Harmful Algae 96 (2020) 101799

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

Harmful algal blooms and coastal communities: Socioeconomic impacts and actions taken to cope with the 2015 U.S. West Coast domoic acid event

Stephanie K. Moore[a,*], Stacia J. Dreyer[b,c], Julia A. Ekstrom[d], Kathleen Moore[c], Karma Norman[e], Terrie Klinger[c], Edward H. Allison[c,f], Sunny L. Jardine[c]

[a] *Environmental and Fisheries Sciences Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd E, Seattle, WA 98112, USA*

[b] *Arizona State University, School for the Future of Innovation in Society, 1120 South Cady Mall, Tempe, AZ 85287, USA*

[c] *University of Washington, School of Marine and Environmental Affairs, 3707 Brooklyn Ave NE, Seattle, WA 98105, USA*

[d] *Policy Institute for Energy, Environment, and the Economy, University of California, 1605 Tilia St, Suite 100, Davis, CA 95616, USA*

[e] *Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd E, Seattle, WA 98112, USA*

[f] *WorldFish, Jalan Batu Maung, Batu Maung, Pulau Pinang 11960, Malaysia*

ARTICLE INFO

Keywords:
harmful algal bloom
socioeconomic impacts
cultural impacts
coping actions
resilience
domoic acid

ABSTRACT

The 2015 U.S. West Coast domoic acid event was caused by a massive harmful algal bloom (HAB) that consisted mostly of the diatom *Pseudo-nitzschia australis.* It was unprecedented in its toxicity and geographic extent and resulted in extended and widespread closures of the lucrative commercial Dungeness crab and popular recreational razor clam fisheries. The fishery closures led to federal fisheries disaster declarations and generated an economic shock for coastal communities that depend on access to these marine resources. This study reports on the socioeconomic impacts of the 2015 HAB across 16 fishing communities on the U.S. West Coast using primary survey data. The survey instrument, deployed in the summer of 2017, collected information on sociodemographic and economic factors hypothesized to confer resilience or vulnerability to HABs, data quantifying individual impacts, and the coping and adaptive actions taken by individuals to deal with the event. The vast majority of survey participants (84%) were negatively impacted by the 2015 HAB, but individuals employed in fishing-related occupations experienced greater financial, emotional, and sociocultural impacts than those employed in other sectors. Further, those employed in fishing-related occupations were less likely to recover financial losses suffered as a result of the event. This study identifies the pathways through which HABs affect fishery-dependent and fishery-associated sectors of U.S. West Coast communities. The understanding gained can help inform efforts to prepare for future HABs, mitigate their socioeconomic impacts, and aid recovery.

1. Introduction

The societal impacts of harmful algal blooms (HABs) can be severe and include adverse health outcomes (Backer and Moore, 2012), economic loss (Dyson and Huppert, 2010; Hoagland et al., 2002; Jin et al., 2008), disruption to social and cultural practices (Crosman et al., 2019; Ritzman et al., 2018), and losses to both individual and community wellbeing (Willis et al., 2018). Even so, our knowledge of how human societies cope with HABs is extremely limited. In part this is due to poor characterization of the socioeconomic impacts of HABs (Bauer et al., 2010). Most HAB impact assessments have focused on the costs to individual sectors of society, such as public health (Hoagland et al., 2009; Ralston et al., 2011), commercial fisheries and aquaculture (Hoagland et al., 2002; Jin et al., 2008), or recreation and tourism (Dyson and Huppert, 2010; Hoagland et al., 2002). Assessments such as these cannot adequately identify interactions across sectors or the pathways for how losses in one sector can permeate communities to impact other sectors (Ritzman et al., 2018). These assessments are also typically conducted with little or no regard to thresholds that would render some businesses nonviable without external support, or to the underlying social vulnerabilities of communities or populations within them that could result in disproportionate impact. Social impact assessments of HABs and HAB management strategies are almost nonexistent (Ekstrom et al., 2020), even though HABs cause severe social and cultural disruption for individuals, families, tribes, occupational groups, recreational groups, and geographic communities (Bauer, 2006;

* Corresponding author.
E-mail address: stephanie.moore@noaa.gov (S.K. Moore).

https://doi.org/10.1016/j.hal.2020.101799
Received 30 July 2019; Received in revised form 11 February 2020; Accepted 17 March 2020
Available online 21 May 2020
1568-9883/ Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/BY-NC-ND/4.0/).

Crosman et al., 2019; Ritzman et al., 2018; Willis et al., 2018). Our incomplete understanding of the socioeconomic impacts of HABs, and of communities' abilities to respond to them, has limited the development of adaptation strategies to help coastal communities build resilience to future events. This knowledge gap likely also contributes to the inability of communities to create their own individualized action plans.

Nevertheless, increasing recognition of the role of social science in HAB research has led to a call to address the human dimensions of HABs using a socio-ecological systems (SES) approach (Borbor-Córdova et al., 2018; Van Dolah et al., 2016). At its core, this approach offers a framework for considering political and economic interests, as well as the cultural beliefs and values of stakeholder groups, in the practice of HAB management. It recognizes that the ecosystem and human responses to HABs are not independent of one another, and that multiple feedback mechanisms exist that can amplify or dampen the socioeconomic impacts. Furthermore, it provides a framework for assessing the resilience of a system to disturbance and its capacity for change (Resilience Alliance 2010). This is important because the severity of impacts caused by an extreme HAB event will depend on the resilience of coastal communities to these episodic natural disasters.

In this context, resilience is defined as the ability of coastal communities to cope with social, cultural, and economic stresses that can result from environmental change (Adger, 2000), such as an extreme HAB event. Coastal communities are defined as those located in coastal areas and with demonstrable cultural, social, or economic dependence on ocean and coastal resources. This includes fishing-dependent communities that are defined as being "substantially dependent on or substantially engaged in the harvest or processing of fishery resources to meet social and economic needs" (MSFMCA, 2007; Jacob et al., 2001). Some fishing communities may have limited capacity to cope and adapt to HABs because of other chronic or co-occurring socioeconomic and environmental health challenges such as competing ocean uses (Colburn and Jepson, 2012), a lack of young people entering the workforce (the "graying of the fleet"; Donkersloot and Carothers, 2016), and climate change effects (Allison and Bassett, 2015). It is important here to distinguish between coping and adaptation. Coping is defined as a short-term action that enables an individual, household or community to survive a shock, but requires a drawdown on some form of capital (e.g., financial or social) and therefore erodes capacity to cope or adapt to future shocks. However, when this coping involves social capital, some have argued that its use is important in maintaining the relationships, networks and public participation that constitute social capital (Putnam, 2000). Indeed, foundational social capital may facilitate adaptation, which refers to actions taken that better position respondents to weather future changes and shocks by altering livelihood patterns or building or altering an asset platform (Berman et al., 2012; Eriksen et al., 2011; Vincent et al., 2013), where the "asset platform" is the sum of different types of capital assets that sustain people's livelihoods. These are typically divided into five or six categories: financial capital (e.g., income, savings, credit, bonds), physical capital (access to production-related assets such as fishing boat, seafood restaurant, vehicle to get you to/from employment opportunities etc., as well as infrastructure such as harbors, highways etc. that support your ability to draw on your personal/household capital), human capital (e.g., your skills, experience, and qualifications), social capital (your ability to draw on friendships, kinship networks, relationships with authority etc.), natural capital (environmental goods and services that you have access to – in this case, fisheries – mediated by your license/catch share etc., plus other assets such as agricultural land) (Allison and Horemans, 2006). So, for example, asking a relative to pay for next month's rent is "coping", while maintaining and building kinship and social ties to ensure mutual support in hard times is "adapting"; or selling your fishing boat to pay off an overdue bank loan is "coping", while redeploying the boat in a different fishery is "adapting". At the community level, getting by on federal disaster assistance is "coping", while developing a more diversified local economy is "adapting".

On the U.S. West Coast, there are at least 123 communities that might be reasonably described as "fishing communities" (Norman et al., 2007). Dungeness crab is arguably the most important fishery to these communities because it has generated the most commercial fishing revenue in recent years (i.e., > \$200 million annually) and because many vessels participate in the fishery (Fuller et al., 2017). The Dungeness crab fishery in California, Oregon, and Washington (hereafter CA, OR, and WA, respectively) are cooperatively managed under a "3S" management scheme (referring to size, sex, and season), such that only males with a carapace width ≥159 mm can be legally harvested during specific time windows. Depending on state jurisdiction, the U.S. West Coast commercial Dungeness crab fishery typically opens in November or December and closes in late-June to mid-September the following year, with the majority of the total catch occurring in the first six weeks of the season or earlier (Hackett et al., 2004). In 2015, a massive HAB consisting mostly of the diatom species *Pseudo-nitzschia australis* (hereafter the 2015 HAB) postponed the opening of the commercial Dungeness crab fishery by one month in WA and OR and up to five months in CA due to unsafe levels of the toxin domoic acid in crab meat (Jardine et al., 2020; McCabe et al., 2016). This contributed to a \$97.5 million decrease in revenue for the U.S. West Coast commercial Dungeness crab fishery in 2015 compared with the previous year (NMFS, 2016), and resulted in fisheries disaster declarations for CA and the Quileute Tribe in WA.

A number of other fisheries were also impacted by the 2015 HAB, including rock crab, anchovy, sardine, mussel, and razor clam (McCabe et al., 2016). While these fisheries are not as valuable to fishing communities as Dungeness crab, their closures still caused significant cultural and socioeconomic disruption (Crosman et al., 2019; Ritzman et al., 2018). This is especially true for sectors of fishing communities along the OR and WA coasts that rely on tourism from the highly popular recreational razor clam fishery. This fishery can attract as many as 30,000 razor clam diggers to small coastal communities in a single day, and many local businesses depend on commerce associated with clamming activities for a significant portion of their annual income (D. Ayres, personal comm.). The fishery is open year-round in OR with the exception of an annual conservation closure in Clatsop County, while in WA it is open on select weekends usually between late fall and early spring. A season-long closure of the recreational razor clam fishery in WA, such as occurred in 1998-1999 and 2002-2003, is estimated to result in more than US\$24 million in annual lost expenditures (2008 dollars; Dyson and Huppert, 2010). Fishery closures stemming from the 2015 HAB caused WA to lose about 40% of the 2015-2016 razor clam season (Moore et al., 2019).

Fishery closures are an effective management tool for preventing acute illness in humans caused by the consumption of seafood contaminated with HAB toxins. For the toxin domoic acid, the regulatory threshold for human consumption is 20 ppm in shellfish meat, except in the viscera of Dungeness crab where the action level is 30 ppm (FDA, 2011). Domoic acid can cause amnesic shellfish poisoning (ASP) in humans, a disease that can lead to permanent loss of short-term memory and can be life threatening (Bates et al., 1989; Lefebvre and Robertson, 2010; Perl et al., 1990; Teitelbaum, 1990). While fishery closures prevent disease, they can cause severe social, cultural, and economic disruption to fishing communities that can persist long after the bloom has dissipated, resulting in profound hardship (Bauer, 2006; Ritzman et al., 2018).

The fishery closures that were implemented in response to the 2015 HAB paralyzed a large portion of the regional coastal economy, generating an economic shock for fishing communities. A study (Ritzman et al., 2018) that interviewed 36 residents from two U.S. West Coast fishing communities (Long Beach, WA and Crescent City, CA) indicated that economic hardships extended far beyond fishing-related operations to affect other local businesses, particularly the hospitality industry. Additionally, the disruption to traditions surrounding shellfish harvest and consumption threatened cultural identity. The semi-structured interviews probed aspects of resilience, and identified actions that community members took and resources they accessed (or desired to access) to cope with the 2015 HAB, such as government assistance and alternate marketing strategies (Ritzman et al., 2018). Here we report the results of a comprehensive survey of residents, largely employed in the fishing and hospitality industries, from 16 U.S. West Coast fishing communities. The survey, informed by the findings of Ritzman et al. (2018), collected sociodemographic and economic data hypothesized to confer resilience to HAB events as well as data that quantifies individual socioeconomic impacts of the 2015 HAB. These data are analyzed to determine whether the socioeconomic impacts reported and the coping and mitigation actions taken by residents of the two fishing communities studied by Ritzman et al. (2018) were indicative of a wider number of U.S. West Coast fishing communities affected by the 2015 HAB. The focus on resilience enables a purposeful examination of the ability of this coastal SES to respond to and recover from the socioeconomic impacts caused by the extreme 2015 HAB (Cutter et al., 2008), ultimately leading to the development of strategies to enhance social and ecological sustainability (Bauer et al., 2010).

2. Methods

The focal communities for this study were identified by port group as well as social characteristics and shared resources, such as police forces, schools or hospitals, and recreational shellfish harvesting beaches, following Moore et al. (2019). The 16 focal communities (Fig. 1), composed of 31 census designated places (Table 1), included important fishing ports for the U.S. West Coastl. As compared to major city centers with evident commercial fishing activity and infrastructure, such as San Francisco, the focal communities are home to both a relatively high level of socioeconomic involvement in commercial and recreational fishing, and relatively smaller populations. On a per capita basis then, these communities tend to be more reliant on commercial fishing in social and economic terms (Harvey et al., 2018). Nearly all of the focal communities exhibited demographic characteristics that are associated with increased social vulnerability (Colburn and Jepson, 2012). A factor analysis method frequently employed within NOAA Fisheries community analyses is aimed at measuring multiple community demographic characteristics for fishing communities simultaneously (Colburn et al., 2017). Using this approach, all but one of the focal communities in our survey (Half Moon Bay, CA) were moderately or highly socially vulnerable to exogenous social or economic shocks in 2015-2016, including, for example, a fishery closure related to a HAB event (Harvey et al., 2018). These social vulnerability measures account for demographic variables that include community poverty rates, age distributions, and percentage of the community population that identify as members of vulnerable minority populations, as well as other sociodemographic characteristics (Jepson and Colburn, 2013). All of the focal communities have strong connections to the commercial Dungeness crab fishery (Fuller et al., 2017; Norman et al., 2007; Pomeroy et al., 2011). Some of the focal communities also have connections to the recreational razor clam fishery, but tourism activities surrounding clamming is mostly concentrated along the northern OR and WA coast (e.g., Dyson and Huppert, 2010).

The populations of interest for the survey were people directly involved in the shellfish industry, people providing services to support commercial fishing and workboats, and people working in the restaurant and hospitality industry that were likely impacted through loss of revenue from tourists that would normally come to the coast to harvest shellfish recreationally or enjoy seafood dining by the sea as part of their holiday experience. These groups of people were identified by Ritzman et al. (2018) as being most likely to have experienced negative impacts from the 2015 HAB. A mixed mode survey design consisting of mail and online formats was utilized to administer the survey (de Leeuw and Hox, 2011; Dillman et al., 2014). This was done to maximize the likelihood of reaching individuals in the populations of interest.

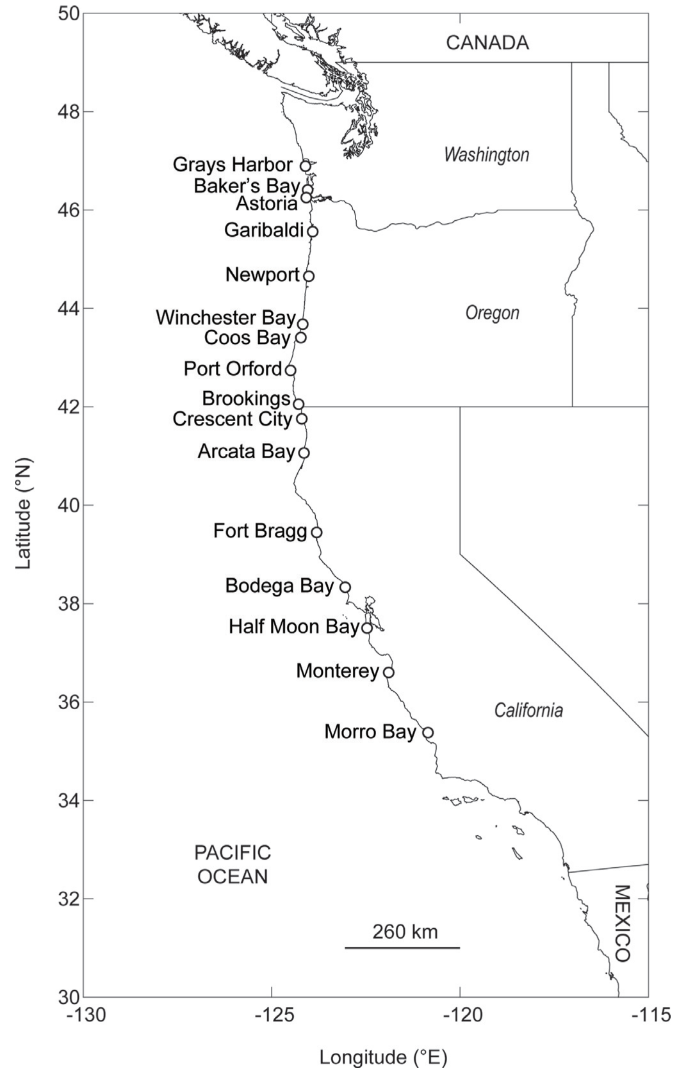

Fig. 1. Map of the U.S. West Coast showing the locations of the 16 focal communities in Washington (2), Oregon (7), and California (7).

2.1. Participants

For the mail survey, participants living or working in the 16 focal communities were recruited from a database managed by InfoUSA® and a mailing list provided by the Pacific Fisheries Information Network (PacFIN; www.psmfc.org). The InfoUSA® list included: all owners/managers of businesses related to the harvesting, processing, and sale of crab and bivalve shellfish; service providers for commercial fishing and workboats (e.g., ports, marinas, boat yards, boat equipment, boat repairers); and hospitality providers (e.g., hotels, restaurants). The PacFIN list included all Dungeness crab permit holders in 2015 and 2016 that resided in the focal communities.

A total of 2019 surveys were sent by regular mail, and recipients returned 209 surveys. Five duplicate responses identified either through written notes to the researchers or exact matches in handwriting, answers, and return dates of surveys were excluded from analysis, resulting in a 10.1% response rate[1] (N = 204, 145 males, 55 females, 4

[1] Calculated according to the Response Rate 2 formula from the AAPOR

Table 1
Population size (from 2015 census data) and lost fishing opportunity for each census designated place (CDP) comprising the 16 focal communities in Washington (WA), Oregon (OR), and California (CA) targeted for the survey (lost fishing opportunity is the proportion of the 2015–2016 season of the commercial Dungeness crab fishery that was closed due to the 2015 harmful algal bloom and are provided from Moore et al., 2019).

State	Community	CDP	Population	Lost fishing opportunity
WA	Grays Harbor	Hoquiam	8434	0.12
		Aberdeen	16,896	
		Ocean Shores	5831	
		Westport	2035	
	Baker's Bay	Long Beach	1389	0.12
		Ilwaco	936	
		Chinook	466	
OR	Astoria	Astoria	9802	0.13
		Warrenton	5469	
	Garibaldi	Garibaldi	779	0.13
		Tillamook	5183	
	Newport	Newport	10,393	0.13
	Winchester Bay	Winchester Bay	382	0.13
		Reedsport	4112	
	Coos Bay	North Bend	9789	0.13
		Coos Bay	16,292	
	Port Orford	Port Orford	1159	0.13
	Brookings	Brookings	6526	0.13
		Harbor	2391	
CA	Crescent City	Crescent City	6670	0.72
		Bertsch-Oceanview	2436	
	Arcata Bay	Trinidad	359	0.72
		Mckinleyville	15,177	
		Eureka	27,226	
	Fort Bragg	Fort Bragg	7287	0.72
	Bodega Bay	Bodega Bay	20,817	0.58
	Half Moon Bay	Half Moon Bay	12,697	0.58
		El Granada	5467	
	Monterey	Monterey	27,810	0.58
		Moss Landing	204	
	Morro Bay	Morro Bay	10,649	0.20

prefer not to answer or other).[2] Just over 11% of the participants either did not reside in one of the 16 focal communities or did not indicate their geographic location. These participants were excluded from the analysis, reducing the sample size to 180 for the mail survey (129 males, 47 females, 4 prefer not to answer or other). Thirty-six participants were from WA (20.0%), 69 from OR (38.3%), and 75 from CA (41.7%).

For the online survey, participants were recruited through advertising the survey on select shellfish-related electronic mailing lists and by word of mouth. Established listservs managed by the Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, Columbia River Crab Fishermen's Association, Oregon Dungeness Crab Commission, and California Dungeness Crab Task Force were used. The online survey was included to reach deckhands and other fishery participants that may not be Dungeness crab permit holders (targeted by the mail survey). Participants were instructed to indicate their interest in participating in the survey by submitting their email contact details. Those who indicated interest were emailed a survey cover letter that included individual embedded hyperlinks to take the survey ($N = 812$). Recipients completed a total of 308 online surveys and 19 incomplete and partial surveys (which were not used in the analyses), resulting in a 40.3% response rate.[3] Participants who did not reside in one of the 16 focal communities or did not provide geographical information were excluded, along with one participant who indicated they were not 18 years of age or older. This resulted in a sample size of 201 for the online survey (125 males, 72 females, 4 prefer not to answer or other). There were 120 participants from WA (59.7%), 22 from OR (11.0%), and 59 from CA (29.4%).

The survey collected standard sociodemographic characteristics of survey participants (both mail and online; $N = 381$). These characteristics, given in Table 2, can be used to determine sampling error and provide helpful context for interpretation of the collected survey data. For example, age is one factor used in NOAA Fisheries' community analyses of social vulnerability (Jepson and Colburn, 2013) and is also relevant because of the “graying of the fleet” trend across many fisheries around the world (e.g., Donkersloot and Carothers, 2016), and political orientation may be associated with certain types of government assistance for coping and/or adapting being more or less acceptable for some individuals. For the purpose of this study, participants are divided into groups comprising those who indicated that they were employed in the fishing industry (*Fish*) and those who indicated that they were employed in other sectors (*Non-Fish*) that could have been affected by the HAB event, such as the restaurant and hospitality industry. This is discussed in more detail in Section 3.1.

2.2. Survey development and implementation

The survey design allowed us to test whether the themes identified by Ritzman et al. (2018) from the semi-structured interviews conducted in two of the 16 focal communities were more broadly applicable to fishing communities impacted by the 2015 HAB event. These themes included the seasonality, distribution, and pervasiveness of economic impacts, sociocultural impacts (cultural connections, community identify, and emotional wellbeing), aspects of community resilience and vulnerability, and future implications. The 45 questions in the survey were organized in four sections concerning (i) community and employment, (ii) impacts of the 2015 HAB event, (iii) future impacts and coping, and (iv) information and communication related to HABs and climate change. The mail and online survey versions, which were both pre-tested by the multi-disciplinary research team at the University of Washington, were designed to be similar, although slight differences were introduced by the mode of distribution. For example, the online survey required responses for each question, whereas the mail version could not. The mail survey is provided as supplementary material.

The mail survey was deployed on July 28, 2017 according to a modified Tailored Design Method that included the survey, pre-paid cash incentive, two follow-up reminder letters, and a post-completion incentive (Dillman et al., 2014). A one-dollar bill incentive was included with the survey as well as a cover letter explaining basic information about the project and the 2015 HAB event. The cover letter indicated that respondents would receive a $5 e-gift card for completing the survey, if they returned their contact information on the contact card provided (for mailing purposes as well as record keeping as required by university bylaws). To ensure anonymity of respondents, contact cards were kept separate from survey responses.

The online survey was deployed in two waves, just under two weeks apart. The first wave included people who had signed up on or before

(*footnote continued*)
standard guidelines (AAPOR, 2016).

[2] We allowed people who had received the mail survey to take the survey online, if they wished. There were 5 people who requested this option. We did not analyze this sample in this study due to the small sample size of this group and potential bias.

[3] We conducted a data scrub to identify invalid responses with assistance from Qualtrics, which is the company whose online software we used to conduct the online survey. This review identified 158 respondents that could reasonably be assumed as spam because they took too long to complete the survey (inattentive) or completed it too quickly (< 3 min), duplicates because the IP address used to complete the survey was repeated and (in some cases) demographics are the same, or out of country because the IP address mapped to locations outside of the United States after running IP address to country lookup. These respondents were subsequently removed from our database.

Table 2
Sociodemographic characteristics of survey participants employed in the fishing industry (*Fish*) and those employed in other sectors (*Non-fish*) in Washington (WA), Oregon (OR), and California (CA) (The value given for "Age" is the mean age of participants with the standard deviation provided in parentheses. Values given for "Education", "Income", and "Political orientation" are the median).

	WA *Fish*	*Non-Fish*	OR *Fish*	*Non-Fish*	CA *Fish*	*Non-Fish*
Age	41.36 (12.08)	48.56 (15.85)	52.73 (14.68)	54.13 (14.55)	51.10 (15.84)	45.45 (15.62)
Gender	61.2% male	47.9% male	81.8% male	53.2% male	96.2% male	56.4% male
Education	Associate's/ some college	Bachelor's degree	Associate's/ some college	Associate's/ some college	High school graduate	Associate's/ some college
Income	$50,000 to $74,999	$50,000 to $74,999	$75,000 to $99,999	$50,000 to $74,999	$75,000 to $99,999	$50,000 to $74,999
Political orientation	Not liberal/ conservative	Moderately liberal	Not liberal/ conservative	Moderately liberal	Not liberal/ conservative	Moderately liberal
*Ethnicity**						
White/ Caucasian	43.5%	71.8%	79.6%	78.7%	82.3%	70.9%
Black/ AfricanAm.	8.2%	9.9%	9.1%	4.3%	2.5%	9.1%
Am. Indian/ AK Native	2.4%	4.2%	6.8%	6.4%	5.1%	1.8%
Asian	36.5%	4.2%	0.0%	2.1%	1.3%	7.3%

* Participants were also able to select Hispanic, some other race, or two or more races but these categories were under 4.0% across state and fish/non-fish so they are not reported here. Also not reported are those who selected "I prefer not to respond."

July 15, 2017, and the second wave included all those who signed up between July 16, 2017 and July 31, 2017. Participants received an email message with a cover letter explaining basic information about the project and the 2015 HAB event and indicating that they would receive a $5 e-gift card for completing the survey, but no pre-paid cash incentive. The email message also included individualized links to take the survey. Subjects in both waves received three reminder email messages. Both the mail and online surveys were closed in the first week of September 2017 and data collection ceased.

3. Results

3.1. Employment

Responses from both the mail and online surveys were combined and analyzed by employment type depending on whether participants were employed in the fishing industry, and therefore impacted directly by the fisheries closures stemming from the 2015 HAB event, or by local businesses that could have been affected indirectly by the fishery closures or other consequences of the HAB event. To assess employment, the following question was asked: *In 2015, what was your primary occupation, or the job that you did for most of the year?* The percent of participants employed in *Fish* and *Non-fish* jobs is listed by State in Table 3. The response options for *Fish* jobs included deckhand, fish processor, fish-related retail,[4] and fishing license owner and/or vessel operator. The response options for *Non-fish* jobs included store, restaurant, hotel/lodge, and all other (e.g., student, retired, etc.).

Table 3
Proportion of survey participants employed in each sector of the fishing industry (*Fish*) and those employed in other sectors (*Non-fish*) in Washington (WA), Oregon (OR), and California (CA) normalized by the number of responses per state.

	WA	OR	CA	*N* (job)
Fish	54.5%	48.4%	59.0%	208
Deckhand	3.8%	3.3%	4.5%	15
Fish processor	18.6%	3.3%	3.0%	36
Fish-related retail*	13.5%	7.7%	16.4%	50
Fishing license owner and/or vessel operator	18.6%	34.1%	35.1%	107
Non-fish	45.5%	51.6%	41.0%	173
Store (employee, manager, owner)	12.2%	11.0%	9.7%	42
Restaurant (employee, manager, owner)	9.0%	20.9%	13.4%	51
Hotel/Lodge (employee, manager, owner)	10.9%	5.5%	11.2%	37
All else (student, retired, other)	13.5%	14.3%	6.7%	43
N (state)	156	91	134	*N* = 381

* Fish-related retail was a response option only for the online participants due to survey mode design error.

A slight majority of all survey participants were employed in *Fish* jobs (54.6% of all participants). The proportion of participants in *Fish* jobs was slightly higher in CA compared with WA and OR (59.0% versus 54.5% and 48.4%, respectively). Participants were asked if their primary occupation now was the same as in 2015, to better understand whether people transitioned out of their jobs. Overwhelmingly, participants remained in the same occupation (93.3% *Fish* and 91.9% *Non-fish*). This may suggest a lack of employment substitution within the sampled populations, strong preferences for current occupations (e.g., high job satisfaction) despite negative shocks, and/or preferences for high-risk and high-return occupations (Anderson, 1980; Gatewood and McCay, 1990; Pollnac et al., 2015). For fishers, economic attributes such as multi-fishery participation may also have helped them to remain in their jobs (Hackett et al., 2015).

3.2. Impacts

Impacts of the 2015 HAB event were assessed through multiple survey questions that asked about general, emotional, financial, and sociocultural impacts. For these questions, participants were offered a five point Likert-type scale ranging from strongly disagree to strongly agree, plus a "not applicable" response option. Overall, *Fish* participants were more likely to agree and/or strongly agree on all statements of impact than were *Non-fish* participants (Fig. 2). There was high agreement among *Non-fish* participants that they could not harvest shellfish for personal use due to the 2015 HAB (62.4%) and that it had a negative impact in general (60.1%), as well as causing stress (57.2%) and negatively impacting family gatherings, holidays, or traditions due to lack of shellfish to eat (53.2%). The highest levels of agreement among *Fish* participants were that the 2015 HAB caused stress (87.5%), a negative impact on finances (87.0%), and a loss of money (80.7%). High levels of agreement among both *Fish* and *Non-fish* participants indicate that shellfish consumption decreased due to the 2015 HAB event (77.4% and 72.8%, respectively; results not shown) and that the HAB event was discussed widely within the community (82.7% and 71.7%, respectively; results not shown). The highest levels of disagreement were among *Non-fish* participants for the statements that the 2015 HAB caused sadness (43.0%) and trouble paying bills (32.4%).

In addition to the three financial impacts listed in Fig. 2, impact to

[4] Fish-related retail was a response option only for the online participants due to survey mode design error.

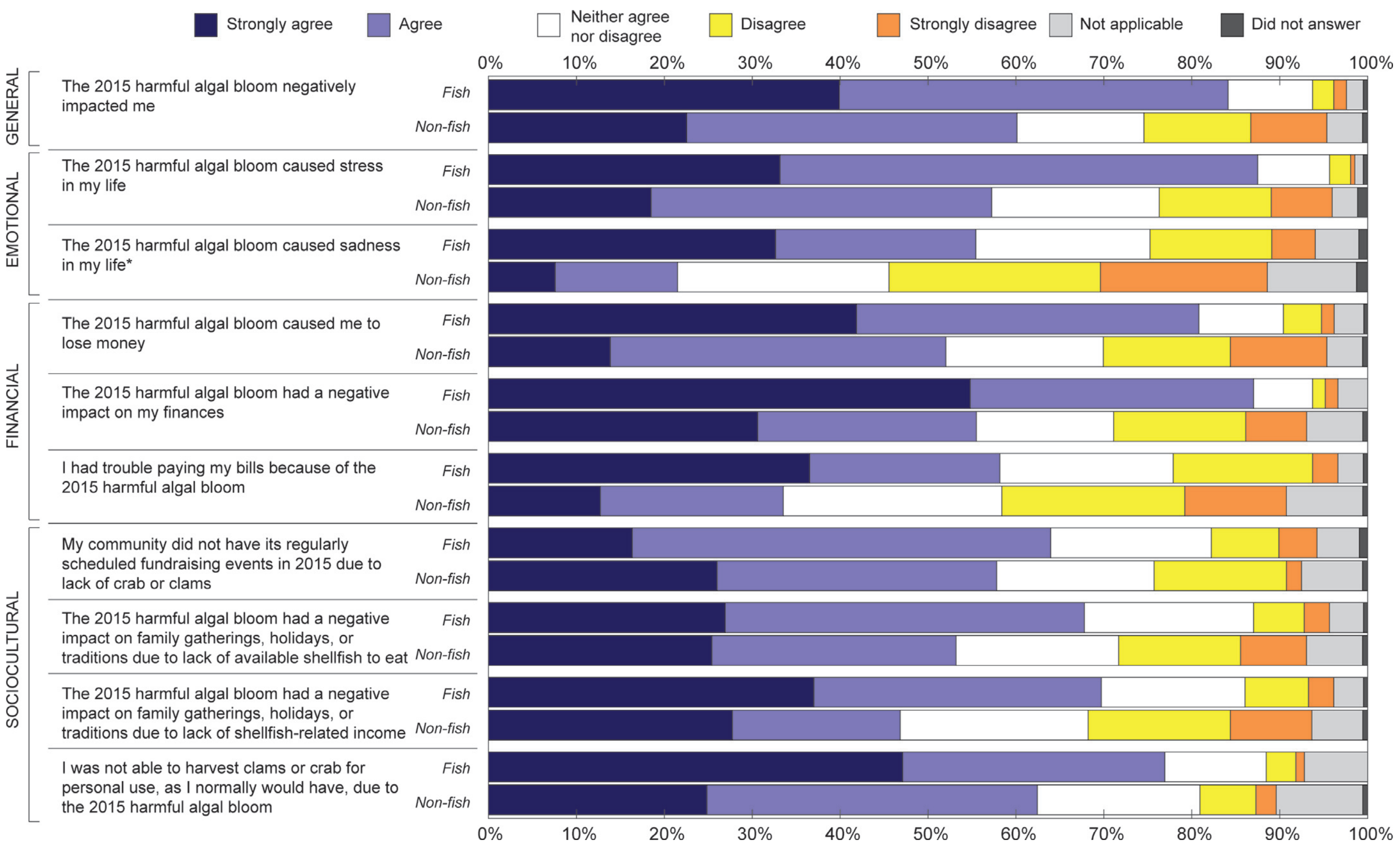

Fig. 2. Levels of agreement with statements of general, emotional, financial, and sociocultural impacts of the 2015 harmful algal bloom among survey participants employed in the fishing industry (*Fish*) and those employed in other sectors (*Non-fish*).

participants' annual income was assessed by asking: *How much did the 2015 harmful algal bloom cause your household's annual income to go up or down?* Seven response options were offered, ranging from less than $100 to $100,000 or more in either direction.[5] For online participants, a question first asked if their income increased, decreased, or stayed the same due to the 2015 HAB. Participants who indicated that their income stayed the same were directed to the next set of questions. The majority of participants (82.2%) indicated an income decrease, 4.2% indicated an income increase, and 13.6% indicated either that their income stayed the same, wrote in "not applicable", or did not answer. Among those who reported a decline in income, *Fish* participants reported greater losses than *Non-fish* participants (Fig. 3). The median decrease for *Fish* participants was $3000 to $9999 in WA and OR, and $10,000 to $99,999 in CA. In contrast, the median decrease for *Non-fish* participants was $1000 to $2999 in WA and CA, and $500-$999 in OR. In CA and OR, *Fish* participants were less likely to recoup their losses than *Non-fish* participants (25.0% versus 39.8%, respectively; Fig. 4). Both *Fish* and *Non-fish* participants in WA were more likely to recoup their losses compared to their counterparts in OR and CA. Notably, participants with a *Fish* job in CA most frequently experienced the greatest income decrease and were the least likely to recoup their losses.

3.3. Actions

Survey participants were asked about coping and adaptive actions that they took to help deal with the financial impacts related to the 2015 HAB. The response options to both questions are shown in Fig. 5, with the exception of "*I was not impacted*". Participants were instructed to mark all that apply. Overall, 16% of survey participants indicated that they were not impacted by the 2015 HAB event (these responses are excluded from the following analyses). Of the 84% of participants who were impacted, many did not report taking any coping (40.5%) or adaptive (26.9%) actions.

The most common coping actions taken by *Fish* participants in WA was to borrow money from friends or family (31.7%), followed by taking no action (17.1%) and applying for food stamps or other forms of government assistance (17.1%; Fig. 5A). In contrast, *Fish* participants in OR and CA were most likely to take no coping actions (48.7% and 55.3%, respectively), followed by borrowing money from friends or family (15.4% and 15.8%; Fig. 5B and C). *Fish* participants in OR were also likely to apply for food stamps or other forms of government assistance (15.4%) or take other actions that they wrote in (15.4%), while in CA taking other actions was also likely (15.8%). The most common actions written in by *Fish* participants were going into debt (i.e., living off credit cards), tightening business practices (including reducing expenditures on labor), and using retirement or other savings. *Non-fish* participants in all three states were most likely to take no coping actions (36.8%, 60% and 45.2% in WA, OR, and CA, respectively; Fig, 5A–C). After taking no coping action, *Non-fish* participants in WA and CA were most likely to borrow money from friends or family (24.6% and 21.4%, respectively) or their employer (21.1% and 21.4%, respectively).

For the adaptive actions, *Fish* participants in WA were most likely to fish other species (33.7%) or advertise (22.9%), whereas *Fish* participants in OR and CA were most likely to take no adaptive action (50.0% and 29.0%, respectively; Fig. 5D–F). *Fish* participants in OR who took adaptive action were likely to take a side job (25.0%), while in CA they were likely to offer discounts (27.6%). The most common adaptive

[5] The direction of income change reported for question 12 was corrected from an increase to a decrease for 24 respondents who had indicated in question 5 that the 2015 HAB caused them to lose money. Likewise, for the 6 respondents who indicated that they had both an increase and a decrease of < $100 it was assumed that they had a decrease.

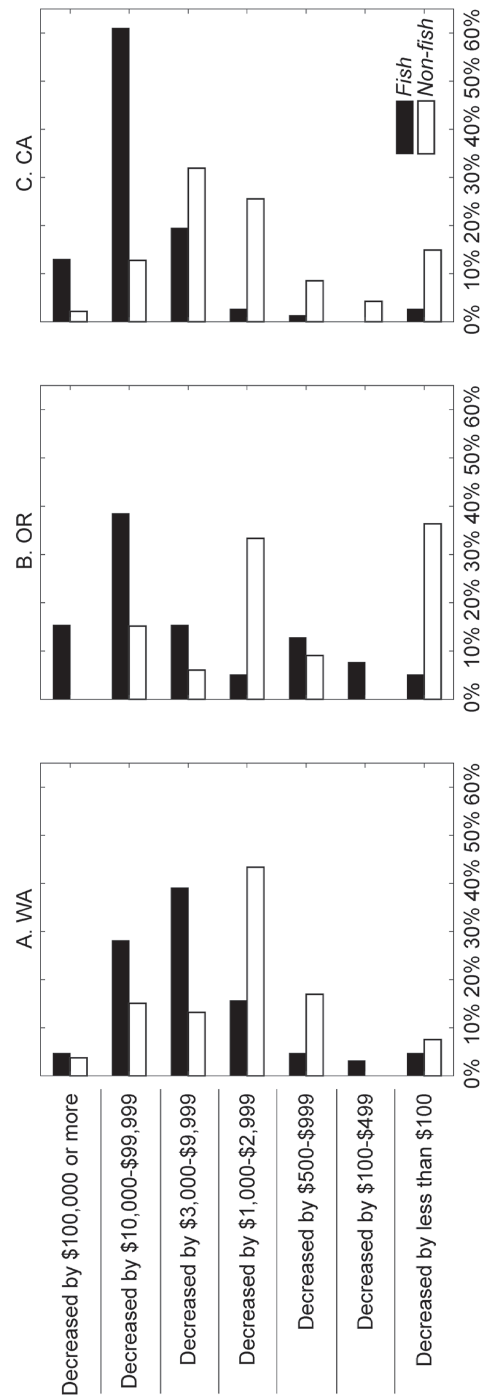

Fig. 3. Proportion of survey participants that had income decreases shown by employment type in Washington (WA), Oregon (OR), and California (CA) normalized by the number of responses per state. *Fish* include participants employed in the fishing industry and *Non-fish* include those employed in other sectors.

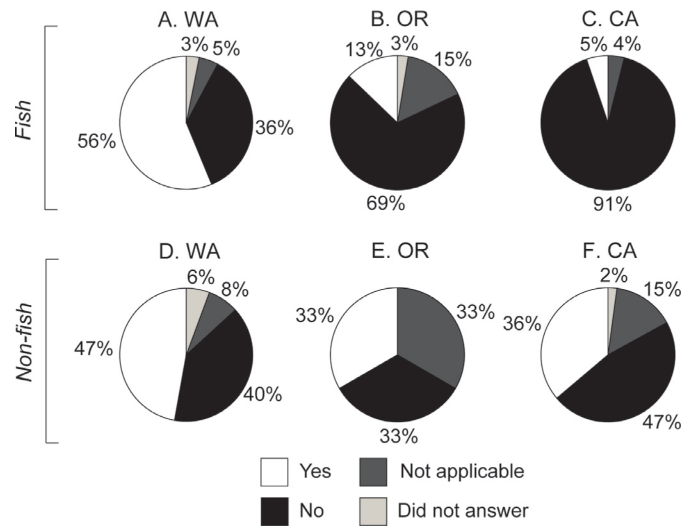

Fig. 4. Responses to the survey question: *If your income decreased, were you able to recoup your losses?* Proportions are shown only for participants who indicated that they had an income decrease by employment type in Washington (WA), Oregon (OR), and California (CA) normalized by the number of responses per state. *Fish* include participants employed in the fishing industry and *Non-fish* include those employed in other sectors.

action taken by *Non-fish* participants in WA was to offer discounts (47.4%) followed by bartering or trading (28.1%). *Non-fish* participants in OR were most likely to take no adaptive action (34.6%), followed by advertising (26.9%) and bartering or trading (23.1%). *Non-fish* participants in CA were most likely to advertise (54.8%), followed by bartering or trading (35.7%) and taking no adaptive action (31.0%).

Survey participants were asked if the actions they took were sufficient to deal with the 2015 HAB event. Of those who were impacted, participants in WA were most likely to answer "*yes*" (85% and 61% for *Fish* and *Non-fish*, respectively) followed by OR (54% and 47% for *Fish* and *Non-fish*, respectively) (Fig. 6). CA participants were most likely to answer "*no*" (27% for both *Fish* and *Non-fish*) compared with WA and OR.

3.4. Future resources

Resources that would be helpful for dealing with a future HAB were assessed by asking: *If a massive harmful algal bloom like the one in 2015 took place, which of the following, if any, would help you?* Response options are shown in Fig. 7; participants were instructed to mark all that applied. Among *Fish* participants, tax relief (22.4%, 29.6%% and 59.5% in WA, OR, and CA, respectively) and increased government services (37.7%, 27.3%% and 41.8% in WA, OR, and CA, respectively) were thought to be the most helpful (Fig. 7). In WA, *Fish* participants thought that increased employment opportunities (27.1%) and financial support (e.g., loans from the government; 24.7%) would also help. *Fish* participants in OR thought that improved information about the bloom that is easy to understand (27.3%) would help, and in CA they thought that financial support (46.8%) and late payment penalty waivers for taxes (41.8%) would help. A substantial portion of *Fish* participants in OR also checked "*Other*" – the most common written responses were better monitoring and allowing fishing when toxin levels "cleared up" or "lowered".

There was less consensus among *Non-fish* participants across all three states about what resources would be most helpful to deal with a future HAB event. *Non-fish* participants in WA thought that tax relief (36.6%) and financial support (33.8%) would be most helpful, while in OR it was improved information about the bloom that is easy to understand (31.9%), and in CA it was financial support (52.7%) and improved information about the bloom that is easy to understand (38.2%)

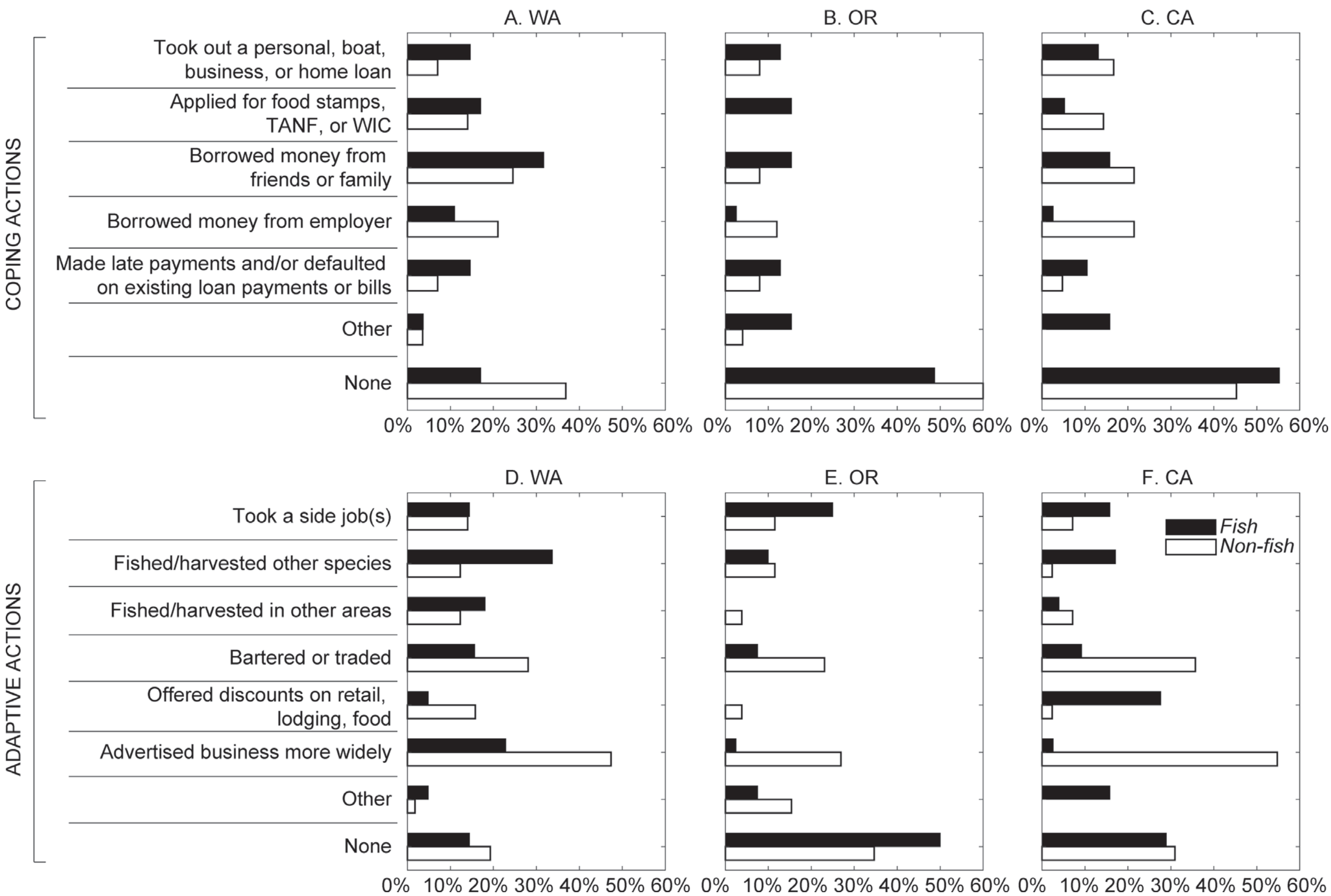

Fig. 5. Proportion of survey participants impacted by the 2015 harmful algal bloom event that took coping (A, B & C) or adaptive (D, E & F) actions shown by employment type in Washington (WA), Oregon (OR), and California (CA) normalized by the number of responses per state. *Fish* include participants employed in the fishing industry and *Non-fish* include those employed in other sectors. Participants were instructed to mark all that applied.

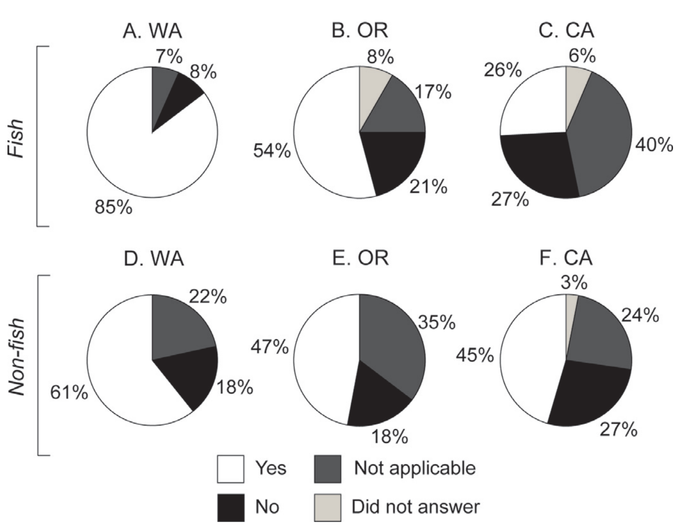

Fig. 6. Responses to the survey question: *Were these actions sufficient to help you deal with the impacts of the 2015 harmful algal bloom?* Proportions are shown only for participants who indicated that they were impacted by employment type in Washington (WA), Oregon (OR), and California (CA) normalized by the number of responses per state. *Fish* include participants employed in the fishing industry and *Non-fish* include those employed in other sectors.

(Fig. 7). Compared to *Fish* participants, a much larger portion of *Non-fish* participants in all three states marked "*None*", indicating that they did not think any of the options would help (4.6-8.9% and 18.2-31.9% for *Fish* and *Non-fish*, respectively). Educational programs or training for alternative employment (2.1-7.6%) were ranked lowest in all three states.

Participants were asked whether they thought that the 2015 HAB was an isolated event or a worsening trend. Response options are shown in Fig. 8. Overall, about half of the participants thought that the 2015 HAB was part of a worsening trend (44.7–59.2%; Fig. 8). Both *Fish* and *Non-fish* participants in CA were the least likely to think that the 2015 HAB was an isolated event (5.1% and 7.3%, respectively). This view may influence the willingness of participants to prepare for future HAB events.

4. Discussion

The fishery closures caused by the 2015 U.S. West Coast domoic acid event negatively impacted 84% of survey participants across the 16 fishing communities examined here. Nearly all the individuals employed in *Fish* jobs reported experiencing negative impacts, but a high proportion (~60%) of individuals employed in *Non-fish* jobs also reported experiencing negative impacts in one or more areas (i.e., emotional, financial, sociocultural). This supports the finding of Ritzman et al. (2018) that the socioeconomic impacts of the 2015 HAB extended to individuals who were not directly employed in fisheries.

The higher proportion of individuals in *Fish* jobs reporting negative impacts in all areas compared with those in *Non-fish* jobs is consistent

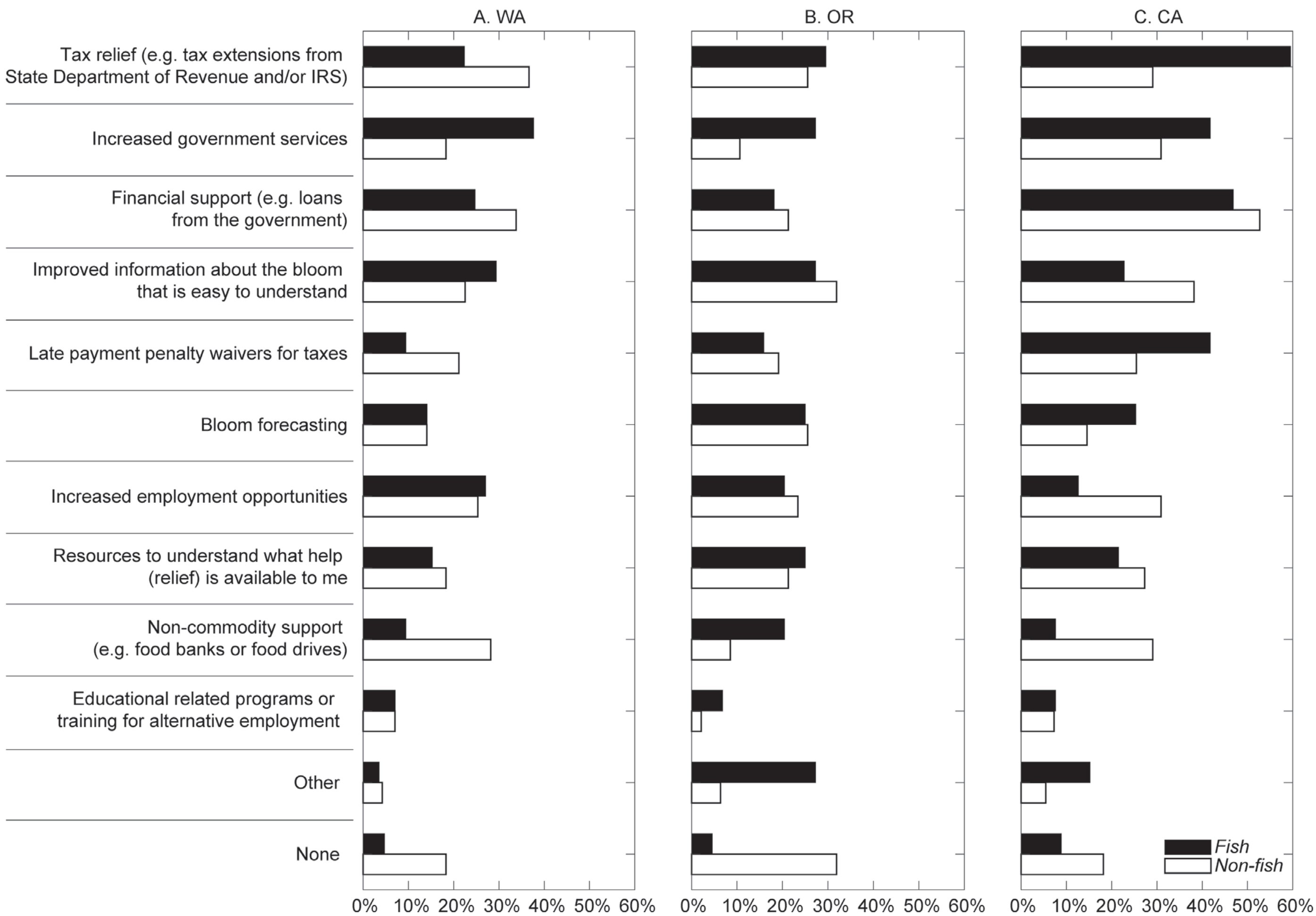

Fig. 7. Proportion of survey participants indicating resources that would help to deal with a future harmful algal bloom shown by employment type in Washington (WA), Oregon (OR), and California (CA) normalized by the number of responses per state. *Fish* include participants employed in the fishing industry and *Non-fish* include those employed in other sectors. Participants were instructed to mark all that applied.

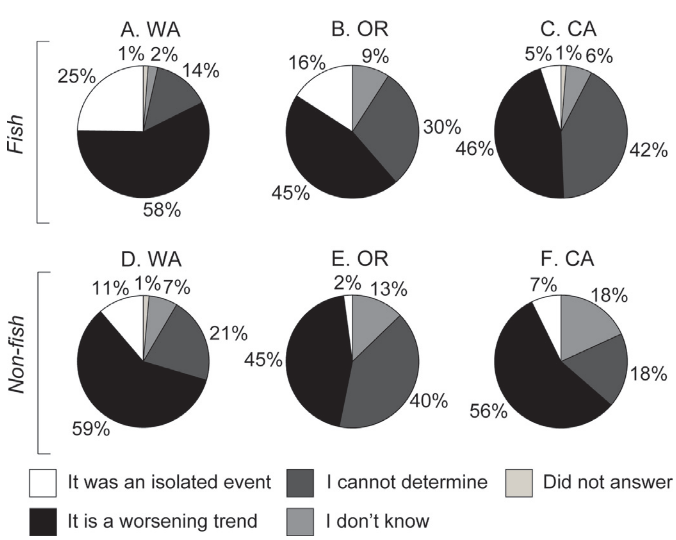

Fig. 8. Responses to the survey question: *Which of the following best describes your views on the 2015 harmful algal bloom?* Proportions are shown by employment type in Washington (WA), Oregon (OR), and California (CA) normalized by the number of responses per state. *Fish* include participants employed in the fishing industry and *Non-fish* include those employed in other sectors.

with the expected direct and indirect impacts of the commercial Dungeness crab fishery closures. Individuals in *Fish* jobs could not harvest, process, or sell Dungeness crab. To offset income losses, some individuals either fished other species or in other areas or took a side job, but many didn't fish at all (Fig. 5; M. Fisher, personal comm.). Individuals in *Non-fish* jobs (primarily those who worked in restaurants, hotels, and other related businesses) may have experienced losses from decreased patronage from fishers and others in the community impacted by the 2015 HAB (J. Ritzman, personal comm.), or from reduced tourism stemming from closures of the recreational razor clam fishery (e.g., Dyson and Huppert, 2010; Ritzman et al., 2018).

Individuals in *Fish* jobs were both more likely to report negative financial impacts and more likely to experience greater financial loss due to the 2015 HAB than those in *Non-fish* jobs. In some communities there were reports of community members rallying around crabbers by organizing fundraisers and offering food boxes.[6] This activation and use of social capital can contribute to cohesion and promote positive adaptation (Abramson et al., 2015). *Fish* participants in CA experienced the greatest income losses and were the least likely to recover their losses compared to their counterparts in WA and OR. This is consistent with the duration of the commercial Dungeness crab fishery closures, which were almost 5 times longer in some parts of CA than in WA and OR. Another factor that may have contributed to this finding is the

[6] https://www.fishermensnews.com/story/2016/04/01/features/hard%ADtimes%ADfor%ADcrescent%ADcity%ADcrabbers/383.html

impact of the 2015 HAB on the Dungeness crab ex-vessel price in CA. The ex-vessel price is the price a fisher receives for their catch at the point of landing. In CA, ex-vessel prices were significantly lower when the commercial Dungeness crab fishery re-opened after the 2015 HAB (Mao and Jardine, 2020). A corresponding decline in ex-vessel prices was not observed in WA and OR. This may have made it more difficult for CA fishers to recover their losses compared with WA and OR fishers.

A much higher proportion of participants with *Fish* jobs experienced impacts to emotional wellbeing (i.e., stress and sadness) due to the 2015 HAB compared to those with *Non-fish* jobs. Factors found to increase the likelihood of fishers experiencing stress include suffering high levels of financial loss, inability to recoup financial losses, experiencing sociocultural impacts, and engaging in adaptive actions such as advertising or taking a side job (Moore et al., 2020). The higher levels of stress reported by participants with *Fish* jobs is also consistent with the finding of Ritzman et al. (2018) that fishers felt frustrated that the closures persisted for so long and experienced poor emotional wellbeing from waiting for the fishery to open.

The proportions of participants reporting sociocultural impacts were similar among *Fish* and *Non-fish* participants. This indicates that the social activities and traditional practices of individuals residing in fishing communities are closely tied to fisheries resources, regardless of whether they are directly employed in a fishing-related occupation. This finding highlights the disruption to cultural ecosystem services caused by the 2015 HAB and the potential for HAB events to erode community identity (Ritzman et al., 2018; Willis et al., 2018). Cultural ecosystem services are “nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences” (Millenium Ecosystem Assessment 2005). These services are tightly bound to human values and behavior, and their loss is not captured by conventional recordings of the economic impacts of HABs. Without this understanding, locally relevant strategies cannot be developed to increase the resilience of coastal communities to future HAB events (Van Dolah et al., 2016; Willis et al., 2018).

When asked about coping or adaptive actions taken to deal with the 2015 HAB, “none” was the most common response among impacted individuals in both *Fish* and *Non-fish* jobs. This may indicate limited resources and strategies available to fishing communities to cope with or adapt to HABs. For example, studies of other systems have shown that although populations can be aware of a problem, they may not be able to identify a means to adapt to it or may be unable to (Liu et al., 2018). For fishers, it may also indicate a preference to wait until the Dungeness crab fishery opened in their usual fishing area rather than gearing up to fish a less valuable species or transiting farther from home ports (with associated increases in fuel costs) to fish in other areas. The 30-day Fair Start Provisions (California Fish and Game Code FGC § 8279.1) may also have deterred fishers from fishing in other areas. This provision was established because of concern that season delays would allow some vessels to target multiple openings and disadvantage vessels in the delayed area. Under this law, vessels that have participated in the Dungeness crab fishery in CA, OR, or WA prior to the delayed area opener are subject to Fair Start and are not allowed to take, possess, or land crab in the delayed area for 30 days after the area opens.

The fair start provisions are an example of an adaptive institution: designed or evolved to address variability, shocks, and change. Coastal fishing communities around the world already have a series of adaptive institutions (e.g., social norms, cultural practices, forms of economic and social organization) and attitudes and beliefs (e.g., psychological preparedness for risk and variability) that are adaptive (Kelly and Adger, 2000). HAB-affected communities on the West Coast may be using these strategies without labeling them as coping or adaptive actions, and not all of these strategies will be identified in surveys (a disadvantage of closed-question methods relative to in-depth participant observation and interview methods). It may also be that some people didn't quite understand the question, or couldn't fit their actions into what they understood by the term. Consequentially, coping and adaptive actions could be underreported by the survey.

Participants with *Fish* jobs were less likely to barter or trade than those with *Non-fish* jobs. West Coast fishers commonly keep some of their catch for household use, gifting, and sharing (Poe et al., 2015). The fishery closures may have created a barrier to this subsistence behavior and made this adaptive action unavailable to fishers. Interestingly, participants with *Fish* jobs in CA were far more likely to offer discounts than their counterparts in WA and OR. This is curious because fishers are price takers; that is, they do not set the price of their catch and are subject to market fluctuations (Jacob et al., 2001). Could it be that deckhands were willing to work for a lower price and considered that offering a discount? Perhaps fishers in price negotiations didn't bargain as much as they usually did and considered that a discount? It may be more plausible that this response does not represent an active decision made by CA fishers, but instead is a result of the significantly lower ex-vessel prices for Dungeness crab in CA compared with WA and OR after the fishery opened (Mao and Jardine, 2020).

Of those impacted by the 2015 HAB, participants in CA were less likely to think that the actions they took were sufficient to help them deal with the event than participants in WA and OR. Only 26% of participants in CA with *Fish* jobs thought that the actions they took were sufficient. This result suggests that strategies available to individuals in fishing communities to help them deal with extreme HABs are limited, and that those that are available are not necessarily effective, especially for those dealing with lengthy fishery closures due to HABs such as occurred in CA. This implies that the Dungeness crab fishery SES may be vulnerable to future HABs unless actions are taken to bolster the coping capacity of individuals and communities.

Dungeness crab fishery participants in CA who were affected by the 2015 HAB eventually received disaster assistance from the federal government. Under federal law, fishery failures that result in losses between 35% and 80% of average revenues compared to the previous five years are eligible for disaster assistance subject to appropriation of funds by congress (NOAA, 2018). Unfortunately, this process is lengthy – for nearly every fishery disaster that occurred over the past decade it has taken more than two years to distribute assistance once a disaster request was made (G. Jaeger, personal comm.). In this case the delay was particularly long and aid was not distributed to affected industry participants until June 2018, almost three years after the fishery closures[7]. Waiting for disaster assistance may therefore be an ineffective coping strategy for some fishers.

Resources that most *Fish* and *Non-fish* participants thought would be helpful for dealing with a future HAB included various forms of financial assistance or relief provided by the government. In particular, participants in CA with *Fish* jobs thought that tax relief would be helpful. The least popular option among both *Fish* and *Non-fish* participants in all three states was education and training for alternative employment. The finding is consistent with most participants indicating that they had not changed occupations between the 2015 HAB and when the survey was deployed, and could indicate a preference for their current occupation. However, the finding is in contrast to that of Ritzman et al. (2018), who report that residents wanted a “one stop shop” for career resources such as business and job training. The low popularity of this option in the survey is consistent with the notion that workers in fishing communities are reluctant to move into other job sectors, choosing instead to continue in their jobs even if it means living in poverty or at a subsistence level (Jacob et al., 2001, and references therein). In addition, participants may perceive a lack of alternative employment opportunities that could hinder successful job swapping (Ritzman et al. 2018, data not shown).

About half of participants thought that the 2015 HAB was part of a

[7] https://www.seafoodnews.com/Story/1139821/California-Crab-Industry-Could-See-Disaster-Checks-in-June

worsening trend. The extensive closures in 2015 were followed by another HAB in 2016 that delayed the opening of the commercial Dungeness crab fishery by up to 1 month in some areas of CA, all of OR, and southern WA. The survey tool used to collect data for this study was implemented in 2017 after an unprecedented two successive years of fishery closures due to HABs. The massive 2015 HAB event was linked to the 2013-15 Northeast Pacific Marine Heatwave (nicknamed "the Blob"; Bond et al., 2015; McCabe et al., 2016; Zhu et al., 2017). While the 2016 HAB event that followed has not yet been definitively linked to warmer than normal ocean conditions, it did coincide with warmer than normal conditions from the 2015-16 El Niño (Jacox et al., 2016). Indeed, every major HAB event on the WA and OR coasts has either coincided with or closely followed periods of warming (McCabe et al., 2016; McKibben et al., 2017). Compelling evidence indicates that warmer waters, projected under climate change, will lead to more frequent and toxic HABs on the U.S. West Coast. However, only about half of survey participants believe that HABs are connected to climate change (Ekstrom et al., 2020). This suggests the need for improved outreach and education for residents of fishing communities on the linkages between climate change and ocean conditions. Such outreach could possibly influence the political will to support improved science and management of HABs, and potentially motivate individuals and fishing communities to adapt to climate-driven perturbations (i.e., recurrent HABs) to the commercial Dungeness crab fishery SES (Ekstrom et al., 2020). Part of preparing for these changes lies in understanding how HABs have impacted communities in the past, what actions have been taken, and what resources will be helpful in the future. Our findings provide a foundation for such preparation. They are, however, drawn from a limited number of survey participants from largely two employment types (fisheries and hospitality) in a subset of communities; as such, they may have limited generalizability to other subpopulations and communities. Additional human dimensions research is needed to inform efforts to prepare for HABs, mitigate their impacts, and aid recovery of impacted communities.

Declaration of competing interests

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.

Acknowledgments

The authors would like to thank Anne Baxter for assisting with participant recruitment and Isabella Colpo for assisting with data entry. John Spengler and Vera Trainer provided valuable advice and assistance in conceptualizing this study. This work was supported by the JPB Foundation and a JPB Environmental Health Fellowship award granted by The JPB Foundation and managed by the Harvard T. H. Chan School of Public Health. The authors are grateful to the Human Subjects Division of the University of Washington, which reviewed the human subjects research approach for this project and determined that it qualified for exempt status.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hal.2020.101799.

References

American Association for Public Opinion Research (AAPOR). 2016. Survey Outcome Rate Calculator 4.0.

Abramson, D.M., Grattan, L.M., Mayer, B., Colten, C.E., Arosemena, F.A., Rung, A., Lichtveld, M., 2015. The Resilience Activation Framework: a conceptual model of how access to social resources promotes adaptation and rapid recovery in post-disaster settings. J. Behav. Health Serv. Res. 42 (1), 42–57.

Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), Public Law 94-265. 2007. As amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Adger, W.N., 2000. Social and ecological resilience: are they related? Progr. Hum. Geogr. 24 (3), 347–364.

Alliance, R., 2010. Assessing Resilience in Social-Ecological Systems: Workbook for Practitioners. Version 2.0. Online: http://www.resalliance.org/3871.php.

Allison, E.H., Bassett, H.R., 2015. Climate change in the oceans: human impacts and responses. Science 350 (6262), 778–782.

Allison, E.H., Horemans, B., 2006. Putting the principles of the sustainable livelihoods approach into fisheries development policy and practice. Mar. Policy 30 (6), 757–766.

Anderson, L.G., 1980. Necessary components of economic surplus in fisheries economics. Can. J. Fish. Aquat. Sci. 37, 858–870.

Assessment, M.E., 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.

Backer, L.C., Moore, S.K., 2012. Harmful algal blooms: future threats in a warmer world. In: Nemr, A.E. (Ed.), Environmental Pollution and its Relation to Climate Change. Nova Science Publishers, New York, pp. 485–512.

Bates, S.S., Bird, C.J., Defreitas, A.S.W., Foxall, R., Gilgan, M., Hanic, L.A., Johnson, G.R., McCulloch, A.W., Dodense, P., Pocklington, R., Quillam, M.A., Sim, P.G., Smith, J.C., Subba Rao, D.V., Todd, C.D., Walter, J.A., Wright, J.L.C., 1989. Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. Can. J. Fish. Aquat. Sci. 46, 1203–1215.

Bauer, M., 2006. Harmful Algal Research and Response: A Human Dimensions Strategy. National Office for Marine Biotoxins and Harmful Algal Blooms, Woods Hole Oceanographic Institution, Woods Hole, MA, pp. 58.

Bauer, M., Hoagland, P., Leschine, T.M., Blount, B.G., Pomeroy, C.M., Lampl, L.L., Scherer, C.W., Ayres, D.L., Tester, P.A., Sengco, M.R., Sellner, K.G., Schumacker, J., 2010. The importance of human dimensions research in managing harmful algal blooms. Front. Ecol. Environ. 8 (2), 75–83. https://doi.org/10.1890/070181.

Berman, R., Quinn, C., Paavola, J., 2012. The role of institutions in the transformation of coping capacity to sustainable adaptive capacity. Environ. Dev. 2, 86–100.

Bond, N.A., Cronin, M.F., Freeland, H., Mantua, N., 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophys. Res. Lett. 42, 3414–3420 doi: 3410.1002/2015GL063306.

Borbor-Córdova, M.J., Pozo-Cajas, M., Cedeno-Montesdeoca, A., Saltos, G.M., Kislik, C., Espinoza-Celi, M.E., Lira, R., Ruiz-Barzola, O., Torres, G., 2018. Risk perception of coastal communities and authorities on harmful algal blooms in Ecuador. Front. Mar. Sci. 5, 365 doi: 310.3389/fmars.2018.00365.

Colburn, L.L., Jepson, M., Himes-Cornell, A., Kasperski, S., Norman, K., Weng, C., Clay, P. M. 2017. Community Participation in U.S. Catch Share Programs. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-F/SPO-179, 136 p.

Colburn, L.L., Jepson, M., 2012. Social indicators of gentrification pressure in fishing communities: a context for social impact assessment. Coast. Manag. 40 (3), 289–300.

Crosman, K.M., Petrou, E.L., Rudd, M.B., Tillotson, M.D., 2019. Clam hunger and the changing ocean: characterizing social and ecological risks to the Quinault razor clam fishery using participatory modeling. Ecol. Soc. 24, 16. https://doi.org/10.5751/ES-10928-240216.

Cutter, S.L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., Webb, J., 2008. A place-based model for understanding community resilience to natural disasters. Glob. Environ. Change 18, 598–606.

de Leeuw, E.D., Hox, J.J., 2011. Internet surveys as part of a mixed-mode design. In: Das, P., Ester, P., Kaczmirek, L. (Eds.), Social and Behavioral Research and the Internet: Advances in Applied Methods and Research Strategies. Routledge, New York, pp. 45–76.

Dillman, D.A., Smyth, Jolene D., Christian, Leah Melani., 2014. Internet, Phone, Mail and Mixed-Mode Surveys: The Tailored Design Method. Jon Wiley & Sons.

Donkersloot, R., Carothers, C., 2016. The graying of the Alaskan fishing fleet. Environ.: Sci. Policy Sustain. Dev. 58 (3), 30–42. https://doi.org/10.1080/00139157.00132016.01162011.

Dyson, K., Huppert, D.D., 2010. Regional economic impacts of razor clam beach closures due to harmful algal blooms (HABs) on the Pacific coast of Washington. Harmful Algae 9 (3), 264–271 doi: 210.1016/j.hal.2009.1011.1003.

Ekstrom, J.A., Moore, S.K., Klinger, T., 2020. Examining harmful algal blooms through a disaster risk management lens: A case study of the 2015 U.S. West Coast domoic acid event. Harmful Algae.

Eriksen, S., Aldunce, P., Bahinipati, C.S., Martins, R., Molefe, J.I., Nhemachena, C., Ulsrud, K., 2011. When not every response to climate change is a good one: Identifying principles for sustainable adaptation. Clim. Dev. 3, 7–20.

FDA, 2011. Fish and Fishery Products Hazards and Controls Guidance. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Food Safety Appendix 5: FDA and EPA Safety Levels in Regulations and Guidance.

Fuller, E.C., Samhouri, J.F., Stoll, J.S., Levin, S.A., Watson, J.R., 2017. Characterizing fisheries connectivity in marine social–ecological systems. ICES J. Marine Sci. 74 (8), 2087–2096. https://doi.org/10.1093/icesjms/fsx128.

Gatewood, J.B., McCay, B., 1990. Comparison of job satisfaction in six New Jersey fisheries. Hum. Org. 49 (1), 14–25.

Hackett, S.C., Dewees, C.M., Krachey, M.J., 2004. Race for Dungeness crab influences processing, markets. Calif. Agric. 58 (4), 190–191 doi: 110.3733/ca.v3058n3704p3190.

Hackett, S., Pitchon, A., Hansen, M.D., 2015. Economic attributes of stayers and leavers in

four California fisheries. CalCOFI Rep. 56, 133–142.
Hoagland, P., Anderson, D.M., Kaoru, Y., White, A.W., 2002. The Economic Effects of Harmful Algal Blooms in the United States: Estimates, Assessment Issues, and Information Needs. Estuaries 25 (4), 819–837.
Hoagland, P., Jin, D., Polansky, L.Y., Kirkpatrick, B., Kirkpatrick, G., Fleming, L.E., Reich, A., Watkins, S.M., Ullmann, S.G., Backer, L.C., 2009. The costs of respiratory illnesses arising from Florida gulf coast Karenia brevis blooms. Environ. Health Perspect. 117 (8), 1239–1243.
Jacob, S., Farmer, F.L., Jepson, M., Adams, C., 2001. Landing a definition of fishing dependent communities: potential social science contributions to meeting National Standard 8. Fisheries 26 (10), 16–22.
Jacox, M.G., Hazen, E.L., Zaba, K.D., Rudnick, D.L., Edwards, C.A., Moore, A.M., Bograd, S.J., 2016. Impacts of the 2015–2016 El Niño on the California Current System: early assessment and comparison to past events. Geophys. Res. Lett. 43 (13), 7072–7080.
Jardine, S.L., Fisher, M., Moore, S., Samhouri, J., 2020. Inequality in the economic impacts from climate shocks in fisheries: the case of harmful algal blooms. Ecol. Econ submitted for publication.
Harvey, C., Garfield, N., Williams, G., Tolimieri, N., Schroeder, I., Hazen, E., Andrews, K., Barnas, K., Bograd, S., Brodeur, R., Burke, B., Cope, J., deWitt, L., Field, J., Fisher, J., Good, T., Greene, C., Holland, D., Hunsicker, M., Jacox, M., Kasperski, S., Kim, S., Leising, A., Melin, S., Morgan, C., Muhling, B., Munsch, S., Norman, K., Peterson, W., Poe, M., Samhouri, J., Sydeman, W., Thayer, J., Thompson, A., Tommasi, D., Varney, A., Wells, B., Williams, T., Zamon, J., Lawson, D., Anderson, S., Gao, J., Litzow, M., McClatchie, S., Ward, E., Zador, S. 2018. Ecosystem Status Report of the California Current for 2018: A Summary of Ecosystem Indicators Compiled by the California Current Integrated Ecosystem Assessment Team (CCEIA). U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-145. https://doi.org/10.25923/mvhf-yk36.
Jepson, M., Colburn, L.L., 2013. Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions. U.S. Dept. of Commerce., NOAA Technical Memorandum NMFS-F/SPO-129, 64 p.
Jin, D., Thunberg, E., Hoagland, P., 2008. Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England. Ocean Coast. Manag. 51, 420–429 410.1016/j.ocecoaman.2008.1001.1004.
Kelly, P.M., Adger, W.N., 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Clim. Change 47 (4), 325–352.
Lefebvre, K.A., Robertson, A., 2010. Domoic acid and human exposure risks: a review. Toxicon 56, 218–230.
Liu, K., Huisingh, D., Zhu, J., Ma, Y., O'Connor, D., Hou, D., 2018. Farmers' perceptions and adaptation behaviours concerning land degradation: a theoretical framework and a case-study in the Qinghai–Tibetan Plateau of China. Land Degrad. Dev. 29 (8), 2460–2471.
Mao, J., Jardine, S., 2020. Market impacts of a toxic algae event: the case of California Dungeness crab. Mar. Resour. Econ submitted for publication.
McCabe, R.M., Hickey, B.M., Kudela, R.M., Lefebvre, K.A., Adams, N.G., Bill, B.D., Gulland, F.M.D., Thomson, R.E., Cochlan, W.P., Trainer, V.L., 2016. An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. Geophys. Res. Lett. https://doi.org/10.1002/2016GL070023.
McKibben, M., Peterson, W., Wood, A.M., Trainer, V.L., Hunter, M., White, A.E., 2017. Climatic regulation of the neurotoxin domoic acid. In: https://doi.org/10.1073/pnas.1606798114.
Moore, K.M., Allison, E.H., Dreyer, S.J., Ekstrom, J.A., Jardine, S.L., Klinger, T., Moore, S.K., Norman, K.C., 2020. Harmful algal blooms: identifying effective adaptive actions used in fishery-dependent communities in response to a protracted event. Front. Mar. Sci. 6. https://doi.org/10.3389/fmars.2019.00803.
Moore, S.K., Cline, M.R., Blair, K., Varney, A., Norman, K., 2019. An index of fisheries closures due to harmful algal blooms and a framework for identifying vulnerable fishing communities on the U.S. West Coast. Mar. Policy. https://doi.org/10.1016/j.marpol.2019.103543.
NMFS, 2016. Fisheries of the United States, 2015. U.S. Department of Commerce, NOAA Current Fishery Statistics No. 2015. Available at: http://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus15/index.
NOAA, 2018. Policy on Disaster Assistance Under Magnuson-Stevens Act 312(a) and 315 and Interjurisdictional Fisheries Act 308(b) and 308(d) (National Marine Fisheries Service Policy 01-122). https://www.fisheries.noaa.gov/webdam/download/64692768.
Norman, K., Sepez, J., Lazrus, H., Milne, N., Package, C., Russell, S., Grant, K., Lewis, R.P., Primo, J., Springer, E., Styles, M., Tilt, B., Vaccaro, I., 2007. Community Profiles for West Coast and North Pacific Fisheries - Washington, Oregon, California, and Other US States. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-85, 602 p.
Perl, T.M., Teitelbaum, J., Hockin, J., Todd, E.C., 1990. Domoic acid toxicity. Panel discussion: definition of the syndrome. Can. Dis. Weekly Rep. 16 (Suppl 1E), 41–45.
Poe, M.R., Levin, P.S., Tolimieri, N., Norman, K., 2015. Subsistence fishing in a 21st century capitalist society: from commodity to gift. Ecol. Econ. 116, 241–250.
Pollnac, R.B., Seara, T., Colburn, L.L., 2015. Aspects of fishery management, job satisfaction, and wellbeing among commercial fishermen in the northeast region of the United States. Soc. Nat. Resour.: Int. J. 28 (1), 75–92.
Pomeroy, C., Thomson, C.J., Stevens, M.M., 2011. California's North Coast Fishing Communities Historical Perspective and Recent Trends: Crescent City Fishing Community Profile. California Sea Grant College Program, Scripps Institution of Oceanography, and University of California San Diego, La Jolla, CA Publication No. T-072c, 057.
Putnam, R.D., 2000. Bowling Alone: The Collapse and Revival of American Community. Simon & Schuster, New York.
Ralston, E.P., Kite-Powell, H., Beet, A., 2011. An estimate of the cost of acute health effects from food- and water-borne pathogens and toxins in the USA. J. Water Health 9, 680–694.
Ritzman, J., Brodbeck, A., Brostrom, S., McGrew, S., Dreyer, S., Klinger, T., Moore, S.K., 2018. Economic and sociocultural impacts of fisheries closures in two fishing-dependent communities following the massive 2015 U.S. West Coast harmful algal bloom. Harmful Algae 80, 35–45. https://doi.org/10.1016/j.hal.2018.1009.1002.
Teitelbaum, J., 1990. Acute manifestations of domoic acid poisoning: case presentations. Can. Dis. Weekly Rep. 16 (Suppl 1E), 5–6.
Van Dolah, E.R., Paolisso, M., Sellner, K., Place, A., 2016. Employing a socio-ecological systems approach to engage harmful algal bloom stakeholders. Aquat. Ecol. 50 (3), 577–594.
Vincent, K., Cull, T., Chanika, D., Hamazakaza, P., Joubert, A., Macome, E., Mutonhodza-Davies, C., 2013. Farmers' responses to climate variability and change in southern Africa—is it coping or adaptation? Clim. Dev. 5 (3), 194–205.
Willis, C., Papathanasopoulou, E., Russel, D., Artioli, Y., 2018. Harmful algal blooms: the impacts on cultural ecosystem services and human well-being in a case study setting, Cornwall, UK. Mar. Policy 97, 232–238.
Zhu, Z., Qu, P., Fu, F., Tennenbaum, N., Tatters, A.O., Hutchins, D.A., 2017. Understanding the blob bloom: warming increases toxicity and abundance of the harmful bloom diatom pseudo-nitzschia in California coastal waters. Harmful Algae 67, 36–43. https://doi.org/10.1016/j.hal.2017.1006.1004.