

Indigenous knowledge as data for modern fishery management: a case study of Dungeness crab in Pacific Canada

Natalie C Ban, Lauren Eckert, Madeleine McGreer & Alejandro Frid

To cite this article: Natalie C Ban, Lauren Eckert, Madeleine McGreer & Alejandro Frid (2017) Indigenous knowledge as data for modern fishery management: a case study of Dungeness crab in Pacific Canada, Ecosystem Health and Sustainability, 3:8, 1379887

To link to this article: <http://dx.doi.org/10.1080/20964129.2017.1379887>



© 2017 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group on behalf of Ecological Society of China



Published online: 31 Oct 2017.



Submit your article to this journal [↗](#)



Article views: 20



View related articles [↗](#)



View Crossmark data [↗](#)

ARTICLE



Indigenous knowledge as data for modern fishery management: a case study of Dungeness crab in Pacific Canada

Natalie C Ban^a, Lauren Eckert^a, Madeleine McGreer^b and Alejandro Frid^{a,b}

^aSchool of Environmental Studies, University of Victoria, Victoria, BC, Canada; ^bCentral Coast Indigenous Resource Alliance, Campbell River, BC, Canada

ABSTRACT

Introduction: Fisheries management is often data-limited, and conducted at spatial scales that are too large to address the needs of Indigenous peoples, whose cultures depend upon the local availability of marine resources.

Outcomes: We combined Indigenous ecological knowledge with simulation modelling to inform modern fishery management. Semi-structured interviews with Indigenous fishers in coastal British Columbia, Canada, uncovered severe declines in the abundance and catches of Dungeness crab (*Cancer magister*) since the 1990s. We modelled the current probability of “successful” crab harvesting trips—as defined by expectations from past catches by Indigenous fishers—using fishery-independent data from nine sites. These probabilities were very low (<20%) for all sites except one.

Discussion: Our study highlights that local depletions, which Indigenous fishers attribute to commercial and recreational fisheries, have been widespread and undetected by federal managers who manage Dungeness crab at regional scales without fishery-independent data. Further, local depletions impacted the ability of Indigenous fishers to access traditional foods.

Conclusion: Integrating Indigenous knowledge with scientific research is crucial to inform locally-relevant fisheries management and conservation.

ARTICLE HISTORY

Received 28 May 2017

Revised 15 August 2017

Accepted 12 September 2017

KEYWORDS



Indigenous knowledge;
marine conservation;
Dungeness crab;
spatial management;
co-management;
stewardship


Introduction

Coastal Indigenous peoples have relied on marine resources for thousands of years, and have developed locally relevant management strategies to ensure sustainability. Indigenous marine management practices (hereafter “Indigenous management”) are ubiquitous where people rely on marine resources, and vary in implementation and application to match local ecosystems and customs (Berkes 2012; Lepofsky and Caldwell 2013). Despite the diversity of Indigenous cultures globally, common Indigenous management approaches exist. For instance, customary tenures delimit areas of the ocean where rights of extraction, management, and access are attributed to specific entities or people (e.g., a village, chief, or family), and these may involve temporary or permanent closures to harvesting (Aswani and Hamilton 2004; Jupiter et al. 2014). Indigenous management may also limit harvesting to specific seasons and sizes of animals (Lepofsky and Caldwell 2013). These practices are commonly underpinned by worldviews that embed respect for other living beings and guide actions (e.g., take only what you need) (McClanahan et al. 2006; Lepofsky and Caldwell

2013). These worldviews are embedded within stories, customs, and traditions (Berkes 2012).

Rapid changes in management practices and associated shifts in abundances of marine species started when Europeans colonized coastal regions in areas previously under Indigenous management (Ommer 2007). Colonization and associated repression of Indigenous rights caused whole or partial loss of Indigenous management in many ecosystems globally (Adams and Mulligan 2003; Berkes 2012). For example, in Canada the Indian Act and associated policies banned First Nations’ cultural practices such as potlaches (gift-giving feasts that serve as crucial governance mechanisms), prohibited Indigenous fishing methods such as weirs (Atlas et al. 2017), confined Indigenous people inside Indian Reserves, and forcibly removed children from their language and families, confining them into residential schools (Harris 2002). These policies severely diminished the well-being of First Nations, disrupting Indigenous knowledge and management practices (Truth and Reconciliation Commission 2015). Furthermore, the industrialization and globalization of fisheries caused rapid declines in many marine species, compounding impacts on Indigenous

CONTACT Natalie C Ban  nban@uvic.ca  School of Environmental Studies, University of Victoria, PO Box 1700 STN CSC, Victoria, BC V8W 2Y2, Canada

 Supplemental data for this article can be accessed [here](#).

© 2017 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group on behalf of Ecological Society of China

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

peoples. Whaling, for instance, decimated marine mammal populations (Roman and Palumbi 2003), and the advent of advanced fishing technologies such as trawling and factory freezer vessels resulted in rapid expansion of fishing footprints and reductions of many species (Pauly, Watson, and Alder 2005; Swartz et al. 2010).

The people most affected by changes in management and species abundance are coastal residents – especially Indigenous peoples – who rely upon local marine resources for sustenance, cultural well-being, and livelihoods (Allison and Ellis 2001; Allison et al. 2012; Eckert et al. *In press*). Small-scale coastal fishers observe the local marine environment consistently when fishing, and hence are attuned to changes in abundance or catchability of targeted species (Johannes, Freeman, and Hamilton 2000). Contemporary fisheries management requires data to develop stock assessments and monitor populations (Walters and Martell 2004). However, data are commonly limited (Costello et al. 2012). Even for fisheries with some data, monitoring efforts can be limited in space and time, and local fishers are commonly the first to notice changes in species abundance (Silvano and Valbo-Jørgensen 2008; Eckert et al. *In press*). Thus there have been recommendations to integrate local and traditional knowledge into fisheries management and conservation (Drew 2005; Silvano and Valbo-Jørgensen 2008; Beaudreau and Levin 2014).

Local and traditional ecological knowledge can complement ecological data to augment fisheries management (Neis et al. 1999; Johannes, Freeman, and Hamilton 2000; Drew 2005; Murray et al. 2008). Local knowledge represents lifetime observations by fishers, while traditional ecological knowledge is accumulated intergenerationally and encompasses Indigenous peoples' practices, beliefs, and worldviews passed down through oral traditions (Berkes, Colding, and Folke 2000; Berkes 2012). Indigenous knowledge refers to the combination of local and traditional knowledge held by Indigenous peoples (Berkes 2012). Traditional and local knowledge have led to the "discovery" of ecological or behavioral phenomena previously unknown to scientists. For example, in the Western Solomon Islands, Indigenous peoples pinpointed population changes of bumphead parrotfish (*Bolbometopon muricatum*) and provided conservation strategies (Aswani and Hamilton 2004). In Canada, cod fishers identified aspects of Atlantic cod (*Gadus morhua*) movements and population structure (Murray et al. 2008). In the Brazilian Amazon, local fishermen identified changes in the relative abundance of several fish species after the construction of a local dam, consistent with subsequent scientific surveys (Hallwass et al. 2013).

Local and traditional knowledge can also assist in fisheries management by extending spatial and

temporal data (Beaudreau and Levin 2014), but the accuracy of human memory regarding past catches and abundance of species is challenging to assess because comparable empirical data rarely exist. Memories might be biased toward extreme events, potentially exaggerating accounts of declines. Alternatively, "generational amnesia", also known as "shifting baselines", might mask the true extent of declines (Papworth et al. 2009; Daw 2010). We are aware of only one empirical study that compared resource user memories of catch changes to their own catch logbooks from the past. This study found that good and poor catches were recalled with reasonable accuracy, and that recalled typical catches were overestimated but comparable to mean values (Thurstan et al. 2016). Thus, while human memory is not perfect, it can help to identify the direction and magnitude of change in the temporal trajectories of fished species. Where change is inadequately documented either spatially or temporally, fisher's knowledge is particularly critical as a nontraditional data source (Johannes, Freeman, and Hamilton 2000).

Motivated to revitalize their management practices and address the decline of species inherent to traditional foods, Indigenous people now seek to increase their role in modern fisheries management and conservation (Sheppard, Beumer, and McKinnon 2008; Stephenson et al. 2014; Frid, McGreer, and Stevenson 2016). Dungeness crab (*Cancer magister*) in the Central Coast of British Columbia (BC), Canada (Figure 1), are at the center of these issues. The species is important to traditional culture and diets of the four First Nations in the region: Kitasoo/Xai'xais, Wuikinuxv, Heiltsuk, and Nuxalk. Food, social, and ceremonial (FSC) fishers from these Nations, however, have experienced recent declines in their catch rates of Dungeness crab. The Canadian constitution recognizes and affirms the right of Indigenous peoples to FSC fisheries. To address declining crab catches, since 2007 these First Nations have been asking the federal management agency, Fisheries and Oceans Canada (DFO), to reduce exploitation by commercial and recreational fishers. In response, DFO has asked First Nations to provide evidence of a problem in satisfying FSC fishery needs. As a step toward providing that evidence, in 2014 the four Central Coast First Nations began a collaborative large-scale spatial experiment, applying Indigenous law to close 10 sites to commercial and recreational crab fishing, and sampling Dungeness crab at these locations and 10 additional sites open to all fisheries (Frid, McGreer, and Stevenson 2016). DFO did not legislate the spatial closures, yet each First Nation publicly asked commercial and recreational fishers to respect their laws, and conducted patrols to request noncompliant fishers to remove their traps. Over a 10-month monitoring period

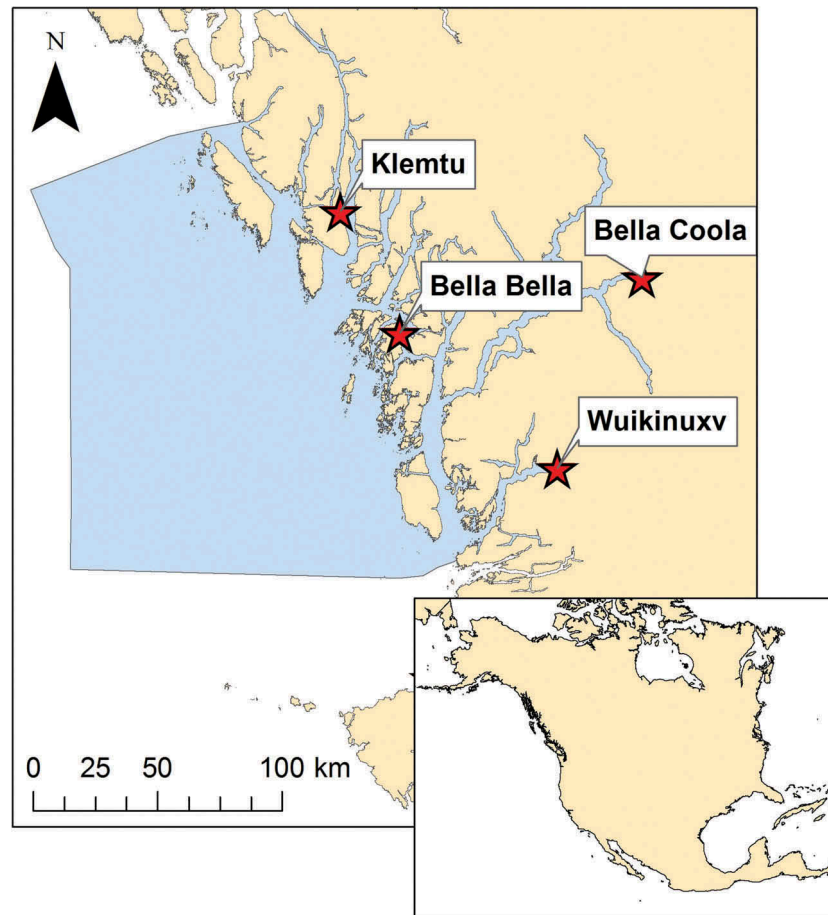


Figure 1. Map of the study region. The blue shaded area is the central coast marine region, and the stars point to community locations. The kitasoo/Xai'xais First Nation live in Klemtu, the Heiltsuk First Nation in Bella Bella, the Nuxalk First Nation in Bella Coola, and the Wuikinuxv First Nation in Wuikinuxv.

(late April 2014 to early February 2015) compliance was generally good, and the body size and catch-per-unit effort of legal-size male Dungeness crabs increased at closed sites but declined at open sites (Frid, McGreer, and Stevenson 2016). According to Indigenous fishers, however, crab populations remain depressed, even within spatial closures, relative to their historical baseline. During subsequent discussions, DFO managers argued that the spatial experiment provided insight only into the effects of commercial and recreational fisheries, and requested further research to assess whether Indigenous peoples were currently unable to meet their FSC needs for Dungeness crab. That request from DFO managers was the impetus for the research we present here.

Our research has two components. First, we interviewed First Nation members to (a) document changes to Dungeness crab abundance and catches as observed and experienced by FSC fishers over the course of their lifetime, (b) estimate the number of Dungeness crabs required for FSC purposes by each community, and (c) define a successful FSC harvest, based on their needs and expectations from past catches (i.e., before recent declines) by FSC fishers. Second, we then used the survey data collected during the spatial experiment

(Frid, McGreer, and Stevenson 2016) and information obtained from interviews to model the probabilities of successful FSC harvests for Dungeness crab at nine locations. Through these analyses, we illustrate the integration of Indigenous knowledge and science to address a modern fishery problem with implications for Indigenous rights, providing a general approach applicable elsewhere in the world.

Methods

Biological and management contexts

Dungeness crab live from southern California to Alaska. The species has a relatively fast life-history, reaching sexual maturity at two to three years of age and growing to commercially harvestable size in two to four years (Rasmuson 2013). Thus, local increases in relative abundance (i.e., at the scale of individual bays) can occur within one or two years after reductions in fishery pressure (Taggart et al. 2004; Frid, McGreer, and Stevenson 2016). Also, nutrient subsidies associated with forest inputs and runs of anadromous fish may contribute to local variation in Dungeness crab productivity (Harding and Reynolds

2014). Recruitment variation, however, is sensitive to oceanographic forcing and can strongly influence temporal trends in population size at regional scales (Shanks and Roegner 2007).

DFO manages Dungeness crab at very large spatial scales (i.e., regional). For both commercial and recreational sectors, legal retention of Dungeness crab is limited to males with notch-to-notch carapace widths of 154 mm or greater. In our study area, the daily limit per recreational fishing licence is six crabs (DFO 2016). First Nations FSC fishers do not have catch limits. In the Central Coast, FSC crab harvest is also regulated by ancestral governance structures. DFO does not conduct fishery-independent surveys in the study area.

Interviews

We carried out semi-structured interviews (Longhurst 2003) in August and September 2016 with FSC Indigenous fishers in the villages of Bella Bella (Heiltsuk First Nation), Bella Coola (Nuxalk First Nation), Klemtu (Kitasoo/Xai'xais First Nation), and Wuikinuxv (Wuikinuxv First Nation) (Figure 1). We targeted participants with extensive experience (>20 years) fishing for crabs in each First Nation. We identified potential participants through recommendations by each Nation's stewardship staff. We also allowed participants to self-select in response to community workshops and flyers that outlined the purpose of our study and the criteria for participation. We considered our sample to be sufficiently large when concept saturation was reached (i.e., when additional interviews did not reveal new themes in participants' responses) (Bernard 2011). We used best practices in social science methodologies to design interviews, including asking questions in a neutral manner so as not to bias responses.

Interview questions focused on the participants' early and recent crab fishing experiences, changes observed during their lifetimes of crab fishing, and crab food needs. We then defined the time periods of early and recent experiences fishing for crabs based on the years that participants had their first experiences fishing for crabs, and when they had their most recent trips to fish for crabs. Interviews lasted 30–120 min; some participants did not answer all questions (e.g., could not recollect the answer), and some participants provided more than one answer for some questions (e.g., if using multiple types of traps). We report percentage responses based on sample sizes for each question. Interviews were audio-recorded.

Analysis

In interview methodologies, all aspects of the interview are considered data. We thus analyze both the

quantitative responses, and also report qualitative responses (e.g., participants' opinions about causes of declines). To estimate changes in crab catches and abundance, we quantitatively summarized participants' responses about catch rates and abundance during their early and recent years of crab fishing. We also asked about gear types used. To estimate food needs, we asked participants how many crabs they desired to eat per year for home meals. We assumed that community members, on average, had a similar desire to eat crabs, and multiplied the desired crabs per person by the current population in the study communities to estimate crab needs per year. While we included all people in our estimates – including children too young to eat crabs – we did not account for crabs shared with visitors, gifted to relatives who live elsewhere, or traded with other First Nations. We assumed that over- and under-estimates would offset each other, thereby providing a reasonable estimate of annual crab needs for home consumption.

During interviews, we asked participants to define the catch rate that, informed by their past experiences, would represent a successful FSC trip using commercial or recreational cage traps. Applying this definition, we then conducted computer simulations to estimate the probabilities of successful FSC trips for harvesting Dungeness crab at different sites under current levels of local abundance. To estimate current abundances, we used survey data collected in 2014–2015 during the spatial experiment (Frid, McGreer, and Stevenson 2016), restricting analysis to sites with a minimum of five sampling days ($n = 9$ sites), the depths where most FSC crab harvests occur (≤ 20 m), and the target sex and size class (males with notch-to-notch carapace width ≥ 154 mm). Using a uniform sampling function in R (version 3.3.1), we randomly selected 10,000 pairs of such data points from each location, and added the number of crab in the two sample points, simulating a single fisher with two traps. Per location, we then calculated the percent of random draws that met the threshold for a successful trip, as defined by the interview participants, reflecting the probability of a successful trip to a given site. To gain further insight into the probabilities of success under expectations below those identified by Indigenous fishers, we conducted additional simulations in which we relaxed the criterion for success to two-thirds and one-third of the Indigenous-defined threshold of a successful trip.

Results

A total of 38 fishers with extensive experience fishing for Dungeness crabs were interviewed in Bella Bella ($n = 13$), Bella Coola ($n = 9$), Klemtu ($n = 8$), and Wuikinuxv ($n = 8$). All participants targeted

Dungeness crab, though three participants also mentioned catching Red Rock crab (*Cancer productus*) occasionally. The number of years of crab harvest experience ranged 20–89 years (median 50 years; mean 48.2 years). Participants' first memories of crab fishing ranged from the years 1926 to 1996 (median 1969; mean 1970). We defined this period (1926–1996) as the participants' first experiences crab fishing, and we refer to it as "prior to 1996" or "first experiences". Most participants had harvested crabs within a year preceding the interview. The exceptions were three people who had not harvested crabs since the early 2000s, two since 1997, and one since 2003. We refer to participants' most recent crab harvesting experiences as "recent experiences" or "after 1997", which capture the years 1997–2016.

The technology used for crab fishing has changed over time (Table S1). Prior to 1996, 69.4% of participants used homemade hoop traps, whereas 13.9% used commercial cage traps, and 27.8% recreational cage traps. After 1997, the usage was 48.6% for commercial traps, 45.7% for recreational traps, and 14.3% of participants still occasionally used hoop traps. The number of traps used per fisher ranged from 1 to 10 prior to 1996, with a mean of 2.6 and median of 2. After 1997, the number of traps ranged from 1 to 20, with a mean of 3.7 and a median of 2. Soak time for traps has increased from an average of 3.1 h in the early years, to 13.2 h in recent years. Soak time changes were due largely to different technologies.

Hoop traps are open, and are soaked for tens of minutes, whereas cage traps are closed and soaked for hours or even days. Traps were set at a mean of 15.2 m (median 10 m), and now are deeper at a mean of 21.0 m (median 14.6 m). Given the shift to modern cage traps, any perceived declines in crab abundance are likely to be conservative, as – for a given level of abundance – catch rates likely are greater with more efficient modern technology.

Changes to crab catches

Participants observed changes over time for catches of legal-size males (Table S2), which are the only crabs retained with one exception (one participant reported regularly keeping some females in the early years). During the early years (1926–1996), the median typical, best, and worst catches were similar (Figure 2) because crabs were reported as abundant in those early years, and people stopped fishing for crabs once they caught enough to feed their families. In contrast, in recent years (1997–2016) typical, best, and worst catches differ substantially (Figure 2). Notably, the median typical catch declined by 77% relative to the early years (Figure 2), with most participants dating the onset of declines to the early 2000s. Reported catches by decade illustrate declines during the 2000s (Figure 3). Indeed, relative to their first years, fishers reported using more numerous and

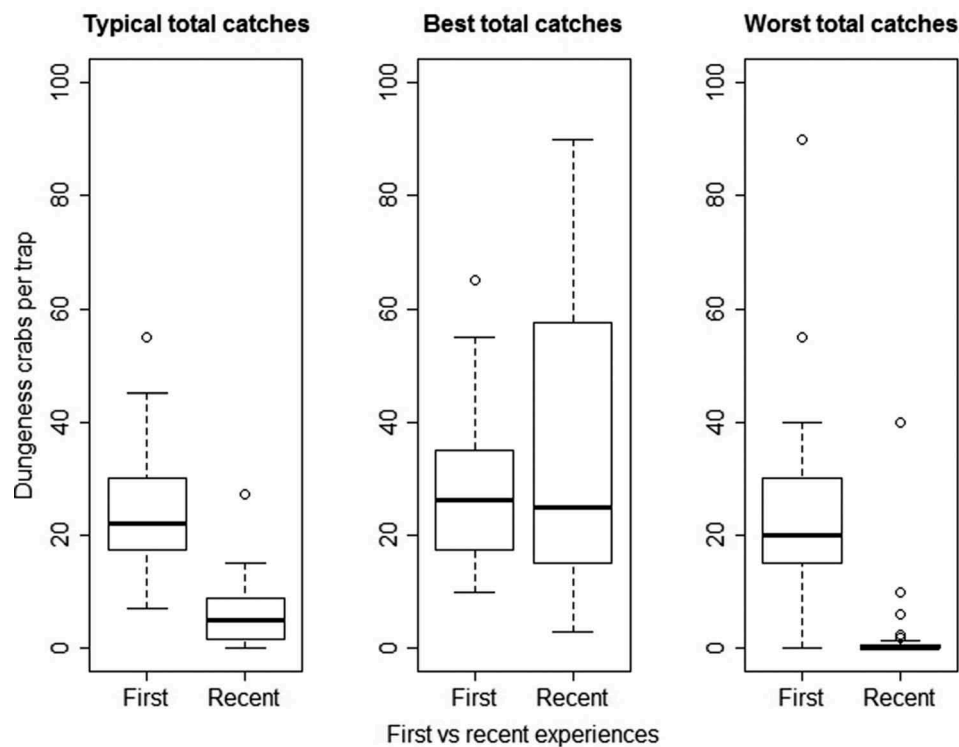


Figure 2. Typical, best, and worst catches reported by participants from their first years (1926–1996, median 1969) and recent years harvesting Dungeness crabs (1997–2016, median 2016). Boxes enclose the median (centerline) and 25th and 75th percentiles. Targeted crabs are legal-size males.

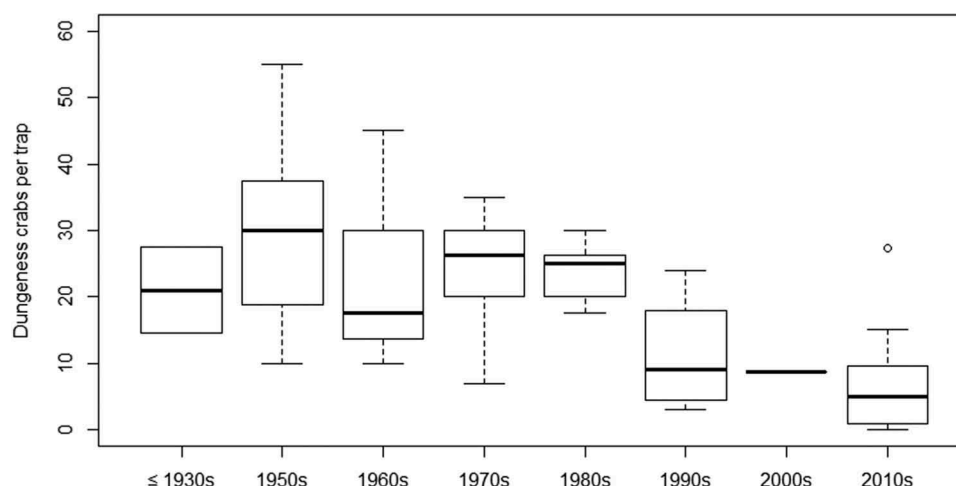


Figure 3. Typical Dungeness crab catches by decade reported by participants. Sample sizes are as follows: ≤1930s $n = 2$, 1940s $n = 0$, 1950s $n = 7$, 1960s $n = 11$, 1970s $n = 6$, 1980s $n = 7$, 1990s $n = 4$, 2000s $n = 1$, 2010s $n = 27$. Targeted crabs are legal-size males.

modern traps while harvesting fewer crabs, including zero catches.

Avoidance of areas where other crab fishing is occurring has changed over time. Prior to 1996, only 6.1% of fishers avoided an area because commercial crab fishing had taken place. During the early period, most fishers (84.8%) did not encounter commercial crab fishing, and only 17.1% noted declines in their own catch rates in areas that had just undergone commercial exploitation. In contrast, in recent years, 66.7% of participants avoided areas where commercial crab fishing had taken place. Participants explained that they avoided such areas both to allow depleted bays to recover, and to increase their catches by going elsewhere. Out of 36 respondents who answered the question, 28 participants (77.8%) observed severe declines in their catches in places where commercial or recreational crab fishing had occurred, 8 (22.2%) observed moderate declines, and 2 people (5.6%) observed no change. Some participants provided more than one answer to differentiate changes to crab catches in specific locations (two participants reported moderate and severe declines, depending on the place).

Changes to crab abundance

Many participants described being able to see crabs on the seafloor while setting or handling traps in shallow water, and therefore were able to comment on crab abundance, in addition to catches. All participants observed changes in crab abundance during their lifetime experiences, with most changes described as severe (82.9%), and the rest as moderate (17.1%). Many participants commented on seeing a seafloor full of crabs in the early years of crab fishing. Participants attributed changes to both commercial (90.3%) and recreational (83.9%) crab fisheries, as

well as lack of monitoring and management (12.9%) and other causes such as pollution (9.7%).

Crab food needs

In their first years of crab harvesting, participants reported needing 1–4 crabs (mean = 1.5) per person at meals (Table S3). Meals fed an average of 9.6 people, and crab meals were served about 17 times annually. In their most recent years crab fishing, participants served 1–3 crabs (mean = 1.4) per meal per person. On average, these meals fed 4 people, and occurred about 13 times annually. Several participants reflected that, traditionally, crab meals were typically shared with elders and other community members, but less people are now served at family meals due to decreased abundance of crabs.

To estimate food needs, we asked participants how many crabs they desired to eat per year for home meals. Assuming that the participants are representative of the four communities' desire to eat crabs, and that all ~4200 combined residents of Bella Bella, Bella Coola, Klemtu, and Wuikinuxv wish to eat crabs, the modern annual need for crabs to be served during home meals would be ~160,000 crabs per year. Additionally, crabs are served at community feasts. On average, although 71.4% of participants have noticed a decline in the frequency crabs are served at feasts, about 75 crabs were served at feasts where crabs were available during modern times.

Probabilities of successful FSC harvesting trips

Based on the median values provided by participants, a successful FSC harvesting trip was defined as having a catch of 15 legal-size male Dungeness crabs (Table S2) while using 2 commercial or recreational

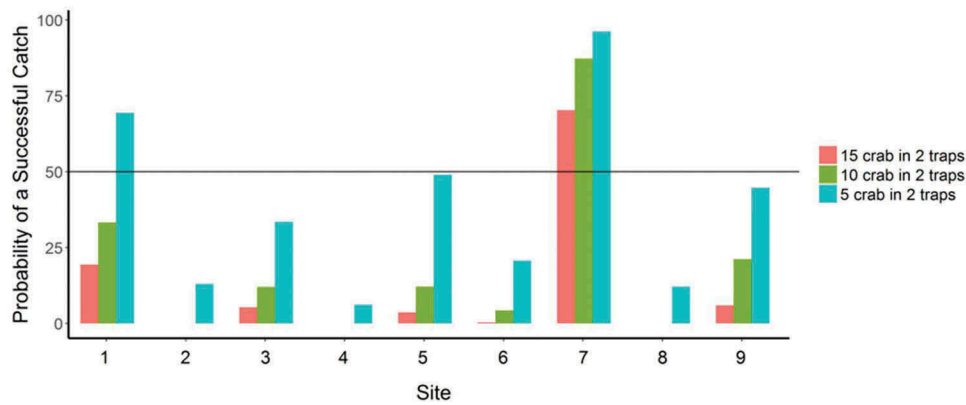


Figure 4. Simulated probabilities of successful crab catches at nine locations, using three different thresholds for success: a successful crab trip as defined by Indigenous crab fishers (median catch = 15 crabs caught with 2 traps), and two consecutively lower thresholds. Sites are numbered, rather than named, to protect sensitive locations used by First Nations.

traps (range 1–4 traps). The alternative, lower thresholds used in the simulation analysis were two-thirds and one-third of these values (10 and 5 crabs, respectively).

Probabilities of yielding a successful FSC trip (i.e., 15 crabs) were very low (<20%) for all sites except Site 7, which had a 70% probability of success. When lowering the threshold by two-thirds (i.e., 5 crabs), only two sites had a greater than 50% chance of success (Figure 4)

Discussion

We documented severe reductions in the catch rates of Indigenous FSC fishers on the Central Coast of BC, estimating that at eight of nine sites they no longer could meet their FSC needs. Dungeness crab, however, grow fast, mature early, and have high fecundity (Rasmuson 2013). These life-history characteristics can allow local abundances to increase rapidly in response to reduced fishery pressure (Taggart et al. 2004; Frid, McGreer, and Stevenson 2016). Therefore, our observations about declining catch rates at local scales do not necessarily imply a regional population decline. They do suggest, however, that the regional scales of management used by DFO have masked local depletions experienced by Indigenous fishers. In addition to this mismatch of spatial scales, there is a lack of long-term fishery-independent data for establishing historical baselines and assessing management effectiveness. Our case study demonstrates that these management issues and data gaps can be partially addressed by using long-term Indigenous observations to inform modern fishery management.

According to interview participants, their observations of declining catch rates and abundances of Dungeness crab largely reflect the impact of commercial and recreational fisheries. Other potential causes of declines, which are not mutually exclusive with fishery effects, include shifts in oceanographic

conditions that affect recruitment (Shanks and Roegner 2007). There is also concern for the potential effects of ocean acidification on larval survival, with potential effects on future population trends (Miller et al. 2016). Although predators such as sea otters (*Enhydra lutra*) have caused local depletions elsewhere (Shirley et al. 1996), Indigenous fisher observations do not support that possibility for their main crab fishing areas in our study area.

Dungeness crabs are just one example of how Indigenous knowledge may contribute to modern fishery management of species important to traditional diets. For instance, a similar case study recently extended the baseline for the abundance and declining body sizes of Yelloweye rockfish (*Sebastes ruberrimus*), from 2003 (fishery-independent scientific data) to the 1950s (Indigenous knowledge interview data) (McGreer and Frid 2017; Eckert et al. In press). Many other culturally important species have also declined, thereby increasing the motivation of First Nations to influence management (e.g., Pacific herring (*Clupea pallasii*) (Jones, Rigg, and Pinkerton 2017; Kitasoo/Xai'xais First Nation 2017), geoduck (*Panopea generosa*) (Klain, Beveridge, and Bennett 2014)). Such declines severely affect the ability of Indigenous people to carry out culturally important fishing practices, thereby degrading their overall cultural identity and well-being. As one participant noted: “We know the crabs are much smaller than way back then. [...] When I was a kid [...] we basically lived off the [sea and] land [...] and now over the past 50–60 years this whole town exploded with diabetes.”

The Canadian federal government elected in 2015 promised to work with First Nations on issues that concern them. The mandate letter for DFO states that a priority is to “work with the provinces, territories, Indigenous Peoples, and other stakeholders to better co-manage our three oceans” (Government of Canada 2015), and Canada signed onto the United

Nations Declaration on the Rights of Indigenous People (UN General Assembly 2008) in 2016. While these commitments have not yet resulted in changes to Dungeness crab management, Central Coast First Nations and DFO recently formed a joint technical working group to improve evidence-based management of Dungeness crab, conducted jointly and collaboratively between federal and First Nation governments. Canada has an opportunity to implement substantial policy shifts that provide First Nations with joint fisheries management responsibilities (Von Der Porten et al. 2016).

The reassertion of rights to marine management by Indigenous peoples in BC is part of a broader global phenomenon of Indigenous self-determination of their resources (Borrows 2002; Alfred and Corntassel 2005; Von Der Porten et al. 2016). For instance, in Vanuatu Indigenous people have regained the ability to control activities in marine areas that they own (Hickey 2006), and the Maori in New Zealand are reclaiming fisheries management rights (Bess 2001). In Australia, a High Court decision in 2008 ruled that the Northern Territory government did not have the right to allow commercial fishers to fish tidal waters over Aboriginal-owned land (Altman 2008). In Canada, efforts are underway to recognize Indigenous legal traditions, including Indigenous resource management laws (Napoleon and Friedland 2014; Friedland and Napoleon 2015). The future is likely to bring many more efforts of Indigenous self-determination through resource management in Canada and elsewhere.

Our study had several limitations. Given the lack of biological data about Dungeness crab in the study region, we interviewed First Nations fishers about their experiences and perceptions of change. While there is support in the literature for using interviews to reconstruct catches and abundance, human memory can be fallible, especially with increased time (Thurstan et al. 2016), and thus we cannot quantify the accuracy of estimates derived from the interview data. Additionally, we did not interview commercial and recreational fishers, and their observations can also help address scientific data gaps (Beaudreau and Levin 2014). While interviewing First Nation subsistence fishers was, due to their decades of reliance upon local resources and their livelihood needs, most efficient and practical for the purposes of this study, in the future, research should expand to include additional sectors.

Another limitation of our research and similar studies (Klain, Beveridge, and Bennett 2014; Von Der Porten et al. 2016) is that, to date, they have focused on single species. This focus is necessary to expedite the inclusion of Indigenous people in contemporary fisheries management, which emphasizes individual species or suites of species rather than

ecosystems. However, a cornerstone of many Indigenous worldviews is that everything is connected (Berkes 2012; Kitasoo/Xai'xais First Nation 2017), and single-species management contradicts these beliefs (Berkes 2012). Similarly, ecologists understand the importance of managing fisheries in ways that recognize interactions between multiple target and nontarget species (Francis et al. 2007). Accordingly, future research and management efforts should incorporate the interconnectedness of Indigenous worldviews, which also is shared by the science of ecology. One way forward is to actively integrate Indigenous management practices into contemporary fisheries management (Raymond-Yakoubian, Raymond-Yakoubian, and Moncrieff 2017) and apply Indigenous knowledge into contemporary marine spatial planning and marine protected area design and management (Ban, Picard, and Vincent 2009; Marine Plan Partnership 2017).

Acknowledgments

This project was a partnership with the Heiltsuk, Kitasoo/Xai'xais, Nuxalk, and Wuikinuxv First Nations. We thank interview participants and stewardship staff for their time and insight, especially Barry Edgar, Iris Siwallace, Alex Chartrand Jr., and Brian Johnson for assisting with interviews and logistics, and Megan Moody (Nuxalk), Mike Reid and Kelly Brown (Heiltsuk), Dani Shaw (Wuikinuxv), and Barry Edgar (Kitasoo/Xai'xais) for insightful and constructive edits to the paper. Ken Cripps provided the vision for initiating this research.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

NCB was supported by SSHRC, NSERC and MEOPAR. AF and MM were supported by the Gordon and Betty Moore Foundation (grant 1406.03, 2016/17), the Aboriginal Aquatic Resource and Oceans Management Program (grant ARM2015-MLT-7006-3, 2016/17), the Marine Planning Partnership (via Tides Canada grant CCS P098-06143, 2016/17), and the Tula Foundation.

References

- Adams, W. M., and M. Mulligan, editors. 2003. *Decolonizing Nature: Strategies for Conservation in a Post-Colonial Era*. London: Earthscan Publications.
- Alfred, T., and J. Corntassel. 2005. "Being Indigenous: Resurgences against Contemporary Colonialism." *Government and Opposition* 40: 597–614. doi:10.1111/goop.2005.40.issue-4.
- Allison, E. H., B. D. Ratner, B. Åsgård, R. Willmann, R. Pomeroy, and J. Kurien. 2012. "Rights-Based Fisheries Governance: From Fishing Rights to Human Rights."

- Fish and Fisheries* 13: 14–29. doi:10.1111/faf.2011.13.issue-1.
- Allison, E. H., and F. Ellis. 2001. “The Livelihoods Approach and Management of Small-Scale Fisheries.” *Marine Policy* 25: 377–388. doi:10.1016/S0308-597X(01)00023-9.
- Altman, J. 2008. Understanding the Blue Mud Bay Decision. Crikey. PrivateMedia, <https://www.crikey.com.au/2008/08/01/understanding-the-blue-mud-bay-decision/>.
- Aswani, S., and R. Hamilton. 2004. “Integrating Indigenous Ecological Knowledge and Customary Sea Tenure with Marine and Social Science for Conservation of Bumphead Parrotfish (*Bombometopon muricatum*) in the Roviana Lagoon, Solomon Islands.” *Environmental Conservation* 31: 69–83. doi:10.1017/S037689290400116X.
- Atlas, W. I., W. G. Housty, A. Béliveau, B. DeRoy, G. Callegari, M. Reid, and J. W. Moore. 2017. “Ancient Fish Weir Technology for Modern Stewardship: Lessons from Community-Based Salmon Monitoring.” *Ecosystem Health and Sustainability* 3: 1341284.
- Ban, N. C., C. R. Picard, and A. C. J. Vincent. 2009. “Comparing and Integrating Community-Based and Science-Based Approaches in Prioritizing Marine Areas for Protection.” *Conservation Biology* 23: 899–910. doi:10.1111/j.1523-1739.2009.01185.x.
- Beaudreau, A. H., and P. S. Levin. 2014. “Advancing the Use of Local Ecological Knowledge for Assessing Data-Poor Species in Coastal Ecosystems.” *Ecological Applications* 24: 244–256. doi:10.1890/13-0817.1.
- Berkes, F. 2012. *Sacred Ecology*. third ed. New York: Routledge.
- Berkes, F., J. Colding, and C. Folke. 2000. “Rediscovery of Traditional Ecological Knowledge as Adaptive Management.” *Ecological Applications* 10: 1251–1262. doi:10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.
- Bernard, H. R. 2011. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Lanham, MD: Alta Mira Press.
- Bess, R. 2001. “New Zealand’s Indigenous People and Their Claims to Fisheries Resources.” *Marine Policy* 25: 23–32. doi:10.1016/S0308-597X(00)00032-4.
- Borrows, J. 2002. *Recovering Canada: The Resurgence of Indigenous Law*. Toronto, ON: University of Toronto Press.
- Costello, C., D. Ovando, R. Hilborn, S. D. Gaines, O. Deschenes, and S. E. Lester. 2012. “Status and Solutions for the World’s Unassessed Fisheries.” *Science* 338: 517–520. doi:10.1126/science.1223389.
- Daw, T. M. 2010. “Shifting Baselines and Memory Illusions: What Should We Worry about When Inferring Trends from Resource User Interviews?” *Animal Conservation* 13: 534–535. doi:10.1111/j.1469-1795.2010.00418.x.
- DFO. 2016. *Integrated Fisheries Management Plan Summary, Crab by Trap, Pacific Region, January 1st to December 31st, 2016*. Nanaimo, BC: Fisheries and Oceans Canada.
- Drew, J. A. 2005. “Use of Traditional Ecological Knowledge in Marine Conservation.” *Conservation Biology* 19: 1286–1293. doi:10.1111/j.1523-1739.2005.00158.x.
- Eckert, L., N. C. Ban, A. Frid, and M. McGreer. In press. “Diving Back in Time: Extending Historical Baselines for Yelloweye Rockfish with Indigenous Knowledge.” *Aquatic Conservation: Marine and Freshwater Ecosystems*. <https://doi.org/10.1002/aqc.2834>.
- Francis, R. C., M. A. Hixon, M. E. Clarke, S. A. Murawski, and S. Ralston. 2007. “Ten Commandments for Ecosystem-Based Fisheries Scientists.” *Fisheries* 32: 217–233. doi:10.1577/1548-8446(2007)32[217:TCFBFS]2.0.CO;2.
- Frid, A., M. McGreer, and A. Stevenson. 2016. “Rapid Recovery of Dungeness Crab within Spatial Fishery Closures Declared under Indigenous Law in British Columbia.” *Global Ecology and Conservation* 6: 48–57. doi:10.1016/j.gecco.2016.01.002.
- Friedland, H., and V. Napoleon. 2015. “Gathering the Threads: Developing a Methodology for Researching and Rebuilding Indigenous Legal Traditions.” *Lakehead Law Journal* 1: 16–44.
- Government of Canada. 2015. *Minister of Fisheries, Oceans and the Canadian Coast Guard Mandate Letter*. Ottawa, ON: Government of Canada.
- Hallwass, G., P. F. Lopes, A. A. Juras, and R. A. Silvano. 2013. “Fishers’ Knowledge Identifies Environmental Changes and Fish Abundance Trends in Impounded Tropical Rivers.” *Ecological Applications* 23: 392–407. doi:10.1890/12-0429.1.
- Harding, J., and J. D. Reynolds. 2014. “From Earth and Ocean: Investigating the Importance of Cross-Ecosystem Resource Linkages to a Mobile Estuarine Consumer.” *Ecosphere* 5: 1–23. doi:10.1890/ES14-00029.1.
- Harris, R. 2002. *Making Native Space: Colonialism, Resistance, and Reserves in British Columbia*. Vancouver: University of British Columbia Press.
- Hickey, F. R. 2006. “Traditional Marine Resource Management in Vanuatu: Acknowledging, Supporting and Strengthening Indigenous Management Systems.” *SPC Traditional Marine Resource Management and Knowledge Information Bulletin* 20: 11–23.
- Johannes, R. E., M. M. R. Freeman, and R. J. Hamilton. 2000. “Ignore Fishers’ Knowledge and Miss the Boat.” *Fish and Fisheries* 1: 257–271. doi:10.1046/j.1467-2979.2000.00019.x.
- Jones, R., C. Rigg, and E. Pinkerton. 2017. “Strategies for Assertion of Conservation and Local Management Rights: A Haida Gwaii Herring Story.” *Marine Policy* 80: 154–167. doi:10.1016/j.marpol.2016.09.031.
- Jupiter, S. D., P. J. Cohen, R. Weeks, A. Tawake, and H. Govan. 2014. “Locally-Managed Marine Areas: Multiple Objectives and Diverse Strategies.” *Pacific Conservation Biology* 20: 165–179. doi:10.1071/PC140165.
- Kitasoo/Xai’xais First Nation. 2017. *Kitasoo/Xai’xais Management Plan for Pacific Herring*. Klemtu, British Columbia, Canada. Klemtu, BC. <http://klemtu.com/app/uploads/2016/05/Herring-Mgmt-Plan-Feb17-16-final.pdf>.
- Klain, S. C., R. Beveridge, and N. J. Bennett. 2014. “Ecologically Sustainable but Unjust? Negotiating Equity and Authority in Common Pool Marine Resource Management.” *Ecology and Society* 19: 52. doi:10.5751/ES-07123-190452.
- Lepofsky, D., and M. Caldwell. 2013. “Indigenous Marine Resource Management on the Northwest Coast of North America.” *Ecological Processes* 2: 12. doi:10.1186/2192-1709-2-12.
- Longhurst, R. 2003. “Semi-Structured Interviews and Focus Groups.” In *Key Methods in Geography*, editors N. Clifford, M. Cope, T. Gillespie, and S. French, 117–132. London: Sage Publications.
- Marine Plan Partnership. 2017. Marine Plan Partnership for the North Pacific Coast. <http://mappocean.org/>.

- McClanahan, T. R., M. J. Marnane, J. E. Cinner, and W. E. Kiene. 2006. "A Comparison of Marine Protected Areas and Alternative Approaches to Coral-Reef Management." *Current Biology* 16: 1408–1413. doi:10.1016/j.cub.2006.05.062.
- McGreer, M., and A. Frid. 2017. "Declining Size and Age of Rockfish (*Sebastes* Spp.)." *Inherent to Indigenous Cultures of Pacific Canada. Ocean & Coastal Management* 145: 14–20.
- Miller, J. J., M. Maher, E. Bohaboy, C. S. Friedman, and P. McElhany. 2016. "Exposure to Low pH Reduces Survival and Delays Development in Early Life Stages of Dungeness Crab (*Cancer Magister*)." *Marine Biology* 163: 118. doi:10.1007/s00227-016-2883-1.
- Murray, G., B. Neis, C. T. Palmer, and D. C. Schneider. 2008. "Mapping Cod: Fisheries Science, Fish Harvesters' Ecological Knowledge and Cod Migrations in the Northern Gulf of St." *Lawrence. Human Ecology* 36: 581–598. doi:10.1007/s10745-008-9178-1.
- Napoleon, V., and H. Friedland. 2014. "Indigenous Legal Traditions: Roots to Renaissance." In *The Oxford Handbook of Criminal Law*, editors M. D. Dubber and T. Hörnle, 225–247. Oxford, UK: Oxford University Press.
- Neis, B., D. C. Schneider, L. Felt, R. L. Haedrich, J. Fischer, and J. A. Hutchings. 1999. "Fisheries Assessment: What Can Be Learned from Interviewing Resource Users?" *Canadian Journal of Fisheries and Aquatic Sciences* 56: 1949–1963. doi:10.1139/f99-115.
- Ommer, R. E. 2007. *Coasts under Stress: Restructuring and Social-Ecological Health*. Montreal: McGill-Queen's Press-MQUP.
- Papworth, S., J. Rist, L. Coad, and E. Milner-Gulland. 2009. "Evidence for Shifting Baseline Syndrome in Conservation." *Conservation Letters* 2: 93–100.
- Pauly, D., R. Watson, and J. Alder. 2005. "Global Trends in World Fisheries: Impacts on Marine Ecosystems and Food Security." *Philosophical Transactions of the Royal Society B* 360: 5–12. doi:10.1098/rstb.2004.1574.
- Rasmuson, L. K. 2013. "The Biology, Ecology and Fishery of the Dungeness Crab, *Cancer Magister*." *Advances in Marine Biology* 65: 95–148. doi:10.1016/B978-0-12-410498-3.00003-3.
- Raymond-Yakoubian, J., B. Raymond-Yakoubian, and C. Moncrieff. 2017. "The Incorporation of Traditional Knowledge into Alaska Federal Fisheries Management." *Marine Policy* 78: 132–142. doi:10.1016/j.marpol.2016.12.024.
- Roman, J., and S. R. Palumbi. 2003. "Whales before Whaling in the North Atlantic." *Science* 301: 508–510. doi:10.1126/science.1084524.
- Shanks, A. L., and G. C. Roegner. 2007. "Recruitment Limitation in Dungeness Crab Populations Is Driven by Variation in Atmospheric Forcing." *Ecology* 88: 1726–1737. doi:10.1890/06-1003.1.
- Sheppard, R., J. Beumer, and S. McKinnon. 2008. *Northern Australia-Indigenous Fisheries Management*. editors, J. Nielsen, J. J. Dodson, K. Friedland, T. R. Hamon, J. Musick, and E. Verspoor, Reconciling Fisheries with Conservation, Vols I and II. 499–504. Bethesda, MD: American Fisheries Society.
- Shirley, T. C., G. Bishop, C. E. O'Clair, S. J. Taggart, and J. L. Bodkin. 1996. "Sea Otter Predation on Dungeness Crabs in Glacier Bay, Alaska." In *Proc Int Symp Biol Manage Econ Crabs High Latitude Habitats*, 96–02. Fairbanks, AK: Alaska Sea Grant College Program, University of Alaska.
- Silvano, R. A., and J. Valbo-Jørgensen. 2008. "Beyond Fishermen's Tales: Contributions of Fishers' Local Ecological Knowledge to Fish Ecology and Fisheries Management." *Environment, Development and Sustainability* 10: 657. doi:10.1007/s10668-008-9149-0.
- Stephenson, J., F. Berkes, N. J. Turner, and J. Dick. 2014. "Biocultural Conservation of Marine Ecosystems: Examples from New Zealand and Canada." *Indian Journal of Traditional Knowledge* 13: 257–265.
- Swartz, W., E. Sala, S. Tracey, R. Watson, and D. Pauly. 2010. "The Spatial Expansion and Ecological Footprint of Fisheries (1950 to Present)." *Plos One* 5 (12): e15143. doi:10.1371/journal.pone.0015143.
- Taggart, S. J., T. C. Shirley, C. E. O'Clair, and J. Mondragon. 2004. Dramatic Increase in the Relative Abundance of Large Male Dungeness Crabs *Cancer Magister* following Closure of Commercial Fishing in Glacier Bay, Alaska. 243–253 in *American Fisheries Society Symposium*.
- Thurstan, R. H., S. M. Buckley, J. C. Ortiz, and J. M. Pandolfi. 2016. "Setting the Record Straight: Assessing the Reliability of Retrospective Accounts of Change." *Conservation Letters* 9: 98–105. doi:10.1111/conl.12184.
- Truth and Reconciliation Commission. 2015. Honouring the Truth, Reconciling for the Future: Summary of the Final Report of the Truth and Reconciliation Commission of Canada., Truth and Reconciliation Commission, Ottawa, Canada.
- UN General Assembly. 2008. *United Nations Declaration on the Rights of Indigenous Peoples*. United Nations General Assembly. http://www.un.org/esa/socdev/unpfii/documents/DRIPS_en.pdf
- Von Der Porten, S., D. Lepofsky, D. McGregor, and J. Silver. 2016. "Recommendations for Marine Herring Policy Change in Canada: Aligning with Indigenous Legal and Inherent Rights." *Marine Policy* 74: 68–76. doi:10.1016/j.marpol.2016.09.007.
- Walters, C. J., and S. J. D. Martell. 2004. *Fisheries Ecology and Management*. Princeton, NJ: Princeton University Press.