocean suggests that the public is not well versed in ocean-related functions, processes, and issues [69,58,66,27,38]. A national study found that only 24% of Americans had heard of OA, and only 32% of this subpopulation recognizes CO_2 as a driver [38]. These findings are consistent with other research on the limited understanding of the causes and impacts of climate change [7,60,70].

2.2.2. Awareness of risk for oceans and ocean acidification

While few studies have investigated the variables that influence perceptions of OA risk, analogous research highlights the wide range of factors that are theorized to influence perceptions of climate change risk (for a review, see [71,75]). Experiential factors that make climate risk personal play a significant role in influencing concern [34,32]. For example, Spence et al. found that experience with flooding contributed to higher levels of concern for climate change [65]. Similarly, Brody et al. found that proximity to the coast influenced concern for sea level rise and climate change, although temperature change did not significantly increase concern [8]. In addition, storytelling, especially that which involves personal experience or imagery, can positively influence environmental risk perception and policy support by relating to the experiential ways that individuals process risk [26,64,72,32]. Studies specific to OA have found that even reading a basic definition of OA has a positive effect on individual concern [58,69]. Furthermore, Donkersloot found that providing information on how OA can influence Alaska fisheries increased concern in shellfish farmers in Southern Alaska, as well as an interest in participating in local OA monitoring initiatives [20].

Increasing both public understanding and awareness of risk are considered critical elements in building the capacity of a society to make informed decisions and adapt to environmental risks such as changing climate or ocean acidification [33]. These assertions are built on the premise that greater knowledge and awareness of risk will enable the public make informed decisions. While these are important components in decision-making, values, ideologies, political environments, and trust can have an influence as well [42,31].

3. Methods

3.1. Questionnaire design

A mail-based questionnaire was used to understand awareness of OA among Alaska residents and determine the variables that influence concern for OA. Participants were first asked about their involvement in and reliance on Alaska's commercial and subsistence fishing sectors. A number of questions to gauge knowledge of, belief in, and concern for both OA and climate change followed. In the next section, respondents were asked to elaborate on the resource they consult most frequently for information on weather and ocean health. Then there were a number of questions to evaluate participants' support for OA and climate change research initiatives and policies. The survey concluded with a number of demographic inquiries.

Participants ($n=2000$) were randomly selected from a mailing list purchased through a national marketing organization. Prior to distribution, a pilot study ($n=28$) was conducted to gauge questionnaire readability and user-friendliness in order to make modifications and consider preliminary results. The questionnaire was distributed based on the Tailored Design Method between September and November of 2013 [18]. Participants were mailed a pre-notice letter that explained the goals and the voluntary nature of the project. Four days later, the questionnaire was mailed to every participant. A dollar bill was included in each mailing to increase survey response [10]. To minimize non-response, a reminder postcard was sent to all participants two weeks later.

3.2. Determining the level of understanding of OA in Alaska

Level of understanding was evaluated through an assessment of the actual and perceived understanding of respondents. First, participants self-assessed their level of understanding based on the following question: "Which statement best represents your understanding of ocean acidification?" To evaluate actual understanding, participants with an understanding of OA were asked to identify and describe what is causing OA through open- and closed-ended questions. Open-ended responses were classified into six non-mutually exclusive categories. Throughout the questionnaire, the terms "carbon dioxide," "human activity," and "natural variability" were not defined further to allow respondents to interpret them as they saw fit.

3.3. Modeling the variables that influence concern for OA

The level of concern for OA was evaluated for multiple timescales, based on the following survey question: "Indicate the extent to which you are concerned or unconcerned about ocean acidification over the following time periods" [time periods: right now, 10 years, 25 years, 50 years, and 100 years]. Following, respondents were asked to rank OA relative to other threats to Alaska fisheries. Individual assessment of economic risk was evaluated by considering perceived links between OA and household income as well as statewide revenue for Alaska fisheries.

A Heckman-corrected ordered probit model was developed to estimate how self-reported concern for OA varies with respondents' involvement in Alaska's fishing sectors, vulnerability to OA, length of residence in Alaska, location in Alaska, and use of scientific sources for information on weather and ocean health (Table 1; [5,28]). Level of concern right now was used as the dependent variable. The chosen independent variables served as proxies for an individual's geographic,

Table 1
Description of the variables used in the ordered probit model.

Variable	Description
Belief	Belief that OA is currently happening in Alaska's waters (0=no; 1=maybe; 2=yes)
Concern	Respondent's concern for OA (range −2=highly unconcerned to 2=highly concerned)
Commercial	Family member is a commercial fisherman (0=no; 1=yes)
Subsistence	Family member subsistence fishes (0=no; #=number of people subsistence fishing supports)
Fishmonths	Months per year respondent relies on AK seafood (range from 0=no months to 12=12 months)
OAVI	Ranked vulnerability [43,46]
AK	Number of years in Alaska (#=number of years)
Community	Number of years in current community (#=number of years)
Indigenous	Identification as an indigenous person (0=no; 1=yes)
Gender	Respondent's self reported gender (0=male; 1=female)
Birthyear	Respondent's self reported birthyear (#=birthyear)
Anch/Fbx	Respondent is a resident of the Municipality of Anchorage or the Fairbanks North Star borough (0=no; 1=yes)
Science	Respondent accesses information on ocean health from scientific sources (0=no; 1=yes)
NOAA	Respondent accesses information on ocean health from the National Oceanic and Atmospheric Association (NOAA) or the National Weather Service (NWS) (0=no; 1=yes)
UnderHS	Respondent has less than a high school education (0=no; 1=yes)
HS	Respondent has a high school education or GED (0=no; 1=yes)
Associate's	Respondent has an associate's degree (0=no; 1=yes)
Bachelor's	Respondent has a bachelor's degree or beyond (0=no; 1=yes)
Democrat	Respondent is a self reported democrat (0=no; 1=yes)
Independent	Respondent is a self reported independent (0=no; 1=yes)
Republican	Respondent is a self reported republican (0=no; 1=yes)
Income1	Respondent's average annual household income is less than $20,000 (0=no; 1=yes)
Income2	Respondent's average annual household income is $20,001 to $50,000 (0=no; 1=yes)
Income3	Respondent's average annual household income is $50,001 to $100,000 (0=no; 1=yes)
Income4	Respondent's average annual household income is greater than $100,001 (0=no; 1=yes)

social, and economic vulnerability to OA. Involvement in Alaska's fishing sectors gauged direct vulnerability to changes in commercial or subsistence fisheries, or reliance on Alaska seafood as a primary source of protein. Vulnerability to OA was based on a study by Mathis et al., which ranked Alaska's boroughs based on social and economic vulnerability to OA [43]. Length of residence in Alaska was considered both by looking at the number of years respondents had spent in their current community as well as the state of Alaska. The model controlled for residents living in the Municipality of Anchorage and the Fairbanks North Star borough, Alaska's two largest census areas, to determine the relative influence of community size. Use of scientific sources for information on weather and ocean health was included because of the positive effects of scientific sources on ocean literacy [66]. General media sources including television, radio, newspaper, and Internet were consistently insignificant, and therefore left out of the final model.

Statistical analysis was conducted in a two-step process using Stata/IC 11.1 for Macintosh. First, a Heckman correction (Eq. (1)) was performed to account for potential bias resulting from sample collection [28]. Belief in OA was chosen as a selection variable that influences whether a response of concern for OA was observed. Eq. (1) displays the ordered probit model that was used to calculate the inverse mills ratio for belief in OA, which was subsequently used as a scaling variable and inserted into the ordered probit model (Eq. (2)). The model included a correction for heteroskedasticity.

$$\begin{aligned}\Pr(\text{Belief}=2) = \Phi(&\beta o+\beta 1\text{Indigenous}+\beta 2\text{Gender}\\&+\beta 3\text{Birthyear}+\beta 4\text{Education}+\beta 5\text{Political}+\beta 6\text{Income})\end{aligned} \tag{1}$$

$$\begin{aligned}\Pr(\text{Concern}=1) = \Phi(&\beta o+\beta 1\text{Commercial}+\beta 2\text{Subsistence}\\&+\beta 3\text{Fishmonths}+\beta 4\text{OAVI}+\beta 5\text{AK}+\beta 6\text{Community}\\&+\beta 7\text{Indigenous}+\beta 8\text{Gender}+\beta 9\text{Birthyear}+\beta 10\text{Anch/Fbx}\\&+\beta 11\text{Science}+\beta 12\text{NOAA}+\beta 13\text{Education}\\&+\beta 13\text{Political}+\beta 13\text{Income}+\beta 14\text{InvMills})\end{aligned} \tag{2}$$

Calculations for the ordered probit model can only include responses in which all questions were answered, limiting the model's sample size to 163. Correlation analyses suggested that there is no strong collinearity between covariates. To further understand the influence of the covariates on concern for OA, STATA was used to calculate the marginal effect of each variable on concern for OA (Concern = 1). The parameters of this model were quantified using maximum likelihood estimation.

4. Results

4.1. Description of the sample

The total response rate to the 2000 mailed surveys was 18%; 311 surveys were completed, and 284 were returned to sender. Table 2 highlights the demographic statistics of the respondents[2]. A majority of respondents were male[3], and about half of the respondents had a bachelor's degree or beyond. Political parties were split almost evenly, with the largest number of respondents identifying as independent (31%).

Table 2
Demographic statistics of both the sample of respondents and the State of Alaska. State of Alaska statistics were retrieved in April 2014 from http://quickfacts.census.gov/qfd/states/02000.html.

		Sample	Alaska
Gender (%)	Female	31	48
	Male	69	52
Indigenous (%)	Yes	19	15
	No	81	85
Age (years)	Minimum	18	–
	Maximum	87	–
	Mean	53	–
Annual family income (%)	\$20–50,000	22	24
	\$50–100,000	37	34
	> \$100,000	32	31
Education (%)	Less than high school education	2	9
	High school education	49	64
	Bachelor's degree or beyond	49	27
Political party (%)	Democrat	22	–
	Independent	31	–
	Republican	27	–
	Other	19	–

The respondents communicated a high reliance on Alaska seafood, which indicates potentially high vulnerability to OA. Alaska seafood served as a primary source of protein for between 30% and 46% of respondents throughout the year, with the highest level of reliance during July, August, and September. Additionally, 39% of respondents indicated that a family member practices subsistence fishing. The respondents, however, were not highly dependent on income from fishing. Only 8% of respondents generated more than 20% of average yearly family income from fishing-related activities. As was expected, these data indicated that fish harvests predominately take place in the late summer months, when acidification events can be enhanced (e.g. [59,17,22,45]).

General media sources were the most common sources for information on weather and ocean health. Television and the Internet had the same percentage of users, at 23% each, whereas only 6% of respondents indicated use of peer reviewed scientific sources. Other frequently consulted sources included the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service (NWS; 18%), radio (11%), weather sources other than the NWS (10%), newspaper (9%), unspecified media sources (8%), trade documents such as fishing publications (2%), and tide books (2%). Fifty three percent of respondents indicated that they access information on weather and ocean health daily.

While respondents were overwhelmingly supportive of increasing OA research, there was more uncertainty about current political action to mitigate OA (Table 3). Around 80% of respondents were supportive of increasing our depth of understanding of OA, which included researching the causes and effects of OA in Alaska, the links between OA and Alaska's fishing industry, and the links between OA and climate change. This mirrors a US public opinion poll that found 81% of respondents supported establishing increased monitoring and creating protected zones for critical ocean areas [69], but expanded this understanding to encompass Alaska-specific OA research. Respondents supportive of increased research spanned all demographics, and came from both fishing and non-fishing backgrounds. In contrast, there was a high degree uncertainty about political action to address OA. Forty eight percent of respondents were unsure about whether politicians were doing enough to address OA, and 59% don't know if their community needs a group to address OA.

[2] All demographic information was self-reported. For political party, respondents were asked which party they most often associated with. Responses to the "Other" option included "non-partisan," "leaning towards democrat," and "green party."

[3] The percentage of males and females in this sample differed from the population probably because the obtained mailing list defaulted to the head of the household. However, Monte Carlo simulations conducted on representative subsamples suggest that this element does not bias the estimated coefficients significantly.

4.2. Level of understanding

Analysis of self-assessed knowledge of respondents indicated that most Alaskans had a limited understanding of OA. A definition of OA was not provided for survey respondents at any point throughout the survey. Twenty four percent of survey participants were not familiar with OA, and among those who had heard of OA, the majority considered their understanding rudimentary (Fig. 1). Of the 76% that had heard of OA, only 34% believed that OA is happening in Alaska, and 28% believed that OA would impact Alaska more than other states in the US. Moreover, although a majority of respondents had heard of OA, these same respondents indicated they had a low level of confidence in their own understanding, which could prevent them from adequately assessing personal risk.

4.2.1. Recognition of OA drivers

Open- and closed-ended questions on the drivers of OA provided a concrete example of the variable level of understanding of OA around the state. Although many responses were simple, a number of respondents demonstrated an ability to accurately link OA to other ocean and atmospheric processes. Of the respondents who identified as having at least “heard of” OA, the most frequently cited driver was carbon dioxide (62%) (Table 4). These responses ranged from simple phrases like “CO_2” to much more detailed descriptions like “record carbon dioxide levels in the atmosphere above 400 ppm for the first time in recorded history are being absorbed in the surface of the ocean and are sequestered in the deep cold waters of the ocean, threatening the calcareous shell tests of many life forms.” The second most frequently cited driver was human activity (45%), with responses such as “CO_2 being put into the air by power plants, autos, melting permafrost, factories, deforestation, airlines”. Only 11% of respondents cited natural variability as a driver, with responses such as “on the west coast of the US, ocean acidification is attributable to the upwelling of cold CO_2-rich waters from deep in the ocean” and “aside from hot spots, which are a drop in the bucket, so to speak, most acidification is naturally caused, and the affect is minimal”. A series of closed-answer questions (n=238) reinforced findings from the open-ended questions (n=78) that participants predominately associated OA with CO_2 and human activity rather than natural variability (Fig. 2).

In other cases, responses highlighted that the respondents held a number of misperceptions of the drivers of OA. These misperceptions included both natural and human causes. For example, on respondent noted “I am a little vague on the subject but believe it refers to the harm done by dumping fish waste into the ocean mainly by fish processors”. Other suggested drivers included cruise ship activity (n=2), acid rain (n=2), and finally volcanoes, earthquakes, or plate tectonics (n=4).

4.3. Level of concern

This study primarily evaluated awareness of OA risk through individual level of concern for OA. Level of concern was investigated on a variety of timescales, and respondents were asked to rank OA as a threat relative to other marine threats. Awareness of economic risk was assessed via individual awareness of the links between OA and annual income as well as statewide revenue for fisheries. For a more detailed analysis, the variables that influence concern for OA were evaluated numerically with an ordered probit model. Participants concern for OA varied between now and 100 years from now (Fig. 3). Consistent with other research on perceptions of OA risk, the majority of respondents were at least “concerned” (52%) about OA in the

Table 3
The percentage of respondents that support various OA and climate change (CC) research and policies. Respondents were asked to give a yes, no, or I don't know response to each of the following questions pertaining to OA or CC policy, and indicate their level of support for increasing various kinds of OA research.

	Yes	No	Don't know
Politicians are doing enough to address OA	9	44	48
Politicians are doing enough to address CC	16	46	37
Policies can be created to address both OA and CC	46	10	44
My community needs a group to address OA	21	20	59
The US should sign international treaties to regulate CO_2 emissions	49	23	28
I support research to better understand the causes and effects of OA	82	7	11
I support research to better understand how OA and CC may or may not be linked	77	11	12
I support research to better understand how OA may or may not impact Alaska fisheries	83	8	9

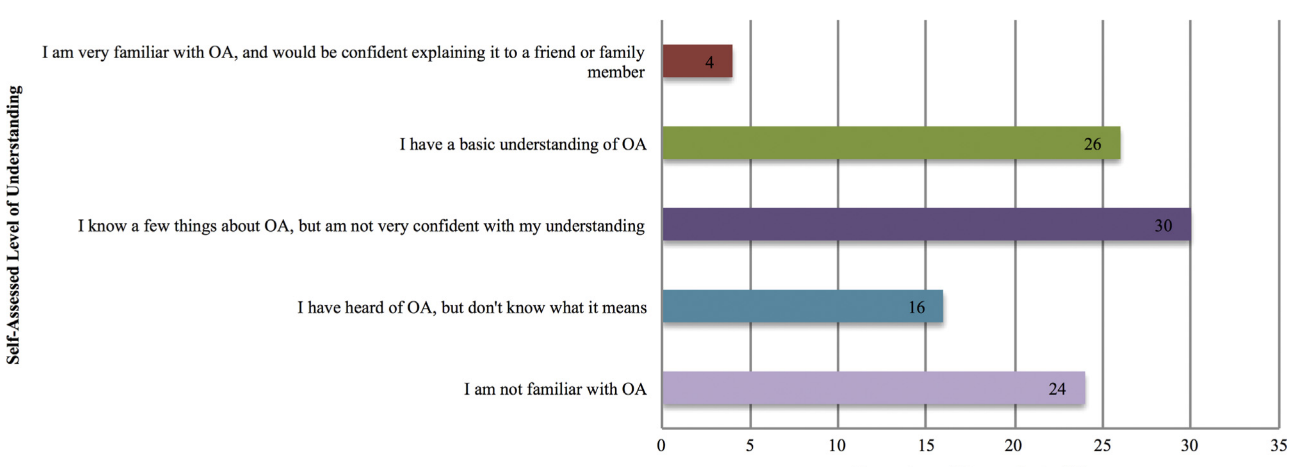

Fig. 1. Self-assessed understanding of OA. Respondents were asked which statement from the list below best represents their understanding of OA. n=302.

present. Furthermore, the investigation of concern over time revealed three notable trends. First, the level of concern increased for those who were already concerned about OA, while the level of concern was stable among those unconcerned. Second, the number of participants indicating they were not sure of their level of concern increased over time. Third, the most significant changes in concern occurred over the next 50 years, and few changes in the level of concern occurred between 50 and 100 years in the future. More specifically, the percentage of respondents who are highly concerned about OA more than doubles between now (15%) and 50 years from now (37%).

Although few respondents exhibited strong concern for OA at this moment in time, respondents ranked OA second as a threat to Alaska's fisheries behind overfishing (Table 5). OA was considered a moderate or strong threat to Alaska fisheries by 79% of respondents, compared to overfishing (88%), oil spills (65%), climate change (65%), mining (61%), and offshore drilling (49%).

Table 4
Perceived drivers of OA based on open-ended questions. Respondents with some level of understanding of OA (indicated by all responses in Fig. 1 other than "I am not familiar with OA") were then asked an open-ended question about what they believe is causing OA. Responses were coded into the six listed non-mutually exclusive categories. Not all responses focused solely on drivers of OA, with some mentioning implications for sea life. Responses mentioning implications for sea life were still coded and included in this table, as they indicate a broader understanding of the interconnectedness of ocean and atmospheric processes. Below, both the number of respondents who mentioned each category as well as the percentage of the subsample that listed each category are shown. $n=76$.

Categories	Description	Number of mentions	Proportion (%)
CO_2	Carbon dioxide	47	62
Human	Humans or industrial activity	34	45
Acidity	Acidity, pH, chemical equations, carbonic acid	28	37
Climate	Climate or the atmosphere	25	33
Life	Implications for sea life	15	20
Natural	Natural processes, geologic activity	8	11

4.3.1. *Perceived economic implications of OA*

In two questions evaluating whether respondents believe OA is linked to both statewide revenue for Alaska's fisheries and their annual household income, results showed that while 41% of respondents recognized that OA will impact Alaska's fisheries, only 13% of respondents believed OA will impact their annual household income. If respondents answered yes to either of the two questions, a follow up question was asked to gauge whether increasing OA would increase or decrease household income ($n=104$) and statewide revenue ($n=161$). The highest percentage of these two subsamples believed that OA would decrease revenue for fisheries (65%), compared to those who thought OA would increase revenue for fisheries (5%), decrease household income (30%), or increase household income (14%). The fraction of respondents that believed OA would decrease revenue for fisheries represents 33% of the total population.

4.3.2. *Influence of unique vulnerability on level of concern for OA*

Understanding which populations are concerned or unconcerned about OA has implications for how to best frame OA and CO_2 mitigation policies. The best-fit coefficients and marginal effects for the variables that influence concern for OA are displayed in Table 6 and discussed below. The pseudo-r^2 value for the model was 0.1339, which is consistent with other fits for this type of study.

4.3.2.1. Fishing involvement. Contrary to what was expected, commercial and subsistence fishermen were not significantly concerned about OA relative to non-fishermen. Furthermore, a variable including rankings of community vulnerability, based on a study by Mathis et al. [43,46], suggested that respondents that are more vulnerable were actually less concerned ($p \leq 0.10$). However,

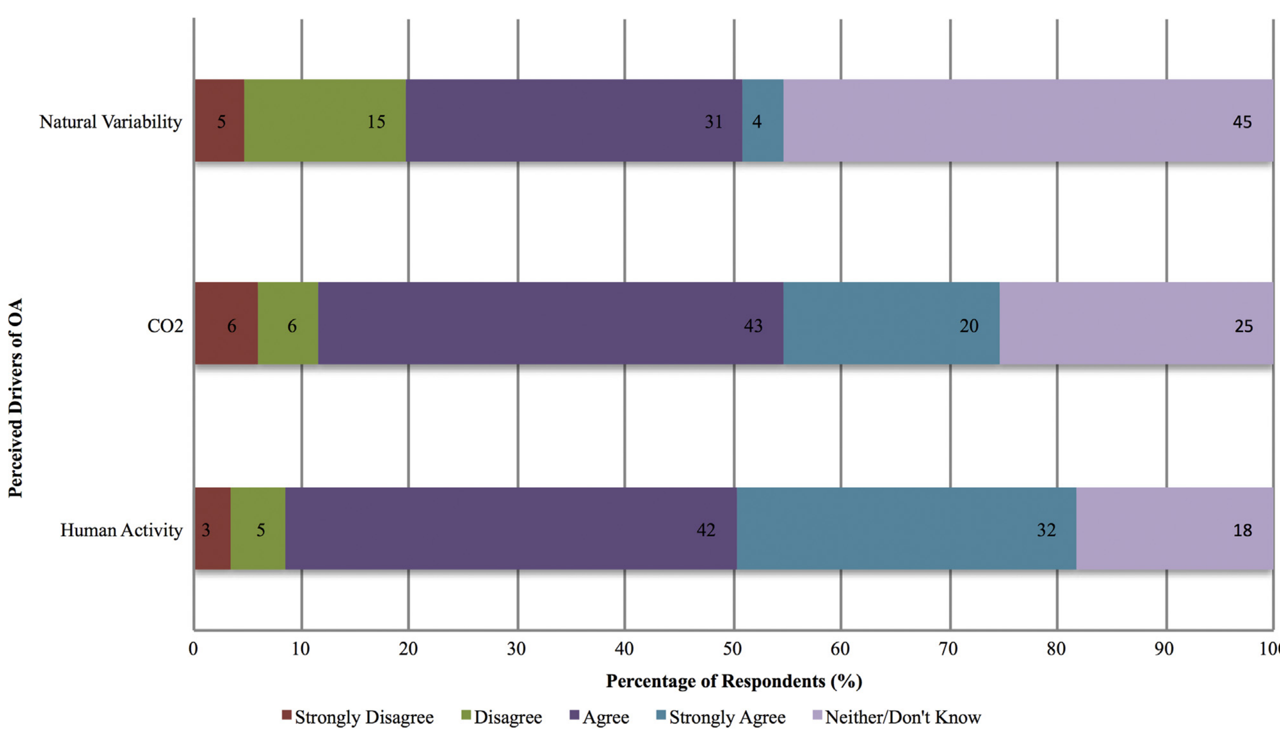

Fig. 2. Understanding of OA drivers based on closed-ended questions. Variables indicate the percentage of respondents who believe that natural variability ($n=230$), human activity ($n=237$), and CO_2 ($n=233$) are currently contributing to OA. This analysis did not include answers from respondents who indicated they had not heard of OA prior to this survey.

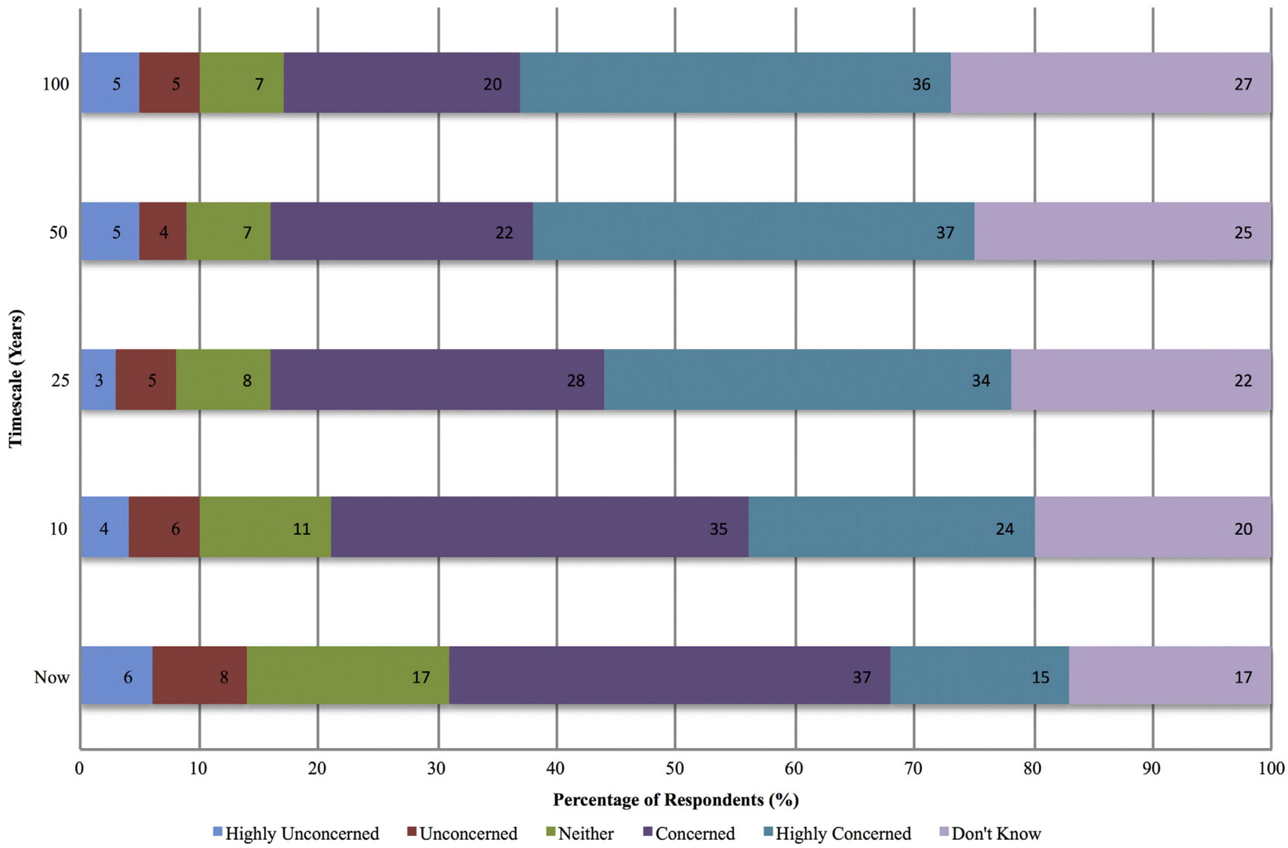

Fig. 3. Concern for OA on various timescales. The degree to which respondents were concerned or unconcerned about OA now (n=303), in 10 years (n=298), in 25 years (n=298), in 50 years (n=297), and in 100 years (n=297).

Table 5
Ranking of threats to Alaska's fisheries. All values are listed as percentages. Rankings were based on the percentage of respondents who considered each source a moderate or strong threat to Alaska fisheries.

Threat to AK fisheries	Threat	No threat	Slight threat	Moderate threat	Strong threat	*n*
	Overfishing	2.36	9.46	19.59	68.58	296
	Ocean Acidification	4.69	15.96	36.62	42.72	213
	Oil spills	6.03	29.08	25.89	39.01	282
	Climate change	13.87	21.53	31.02	33.58	274
	Mining	12.50	26.52	27.27	33.71	264
	Offshore drilling	16.67	34.81	23.70	24.81	270

this model did find that respondents with a greater reliance on Alaska seafood as a primary source of protein throughout the year were slightly more concerned about OA than those with lower reliance ($p \leq 0.10$).

4.3.2.2. Time in Alaska. Although the variables for the number of years a respondent has lived in Alaska and the number of years a respondent has lived in their current community both generated significant trends, the marginal effects for these variables were essentially zero. This suggested that there is no overwhelming impact of these two variables on concern for OA.

4.3.2.3. Demographics, level of education, and political party. Some demographic factors, such as age, gender, and location of residence were significant in influencing the level of concern for OA. Females, on average, were approximately 4.9% more likely to be concerned about OA than males ($p \leq 0.05$). Furthermore, concern for OA increased with age ($p \leq 0.01$). Residents of the municipality of Anchorage or the Fairbanks North Star borough, Alaska's two largest census areas, were 5.8% less likely to be concerned about OA than residents of Alaska's smaller boroughs ($p \leq 0.05$).

The lack of significance in the variables relating to income and political party suggested that there is not a decipherable change in the level of concern between different self-identified political parties and levels of income. To contrast, level of education had a significant impact on concern for OA. Residents with less than a high school education were, on average, 43.9% less likely to be concerned about OA. Respondents with a higher level of education, on average, were more concerned, although these marginal effects did not generate significant trends. With the exception of the political variables, these observed demographic trends were consistent with studies on perceptions of climate-related risk (e.g. [37,63,29,15]).

4.3.2.4. Use of scientific sources. Respondents who use peer reviewed scientific sources for information on weather and ocean health were more likely to be concerned about OA ($p \leq 0.10$). This result is congruent with a previous analysis of ocean literacy [66]. Although a greater percentage of respondents used NOAA sources for information on weather or ocean health, this variable did not generate significant trends.

5. Discussion

5.1. Level of understanding

Solidifying the understanding of OA science can enhance concern and incentivize individual action [77,56,69,51]. While the number of respondents in Alaska who had at least heard of

Table 6
Coefficients and marginal effects generated from the Heckman corrected ordered probit model evaluating variables that influence level of concern for OA.

	Variable	Coefficient (β)	Marginal effect (%)
Fishing involvement	Commercial	−0.21	−3.69
	Subsistence	0.01	0.19
	Fishmonths	*0.03	0.46
	OAVI	*0.59	*8.38
Time in AK	AK	**−0.02	*−0.23
	Community	*0.01	0.19
Demographics	Indigenous	0.05	0.68
	Gender	*0.45	**4.89
	Birthyear	***−0.03	**−0.37
	Anch/Fbx	**−0.44	**−5.78
Use scientific sources	Science	*0.72	0.20
	NOAA	0.25	2.80
Level of education	UnderHS	NA	**−43.87
	HS	*1.18	2.51
	Associate's	*1.46	−3.16
	Bachelor's	*1.65	Omitted
Political party	Democrat	NA	*3.95
	Independent	−0.26	2.26
	Republican	−1.03	−11.56
	Other	−0.43	Omitted
Annual family income	> \$20,000	NA	−13.87
	\$20,001–\$50,000	0.58	−0.40
	\$50,001–\$100,000	0.39	−3.32
	< \$100,001	0.61	Omitted

Marginal effects are displayed for the ordinal option "I am concerned about ocean acidification right now;" $n=163$.

* 10% Significance.
** 5% Significance.
*** 1% Significance.

OA (76%) is three times higher than has been found nation-wide (24%; [38]), the limited understanding and lack of confidence in this understanding of OA is consistent across regions [69,51,38]. One respondent noted, "I hadn't heard or at least been aware of hearing the term ocean acidification before this survey. The term inherently presents cause for concern and I think the general population needs more education about it". Solidifying the understanding that CO_2 emissions from human activity drive OA could give Alaskans the ability to better evaluate their level of support for OA-related policies [21,50]. Furthermore, enhancing the recognition that natural factors cause variability in the severity of acidification around Alaska could increase the capacity for vulnerable communities to prepare and adapt to future change.

Few respondents recognized that OA would disproportionately impact Alaska, or that the impact of OA would be variable around the state, which has implications for community adaptation and fisheries planning. Only 28% of respondents thought OA would impact Alaska more than the rest of the US. Future OA outreach should enhance the understanding of how the extent, duration, and intensity of acidification events will disproportionately impact different regions around the state, and how local economies and food practices, especially in fishing dominated communities, might need to adapt as acidification events intensify.

5.2. Level of concern

The ability of Alaskans to adequately evaluate OA risk relies on understanding how OA may influence Alaska seafood and fisheries revenue, as well as access to cheap sources of protein. While individual and statewide reliance on Alaska fisheries is high, our survey results showed that awareness of fisheries-specific OA risk is low. As Alaska's oceans are not uniformly impacted by acidification, there is not a uniform solution for communicating this message to fishing communities (43). If intensification of OA requires adaptation in certain regions, fishermen and decision makers must be able to make informed choices about potential forms of adaptation such as changing fishing catches, diversifying the employment opportunities, and providing affordable access to alternate sources of protein.

While fishing communities should understand how they must adapt to respond to OA, it is equally important for the public to understand the potential implications for fisheries revenue. Most respondents did not consider themselves economically vulnerable to OA, and only 33% of respondents thought OA would make fisheries less profitable. Framing OA mitigation policies around potential implications for fisheries revenue may help generate public and political support for large-scale mitigation efforts.

OA worst-case scenarios may not occur until 2050 at the earliest, which can make it hard for individuals to evaluate OA as a current threat [54,69,51,58]. As our results indicated, the public is more concerned about OA farther into the future. Solidifying the understanding that any reduction in pH and intensification of OA can have implications for marine species that are irreversible on human timescales will reinforce not only that OA is an immediate concern, but also the importance of taking action now.

5.3. Increasing public understanding and awareness of OA

Educating the public on OA risks through the media and in the classroom can be used to increase widespread exposure to OA science. While scientific sources were the only sources to increase individual concern for OA, most respondents accessed information on weather or ocean health from general media sources such as television, Internet, and radio. Encouraging members of the scientific community to write targeted ads for local media would help educate Alaskans about OA without changing the way that Alaskans currently receive information. Over a longer timeframe, increasing the quantity of OA science in K-12 curricula will reinforce knowledge of OA concepts and the interconnectedness of the ocean, atmosphere, and human activity [11,49]. On average, the respondents had low confidence in their understanding of OA science, and there were a few reoccurring misperceptions about drivers of OA. Beginning OA education at an early age may help limit these misperceptions and increase confidence in the understanding of OA. Furthermore, regionally-focused lesson plans can be used to enhance community understanding of local vulnerability, as has been done in Barrow [1].

In addition to providing general information on OA, communicating fisheries-specific risk is important to ensure fishermen have the knowledge to prepare for future changes in the industry. This could be accomplished by providing a seasonal bulletin for fishing communities with updates on the state of OA in different regions. Bulletins could use examples from specific communities to represent regional change, and use stories that highlight fishermen who have successfully become involved in OA outreach. Another approach would be to create a workshop that provides science education for fishermen. Such a workshop could train select fishermen to serve as liaisons between scientists and their communities. Trained fishermen would have both the trust of their peers and the skills to communicate specific risks with technical understanding and practical field experience. In either of these methods, by reinforcing natural OA drivers and linking relatable fishermen with OA action, locals may become more confident with regional conditions and motivated to take individual action.

6. Conclusions

The results of these study found that most residents of Alaska have a basic understanding of OA science and the concept of OA is inherently concerning to them. Furthermore, when asked about the causes of OA, residents, on average, are more likely to associate CO_2 from human activity to OA than natural variability. Although Alaskans have a high reliance on Alaska seafood, they had a low perception of fisheries-related OA risk.

This study provides a baseline that can be used to further assess the steps that must be taken to increase the quality of OA communication in Alaska. This will give Alaskans the necessary information to make informed decisions about OA mitigation and community adaptation. OA communication techniques should work to solidify the understanding of OA drivers, familiarize fishermen with how OA can influence local conditions, and raise awareness to non-fishermen on the statewide economic implications of OA. Specifically, OA education can be used to limit the development of common misperceptions about OA, and increase individual confidence as well as the understanding of the drivers of OA in Alaska. Furthermore, regionally-focused outreach can work to enhance perceptions of how Alaska is at risk. These efforts will help solidify the understanding of the scientific concepts of OA, why OA matters to Alaskans, and why steps should be taken to mitigate it.

OA communicators should learn the lessons from climate change efforts and not allow misperceptions and disinformation to take hold in the public consciousness. This study clearly showed that even when people had a limited understanding of OA, they largely view the concept as an inherent threat. Clear, effective communication of the challenges of OA should be presented to the public without hyperbole to ensure that when OA mitigation efforts are proposed, they can be considered in the most objective way.

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Glossary

Aragonite: The more soluble polymorph of calcium carbonate, a mineral formed by a number of biophysical processes in both freshwater and marine environments.;
Commercial fisheries: An organization that catches fish or any other seafood to sell for a commercial profit.;
Environmental risk perception: The perceived probability of an individual or community experiencing a negative consequence because of a distinct environmental phenomenon.;
Heckman correction: A two-step procedure used to correct for non-randomly selected samples. A model for determining the probability of experiencing your dependent variable, is used to generate an inverse mills ratio, which is inserted into the final regression equation to corrects for self-selection.;
Inverse mills ratio: The ratio between the probability density function and the cumulative distribution function of a distribution.;
Marginal effect: The change in predicted probability of observing the dependent variable given a one-unit change in the covariate of interest.;
Maximum likelihood estimation: A method of estimating parameters that selects a set of values that generates the highest cumulative probability of observing the outcome.;
Ocean acidification: An ongoing decrease in average global ocean pH.;
Ordered probit model: A popular regression used when the dependent variable is an ordinal variable with more than two outcomes.;
Saturation state: A measure of the thermodynamic potential for a mineral (in this case, calcium carbonate) to preferentially precipitate or dissolve in seawater.;
Subsistence fisheries: The activity of catching fish or any other seafood to feed one's family and relatives.