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RESEARCH ARTICLE

Diving back in time: Extending historical baselines for yelloweye rockfish with Indigenous knowledge

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Abstract

1. Ocean systems, and the culturally and commercially important fishes that inhabit them, face growing threats. Increasingly, unconventional data sources are being used to inform fisheries research and management for data-poor species.
2. Listed as a species of special concern in Canada, yelloweye rockfish (*Sebastes ruberrimus*) are vulnerable to exploitation, and have historical and cultural value to Indigenous people. In this study, Indigenous fishers of British Columbia, Canada, were interviewed and asked about observed changes to the body sizes (length) and abundance of this species over the last ~60 years, and the factors driving these changes. Their current and historical estimates of size and abundance were compared with current biological survey data.
3. Forty-two semi-directed interviews were carried out and 89% of respondents observed a decrease in yelloweye rockfish body sizes since the 1980s. The median historical (1950s–1980s) length was 84 cm, compared with the median modern (2010–2015) length of 46 cm. All but one respondent reported substantial decrease in yelloweye rockfish abundance since their earliest fishing experiences (1950s to1980s, depending on participant's age), with a third suggesting the change was most evident in the early 2000s, followed by the 1980s (21%) and 1990s (17%).
4. Sizes of modern yelloweye rockfish estimated by participants resembled estimates derived from ecological data recorded concurrently at the study region.
5. This study illustrates a repeatable method for using traditional and local knowledge to extend baselines for data-poor species, and highlights the value of integrating Indigenous knowledge into fisheries research and management.

KEYWORDS

fisheries, Indigenous knowledge, Indigenous management, local ecological knowledge, marine conservation, traditional ecological knowledge, yelloweye rockfish

1 | INTRODUCTION

Around the world, many culturally and commercially important fish species exhibit signs of decline (Myers & Worm, 2003; Pauly, Christensen, Dalsgaard, Froese, & Torres, 1998). However, understanding the full extent of declines on a case by case basis is often limited by the quantity and quality of available data. Unconventional data sources, such as traditional and local knowledge, historical photographs, and archival materials, are increasingly being used to estimate baselines for data-poor species, particularly fishes (Beaudreau & Levin, 2014; Lotze & Worm, 2009; McClenachan, 2009; McClenachan, Ferretti, & Baum, 2012; Pitcher, 2004). Historical baselines are crucial; without them, recovery targets and fishery policies fail to recognize the population and ecosystem characteristics that preceded large-scale exploitation (Lotze & Worm, 2009; McClenachan, Cooper, McKenzie, & Drew, 2015; McClenachan et al., 2012; Pauly, 1995).

Traditional and local ecological knowledge (TEK and LEK, respectively) are increasingly recognized for their capacity to complement ecological data and improve fisheries management (Drew, 2005;

Haggan, Neis, & Baird, 2007; Huntington, 2000; Mellado, Brochier, Timor, & Vitancurt, 2014). LEK represents a lifetime of accumulated ecological observations, while TEK is composed of similar observations, passed intergenerationally, and woven into the framework of Indigenous peoples' culture, practices, and beliefs (Berkes, 2012; Berkes, Colding, & Folke, 2000). Both can provide long-term ecological information (i.e. 20–80 years for LEK, centuries for TEK) complementary to scientific data (Beaudreau & Levin, 2014; Haggan et al., 2007; Johannes, 1998; Service et al., 2014). Despite advances in the field of marine historical ecology and growing recognition of the value of unconventional data sources in conservation sciences (Lotze & Worm, 2009; McClenachan et al., 2012, 2015), TEK and LEK have been applied infrequently (Drew, 2005; Johannes, 2000; McClenachan et al., 2012). In cases where integration is pursued, methodological, social, and cultural challenges sometimes emerge (Poe, Norman, & Levin, 2014).

Because of their geographical, cultural, and subsistence ties to marine resources and coastal ecosystems, Indigenous and local communities possess valuable knowledge about species that are scientifically data-poor. Globally, myriad studies support the notion that TEK and LEK from fishers and Indigenous knowledge holders can expand baselines and inform conservation goals (Drew, 2005; Haggan et al., 2007; Johannes, 2000; Martin, McCay, Murray, Johnson, & Oles, 2007; Valbo-Jørgensen & Poulsen, 2000). For example, in the Western Solomon Islands, TEK identified recent population changes of bumphead parrotfish (*Bolbometopon muricatumand*) and highlighted historical conservation strategies for this species (Aswani & Hamilton, 2004). In the Brazilian Amazon, local fishermen identified changes in the relative abundance of several fish species after the construction of a local dam; their assessment was consistent with scientific surveys conducted shortly after (Hallwass, Lopes, Juras, & Silvano, 2013). Similar examples have been documented in Samoa, Fiji, Cook Islands, Palau, and other locations (Johannes, 2002). This is relevant from a conservation standpoint because community support for conservation plans, including marine protected areas (MPAs), is commonly cited as important for meeting conservation and social objectives (Aswani & Hamilton, 2004; Ban et al., 2013; Drew, 2005; Johannes, 2002; King & Faasili, 1999; Turner, 2003). Strategies which engage knowledge-holders and meaningfully incorporate TEK or LEK can produce higher rates of local support and long-term success.

Many Indigenous nations, including those with recognized management and harvest rights, recognize that the formal documentation of TEK and LEK can provide important insights for marine conservation and fisheries management. For example, archaeological evidence indicates that First Nations of coastal British Columbia (BC), Canada, have harvested rockfish (*Sebastes* spp.) consistently for at least 1800 years (McKechnie, 2007), and likely longer, given evidence of the existence of these Nations dating back 14 000 years (Nair, 2017). In recent decades, however, Indigenous fishers from the Kitasoo/Xai'xais, Heiltsuk, Nuxalk, and Wuikinuxv First Nations of BC's Central Coast have been observing declines of rockfish, which they attribute primarily to overexploitation by commercial and recreational fishers. These First Nations are particularly concerned about yelloweye rockfish (*S. ruberrimus*), an important cultural and economic resource, and commissioned this study to complement information from ecological surveys (Frid, McGreer, Haggarty, Beaumont, & Gregr, 2016). Their primary interest was in using TEK and LEK to understand change over time in the sizes and abundance of yelloweye rockfish at traditional fishing sites, thereby informing restoration targets.

Yelloweye and other rockfishes are targeted by commercial, recreational and Indigenous fishers alike. They are vulnerable to overfishing because of their slow life-history traits. Many rockfish species are long-lived (yelloweye rockfish have been aged to 121 years) (Department of Fisheries and Oceans Canada, 2015), take about 1.5 decades to mature (Love, Yoklavich, & Thorsteinson, 2002; Mangel, Kindsvater, & Bonsall, 2007;Yamanaka & Logan, 2010) and form localized populations in structurally complex rocky reefs (Love et al., 2002). Many rockfish species, including yelloweye rockfish, commonly use depths of 100 m or deeper (Love et al., 2002). When brought to the surface by fishers, most species suffer internal damage due to air bladder expansion, which limits options to release bycatch (Jarvis & Lowe, 2008). In addition, as is the case for other groundfishes, fecundity increases with size or age (Dick, Beyer, Mangel, & Ralston, 2017). Fishers tend to remove larger individuals, thereby reducing population productivity (Birkeland & Dayton, 2005; Hixon, Johnson, & Sogard, 2014). In Canada, yelloweye rockfish are listed as a species of “Special Concern” under the Species At Risk Act (SARA) (COSEWIC, 2008). In BC, modelling of outside populations of yelloweye rockfish estimated their present biomass to be at 18% of 1918 levels (Department of Fisheries and Oceans Canada, 2015).

Over thousands of years and many generations, coastal First Nations in BC have developed complex resource management schemes suited to species within their land–sea territories. These systems are codified through stories, ceremonies, family lineages, social institutions, norms, and harvesting practices (Berkes, 2004, 2012; Berkes et al., 2000). Many of these management strategies continue, or are being revitalized. In BC, Indigenous adaptive management strategies are well-documented for a number of marine food resources, such as salmon, eulachon, and herring (Heaslip, 2008; Menzies & Butler, 2007; Snively & Corsiglia, 1997; Thornton, Moss, Butler, Hebert, & Funk, 2010; Turner, Ignace, & Ignace, 2000). Despite the impacts of industrialization and colonization, communities still harvest local ocean resources for food and cultural well-being. The local and traditional knowledge of First Nations individuals and communities could extend historical baselines and improve understanding of recent changes in rockfish populations. In turn, this could inform fisheries management and conservation, including spatial management options such as MPAs.

The goal of this research was to use the Central Coast of BC as a case study to illustrate the use of TEK and LEK to establish historical baselines that extend farther back in time than fishery-independent scientific surveys. The objectives were to (**i**) use interviews to estimate relative changes in yelloweye rockfish size and abundance since the 1950s, (**ii**) identify factors perceived to have caused these changes (e.g. commercial fishing, environmental shifts, etc.), and (**iii**) compare modern TEK and LEK observations with recent scientific surveys of yelloweye rockfishes by the Central Coast First Nations (Frid et al., 2016) and Fisheries and Oceans Canada (DFO).

2 | METHODS

2.1 | Study site

Research was conducted on the Central Coast of BC, Canada, in partnership with four First Nations (populations range from 80 to 1500 individuals) (Figure 1). The region is characterized by both exposed offshore islands and sheltered fjords and inlets.

2.2 | Research process

Research agreements and protocols were developed with each of the four First Nations that had identified the need for this study. Where feasible, the research began in each community with a workshop open to all community members to introduce the project and its goals, and to solicit interest in interview participation. In one community, the workshop occurred after interviews had begun. After the workshops, semi-structured interviews were carried out. After transcription and analyses of interviews, findings were publicly reported in each community, follow-up interviews were conducted, and data were shared per research agreements.

2.3 | Semi-structured interviews

Participants had 20 to 70 years of experience fishing or preparing catch, including targeting yelloweye rockfish. They either self-identified their interest to be interviewed during community workshops, or were recommended by resource stewardship directors from their community. Subsequently, a snowball sampling method (Huntington, 2000) was utilized. In this sampling method, several key participants were initially identified, and in turn these individuals identified other potential participants from their acquaintances. Interviews typically lasted 1–3 hours, and were audio recorded and transcribed.

A vessel-based approach (Murray, Neis, & Johnsen, 2006) was used to frame questions about changes in yelloweye rockfish size (length), depth of catch, and relative abundance. This method guided participants chronologically through the fishing boats they have used throughout their lives, attempting to document each vessel's size, technology, crew composition, etc. The method related answers to the windows of time associated with a given vessel. Questions regarding vessel technology (including questions regarding boat type, engine size, navigational instruments, etc.) were asked to ensure that observed changes in fish population were not driven primarily by changes in boat technology over time. Interviews began with questions about the first boat participants fished on during their youth. The interview then attempted to chronologically reconstruct the participants' life or career experiences fishing, concluding with the participant's estimate of the current typical catch size and abundance of yelloweye rockfish, and general abundance of rockfish as a genus. For analysis, 'typical length catches' reported were interpreted as median length of the catch reported by participants. Other studies have shown that fishers' memories are quite accurate compared with archival data, and hence are useful for constructing historical baselines (Thurstan,

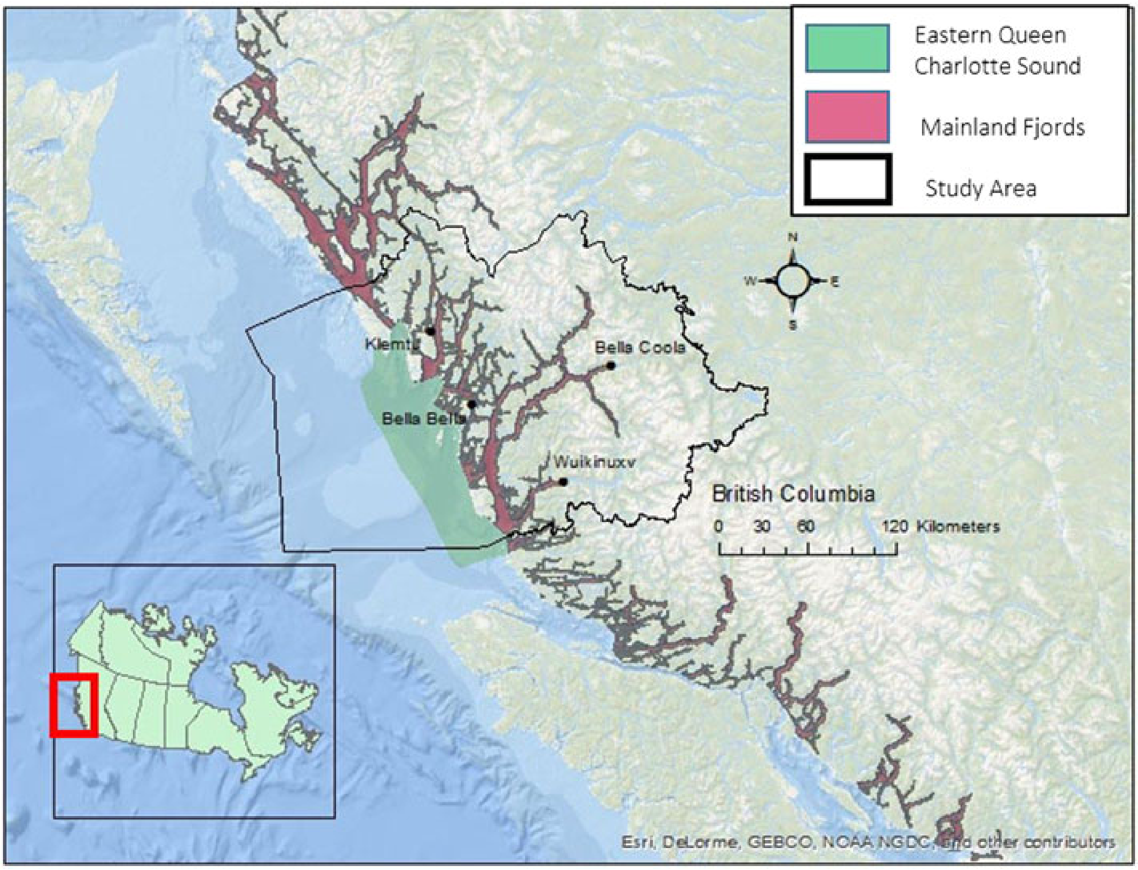

FIGURE 1 Map of study region. Bella Bella is home to the Heiltsuk nation, Bella Coola to the Nuxalk nation, Wuikinuxv to the Wuikinuxv nation, and Klemtu to the Kitasoo/Xai'xais nation. The eastern Queen Charlotte Sound and mainland fjord upper ocean subregions are identified. The study area represents the combined traditional territories of the four nations

Buckley, Ortiz, & Pandolfi, 2016). Most participants felt comfortable providing information only about their earliest and most recent years fishing (henceforth 'historical' and 'modern' years, respectively); these two points in time were the basis for our analyses. Questions throughout the chronology included: yelloweye rockfish typical size and abundance, perceived causes of changes to rockfish populations (if changes were observed), depth fished, and changes to participants' fishing strategies. Participants were also asked to identify on nautical charts where they fish (historically and/or currently) for yelloweye rockfish. Their responses were digitized using ArcGIS © software (ESRI, 2015); fishing locations or other spatial data were not illustrated due to the confidential nature of such locations to First Nations. To gauge opinions on changes in yelloweye rockfish abundance, participants were simply asked whether they had or had not witnessed an abundance change over their lifetime fishing.

Supportive materials (e.g. nautical charts, species ID books) were utilized where appropriate to facilitate information sharing by participants. Participants had at least two decades of experience fishing rockfish, and all targeted yelloweye rockfish. Given the extensive experience of participants and the supplementary use of species-identification field guides during interviews, we are confident that participants provided information specific to yelloweye rockfish rather than to morphologically similar species. When asked about historical length of yelloweye rockfish, most participants responded using the length between their two upheld hands. To facilitate these estimates, size references were offered in the form of rockfish-shaped paper cut-outs illustrating maximum length (91 cm), a moderately large length (75 cm), and length at early maturity (51 cm) (Love et al., 2002). In the three cases that fishers reported weight (kg) rather than length, this was converted to total length (cm) using the regression $TL = 40.445weight^{0.2913}$. The equation was derived from 54 field specimens (a subset of those analysed by Frid et al., 2016) collected at fishing sites described by interview participants. Yelloweye rockfish lengths described by participants during interviews were linked with the spatial locations they mapped. It was assumed that the participant's estimates of historical and modern catch characteristics were derived from these locations.

Because some participants did not wish to use sized cut-outs, researchers also used a tape measure to test and confirm their ability to estimate distance between raised hands to within 5 cm.

2.4 | Analysis

Interview transcripts were coded into coarse categories (e.g. size, abundance, perceived threats), and finer sub-categories for qualitative analysis using NVivo software (NVivo qualitative data analysis software; QSR International Pty Ltd. Version 10, 2012). R-statistical computing software (version 3.1.1) was used to analyse data and graph results. To analyse changes to perceived yelloweye rockfish size over time, a linear mixed model (LMM) was used (Pinheiro & Bates, 2000), with reported typical fish length (interpreted as median length) as the response variable. The predictor variables (fixed effects) were decade, which was a categorical variable with five levels (1950, 1960, 1970, 1980, and 2010), and depth (m). These years represent the beginning years for decades (10 year periods), except for the modern decade (2010), which encompassed only 6 years. Because participants provided an estimated fish length for two decades (a historical decade and the modern decade), participant ID was modelled as a random effect. Visual inspection of quantile–quantile plots, residuals vs fitted plots, and correlation values between variables, were used to verify the assumptions of normality, homogeneity, and variable independence, respectively (Pinheiro & Bates, 2000). This analysis excluded three outlying data points from the 2010s in which fishers targeted depths of 300 m - much deeper than the remaining participants. The three outliers, however, were included in all descriptive statistics and insights derived from them are discussed qualitatively.

2.5 | Ecological data sources

Two types of recent ecological surveys were compared with the interview data. The first consisted of hook-and-line surveys and sampling of landings by Indigenous subsistence fishers carried out by Central Coast First Nations (CCIRA data). These data encompassed 2006–2007 and 2013–2016, and the whole study region, including sheltered channels and fjords (Frid et al., 2016). The second data source consisted of fishery independent surveys carried out and/or collated by DFO (collected via the Pacific Halibut Commission longline survey and northern and southern Pacific Halibut Management Association longline surveys, and trawl surveys) (Department of Fisheries and Oceans Canada 2015, see data sets in McGreer and Frid, 2017). This study restricts analysis of these data to the geographic scope of the interview data: Pacific Marine Fisheries Commission major areas 5B and 5C, and the upper ocean subregions (BCMCA, 2013): Eastern Queen Charlotte Sound and Mainland Fjord. It is notable, however, that these data have poor coverage of sheltered fjords and channels (McGreer & Frid, 2017). Analysis of DFO data was restricted to the years 2010–2015 to best align with modern traditional ecological knowledge and local ecological knowledge data. Given the different biases, sampling methodologies, and sample sizes inherent to each source, interview and ecological survey data were compared only descriptively.

3 | RESULTS

In total, 42 participants took part in semi-structured interviews between May 2015 and May 2016. Some participants did not answer all interview questions, and thus sample sizes vary between data types; the percentages which correspond with each sample size denote the percentage of participant responses within the corresponding sample. Eighty-three per cent (83%, n = 42) of participants were men and 17% women. Fourteen participants identified themselves as Kitasoo/Xai'xais, 14 as Heiltsuk, seven as Wuikinuxv, and seven as Nuxalk. Participants ranged in age from 36 to 88 years, with an average age of 61. Ages were estimated in the case of 12 participants who did not disclose this information. Participants started fishing (or accompanying older fishers) between the ages of 1 and 18 years old (mean = 9.4 years; n = 22). Most remained active fishers, except for six elders who stopped fishing regularly within a decade before our interviews. Twenty-four participants had fished commercially at some point of their lives, though none had fished yelloweye rockfish commercially.

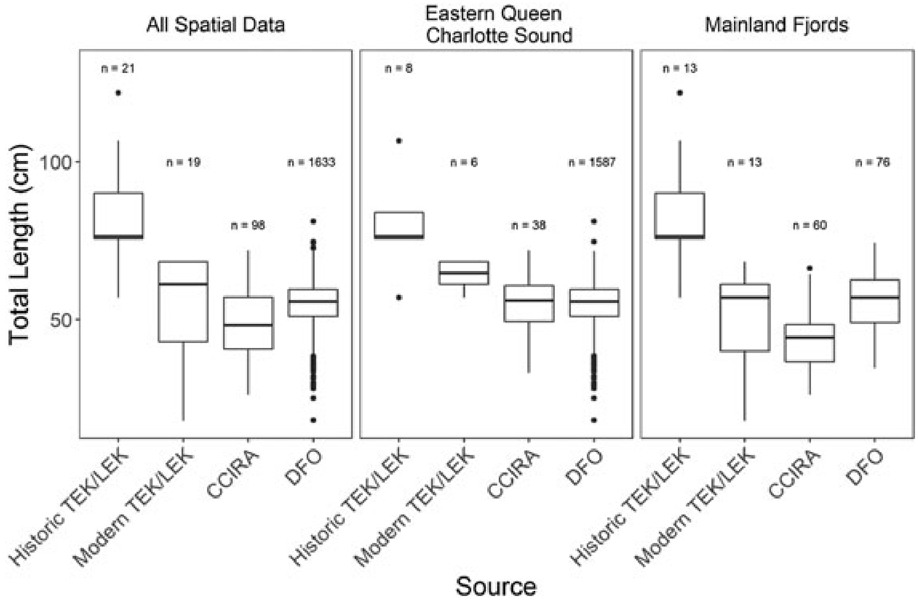

FIGURE 2 Comparison of historical and modern yelloweye rockfish length, comparing all spatial data within the study region to mainland fjords and eastern Queen Charlotte Sound oceanographic subregions within the study region. The size of the boxes is delimited by the first and third quartiles, and the line within each box denotes the median. Outliers are indicated by dots. Panel one compares the four sources from all geographic locations of interest in the study; panel 2 shows only those data from eastern Queen Charlotte Sound, and panel 3 shows only those data from mainland fjords. Historical and modern TEK/LEK labels represent interview data, CCIRA represents ecological data collected by the central coast Indigenous resource alliance, and DFO represents the subset of Department of Fisheries and Oceans Canada data used for comparison

Most respondents (88.5%, n = 35) observed a decrease in individual yelloweye rockfish length since the 1980s, while 11.5% did not. For the study area as a whole, the median historical length (1950s–1980s) was 84 cm (mean of 85 cm) while the median modern (2000–2015) length was 40 cm (mean of 46 cm). The differences were similar when comparing modern and historical sizes within the Mainland Fjords and Eastern Queen Charlotte Sound upper ocean subregions. Modern TEK and LEK of yelloweye lengths were similar to those from ecological survey data (Figure 2).

Most respondents (97.6%, n = 42) also observed a substantial decrease in abundance of yelloweye and other rockfishes since the 1950s, with 33% suggesting the change was most evident in the early 2000s, followed by the 1980s (21%) and 1990s (17%).

Participants observed declines in size and abundance even though all *(n = 25)* had improved their boat technology (e.g. more powerful engines, advanced navigation equipment, etc.) over their lifetime, thereby compensating for local resource depletions by expanding the spatial scope and technological efficiency of their fishing effort. Specifically, 79% of participants (n = 19) had changed their fishing strategies. Nearly half (47.4%) fished deeper (typically by 10–20 m), further from their community (21.1%) or switched gear from simple hand-lines to modern rods, lures, longlines, etc. (10.5%). The remaining (21%) did not modify their fishing strategy.

In recent years, participants fished at an average depth of 112 m (relative to 59 m historically). This change in average depth, however, was driven by three individuals fishing much deeper than their historical experiences, targeting depths of 300 m to 500 m. Notably, these were the only fishers still catching large yelloweye rockfish (90 cm or larger). When excluding these outliers from analysis, the linear mixed model revealed a significant decrease in yelloweye rockfish size in the 2010s, compared with the 1950s, 1960s, 1970s, and 1980s (Table 1; Figure 3). Given that the three deep-fishing outliers were excluded, the linear mixed model did not find a significant effect of depth on length (Table 1; Figure 3).

Participants (n = 36) described the following stressors as major drivers of decreased abundance and length of yelloweye rockfish and other rockfish species: commercial trawling (42%), the rockfish specific fishery (33%), the longline fishery (25%), non-specified commercial activity (22%), and sports fishing (22%). Participants also cited forestry impacts (6%), earthquakes (8%), and climate change (11%). A quote from one participant illustrates the impact of bycatch fatalities via trawling, the most often cited cause of depletions, ‘And we get out there, and there's red snapper [yelloweye rockfish] floating everywhere. Cod fishermen weren't taking them.’ Several fishers related collecting these discarded fish as part of their harvest. In this study, it is assumed that close proximity allowed harvesters to identify species specifically; though some other red-coloured deep-dwelling rockfishes may also have been observed. The discarded yelloweye

TABLE 1 Linear mixed model describing the relationship between yelloweye rockfish length (cm) and decade (coded as a dummy variable, with 1950 as the reference variable), controlling for depth, and with participant ID as a random effect

Predictor	Coefficient	Standard error	DF	*t*-value	*P*-value
Intercept	81.544	13.346	20	6.109	<0.01
1960	−4.428	12.983	13	−0.341	0.74
1970	9.887	13.386	13	0.739	0.47
1980	9.831	13.727	13	0.716	0.49
2010	−40.299	12.225	13	−3.297	<0.01
Depth	0.0241	0.103	13	0.235	0.82

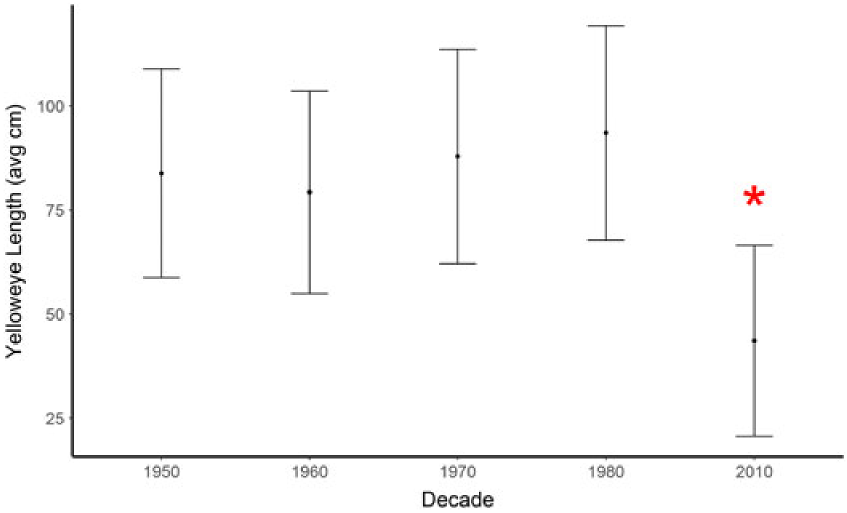

FIGURE 3 Perceived changes to yelloweye rockfish size (length) in relation to decade, where maximum average depth is 150 m. The points are the linear mixed model estimates of yelloweye length (cm). The bars are the 95% confidence interval. *n* = 25. Participant ID was a treated random effect. The asterisk represents a significant difference

rockfish had experienced fatal barotrauma; that is, when brought to the surface at rapid rates, these deep-dwelling fishes experience internal damage as air in their swim bladder expands (Jarvis & Lowe, 2008).

Ninety-one per cent of respondents (*n* = 32) had noticed the impacts of climate change over their lifetimes, in the form of less snow-pack during milder winters, hotter and drier summers, or an increase in extreme weather events. Though few individuals (11%) attributed abundance decreases in yelloweye rockfish or other rockfish species to changes in climate, most had noticed changing water temperatures and recognized the impact this could have on groundfish and other marine resources in the foreseeable future. Ninety-six per cent of participants (*n* = 28) expressed serious concerns for the future of yelloweye rockfish and of ocean ecosystems in general. These concerns included continued stock depletions due to: commercial, sport, and illegal market fishing (39%), mismanagement by the DFO (32%), and other impacts (24%) (e.g. pipeline expansion, climate change, pollution, and fish farms). Of those participants that expressed concerns about the future of resources, 28% expressed concern for stock depletions leading to loss of cultural lifeways, traditional diet, or language.

4 | DISCUSSION

This study illustrates how TEK and LEK can be gathered and used to establish historical baseline estimates that extend back further in time than scientific surveys, using yelloweye rockfish size (length) and abundance on BC's Central Coast as a case study. According to interview participants, changes to yelloweye rockfish size and abundance have been substantial since the 1950s and driven primarily by commercial and recreational fishing pressures. Similar studies have rendered comparable results; work in marine historical ecology that utilizes TEK or LEK has shown its value to extend or generate baseline data, improve spatial resolution of data, identify species abundance trends over time, and others (Hallwass et al., 2013; Lotze & Worm, 2009; Worm et al., 2009). For instance, Mallory, Gilchrist, Fontaine and Akearok (2001) revealed that LEK held within three high Arctic communities indicated abundance decreases in ivory gulls; this decrease was corroborated by ecological surveys shortly thereafter (Mallory et al., 2001). In the Philippines, TEK of participants near the island of Bohol similarly aided in tracking population declines (and extirpations) of finfish populations for which no ecological data existed, prompting researchers to emphasize the potential value of TEK for new monitoring methods (Lavides et al., 2009). In general, TEK and LEK have provided conservation and management information that bolsters or extends pre-existing data (Beaudreau & Levin, 2014; Espinoza-Tenorio, Wolff, Espejel, & Montaño-Moctezuma, 2013; Huntington, 2000; Thornton & Scheer, 2012; Thurstan et al., 2016) using a socially-inclusive approach. As is the case for all methodologies, the use of TEK and LEK face challenges. This study addresses some key hurdles recognized broadly in the relevant literature – sample size limitations, restrictions in temporal accuracy, and subjectivity associated with human observation – which are discussed below.

Though most observations from participants were 'local' (experience-based knowledge developed over long periods of time in one location), they were embedded within the knowledge, practice, and belief systems of First Nations culture that characterize the 'traditional' knowledge, which has informed Indigenous management for millennia (Turner et al., 2000; Berkes, 2012). The information collected thus lies at the intersection between local and traditional knowledge. Our use of vessel-based interview methodology (Murray et al., 2006) was limited because not all participants were willing to recount their complete fishing history. A vessel-based approach, however, did provide accurate information for the earliest and most recent decades in the fishing experience of participants, thereby allowing the documentation of major temporal changes in the population characteristics of yelloweye rockfish. In oceans affected by a growing number of stressors, it is imperative to capture and consolidate anecdotes, observations and stories as a means to look further into the past and understand just how extensive changes have been.

The loss of larger, more fecund yelloweye rockfish is a concern for current population health and sustainability because – for rockfishes in general – fecundity increases exponentially with female length (Dick et al., 2017). Historical length (1950s–1980s) of yelloweye rockfish witnessed by participants was nearly double the modern length. Analysis of the available fishery-independent data highlight that this concern applies to BC's Central Coast and vicinity, where the average length of yelloweye rockfish declined at an average rate of ≈ 4 mm yr^{-1} between 2003 and 2015 (McGreer & Frid, 2017).

Other data sources are commercial catches from the 1960s and 1970s, and catch reconstructions (Department of Fisheries and Oceans Canada, 2015). Because external market factors strongly influence the distribution, effort and behaviour of commercial fishers, commercial fishery-dependent data, however, may not necessarily reflect local changes to species sizes or abundance. Our interviews with Indigenous fishers extended the temporal scope of available information that is not directly influenced by external market forces.

It is notable that information provided by Indigenous fishers during the study is consistent with the declining body sizes of yelloweye rockfish documented by fishery-independent surveys (Frid et al., 2016; McGreer & Frid, 2017). Overall, this lends credibility to both modern and historical size estimates by participants in this study and beyond. This finding aligns with other studies that have used ecological research to corroborate traditional ecological knowledge or local ecological knowledge (Aswani & Hamilton, 2004; Johannes, 1998, 2000; Mallory et al., 2001; Poizat & Baran, 1997), or those that have found concurrence between scientific data and fishers' knowledge (Thurstan et al., 2016).

Peak abundance of adult yelloweye rockfish tends to occur at depths of 90–180 m (Love et al., 2002), which is within the range currently targeted by fishers (mean = 102 m). There is, however, a possibility of depth refuge for the larger size classes of rockfishes, as the only participants who still catch large yelloweye rockfish were three individuals who currently fish substantially deeper (300–500 m) than the typical fishing depth. Their strategy appears to parallel that of large-scale commercial fisheries, which increased their fishing depths to compensate for sequential declines at shallower depths caused by overexploitation (Morato, Watson, Pitcher, & Pauly, 2006). Fishers also may have incidentally caught yelloweye rockfish while fishing for other deep-dwelling species, such as Pacific halibut *(Hippoglossus stenolepis)* or sablefish (*Anoplopoma fimbria)*.

Consistent with other studies (Frid et al., 2016; McGreer & Frid, 2017) the findings suggest that fisheries management for yelloweye rockfish and other long-lived groundfishes needs to incorporate local and Indigenous knowledge into a more conservative and spatially-refined approach to avoid local and regional depletions. Specifically, the four Central Coast First Nations have been working together under the umbrella of the Central Coast Indigenous Resource Alliance (CCIRA) to develop marine use plans and improve fishery management. Their work includes collaborations with provincial and federal governments to develop a marine protected area (MPA) network in BC ('Canada - British Columbia Marine Protected Area Network Strategy', 2014; MaPP, 2015). MPAs and other forms of spatial fishery closures can contribute to the conservation and restoration of rockfishes (Parker et al., 2000; Yamanaka & Logan, 2010), including yelloweye rockfish (Frid et al., 2016). Implementing marine use plans co-authored by First Nations (MaPP, 2015) and establishing MPAs would facilitate these objectives (Berkeley, Hixon, Larson, & Love, 2004).

The stories and timing of depletions told by participants reflect the history of groundfish fisheries in BC. The yelloweye rockfish fishery was unrestricted since its inception and into the early 1980s, until the DFO implemented a licence and logbook system (Yamanaka & Logan, 2010). The fishery expanded into the 1990s and, though the DFO developed total allowable catch (TACs) as part of their management plan, stocks continued to decline rapidly (Haggarty, 2013). According to Yamanaka and Logan (2010), other commercial groundfish fisheries (e.g. trawl, halibut, lingcod, etc.) of the 1980s, 1990s, and early 2000s also caused yelloweye rockfish fatalities as additional targeted allowable catch or as bycatch (Haggarty, 2013; Yamanaka & Logan, 2010). Many interviewees reported experiences in which they had followed commercial groundfish vessels, collecting barotrauma-affected rockfishes thrown overboard en masse. Beyond commercial fishing, the expansion of sports fishing in the last several decades may also be affecting yelloweye rockfish populations, yet biological and compliance monitoring is limited both temporally and spatially (Cooke & Cowx, 2004), a fact which many interview participants lamented. Increased involvement by First Nations in monitoring and management has the potential to improve fisheries management (Danielsen et al., 2009; Gutiérrez, Hilborn, & Defeo, 2011). Based on this work, we suggest direct and formal collaboration between coastal First Nations and federal managers to improve the management and restoration of yelloweye rockfish, and other species of conservation concern. Formal collaboration should include combined goal-setting, monitoring, and assessment in areas relevant to Coastal First Nations.

The declines illustrated in this study are of special concern to First Nations, whose livelihood and culture is embedded in marine harvesting. The Canadian constitution recognizes the Aboriginal right to food, social, and ceremonial (FSC) purposes, and these FSC fisheries are supposed to have priority over commercial and recreational fishing. However, rockfish declines mean that First Nations fishers are not able to supply for their needs. Because First Nations rely on rockfishes – and many other species – for physical and cultural sustenance, conserving and rebuilding yelloweye rockfish and other species is intrinsically linked with upholding their fishing rights. The mismatch between large-scale, federal management and the local-scale realities of complex ecosystems and fishing activities is recognized globally (Hilborn, Orensanz, & Parma, 2005). Overcoming this mismatch by incorporating the local knowledge, expertise, and management intentions of Coastal First Nations alongside federal management has the potential to extend data baselines in data-poor waters and, perhaps lead to management approaches that consistently recognize the constitutional rights of First Nations to local resources.

Several limitations were evident throughout the study. Traditional ecological knowledge and local ecological knowledge are sometimes considered difficult to integrate into scientific management schemes because of their qualitative nature (Gilchrist, Mallory, & Merkel, 2005; Martin et al., 2007). Though this study worked to provide some historical quantitative information about yelloweye rockfish length, its ecological accuracy is limited. In older, larger rockfishes, 2–5 cm differences can represent substantial age differences. Though our data on length of yelloweye rockfish is only accurate to within an estimated 5 cm, changes were so large that the interviews nonetheless captured ecologically-significant changes. In addition, many participants were not willing or able to estimate size measurements, resulting in a small sample size for several questions. Geospatial information was also limited by participants' willingness to share their favourite fishing spots, owing to concern about public dissemination of sensitive locations. It was sometimes difficult or fatiguing for the participant to trace their entire chronological life history through the format of a vessel-based interview; life stages were often skipped to minimize interview fatigue. Finally, time was a limiting factor in data collection; most interviews lasted 1–3 hours, and therefore sample size was limited by research time and the availability of participants. However, the approach of capturing information from the first and last vessels participants fished from worked very well. A few knowledgeable fishermen (typically two or three per community) were out fishing at the time of our community visits, and therefore unavailable for interviews.

Ultimately, this study expanded insights into changes to yelloweye rockfish populations in BC. Importantly, it also upholds traditional ecological knowledge and local ecological knowledge of coastal Indigenous peoples as a valuable source of data that should be integrated into fishery management in Canada and elsewhere, to allow for increased community engagement and as a means to uphold Indigenous rights. The methods used in this study are repeatable and applicable to case studies globally, and provide a potential approach and justification for integrating traditional ecological knowledge and local ecological knowledge into species management schemes broadly.

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REFERENCES

Aswani, S., & Hamilton, R. J. (2004). Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (Bolbometopon Muricatum) in the Roviana lagoon, Solomon Islands. *Environmental Conservation*, *31*, 69–83.

Ban, N. C., Mills, M., Tam, J., Hicks, C. C., Klain, S., Stoeckl, N., & … Chan, K. M. (2013). A social-ecological approach to conservation planning: Embedding social considerations. *Frontiers in Ecology and the Environment*, *11*, 194–202.

Beaudreau, A. H., & Levin, P. S. (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecological Applications*, *24*, 244–256.

Berkeley, S. A., Hixon, M. A., Larson, R. J., & Love, M. S. (2004). Fisheries sustainability via protection of age structure and spatial distribution of fish populations. *Fisheries*, *29*, 23–32.

Berkes, F. (2004). Rethinking community-based conservation. *Conservation Biology*, *18*, 621–630.

Berkes, F. (2012). *Sacred ecology: Traditional ecological knowledge and management systems*. London, UK: Routledge.

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, *10*, 1251–1262.

Birkeland, C., & Dayton, P. K. (2005). The importance in fishery management of leaving the big ones. *Trends in Ecology & Evolution*, *20*, 356–358.

British Columbia Marine Conservation Analysis (BCMCA). (2013). Physical Representation - Oceanographic Regions (renamed Upper Ocean Sub Regions). Retrieved from http://bcmca.ca/datafiles/individualfiles/bcmca_eco_physical_oceanographicregions_atlas.pdf.

Canada - British Columbia Marine Protected Area Network Strategy. 2014.

Cooke, S. J., & Cowx, I. G. (2004). The role of recreational fishing in global fish crises. *Bioscience*, *54*, 857–859.

COSEWIC. (2008). *COSEWIC Assessment and Status Report on the Yelloweye Rockfish Sebastes ruberrimus in Canada*. Committee on the Status of Endangered Wildlife in Canada.

Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P. G., … Yonten, D. (2009). Local participation in natural resource monitoring: A characterization of approaches. *Conservation Biology*, *23*, 31–42.

Department of Fisheries and Oceans Canada. (2015). Stock assessment for the outside population of yelloweye rockfish (*Sebastes ruberrimus*) in British Columbia, Canada for 2014. DFO Canadian Science Advisory Secretariat Science Advisory Report, 60.

Dick, E. J., Beyer, S., Mangel, M., & Ralston, S. (2017). A meta-analysis of fecundity in 337 rockfishes (genus *Sebastes*). *Fisheries Research*, *187*, 73–85.

Drew, J. A. (2005). Use of traditional ecological knowledge in marine conservation. *Conservation Biology*, *19*, 1286–1293.

Espinoza-Tenorio, A., Wolff, M., Espejel, I., & Montaño-Moctezuma, G. (2013). Using traditional ecological knowledge to improve holistic fisheries management: Transdisciplinary modeling of a lagoon ecosystem of southern Mexico. *Ecology and Society*, *18*. art. 6. https://doi.org/10.5751/ES-05369-180206

ESRI. (2015). ArcGIS Desktop.

Frid, A., McGreer, M., Haggarty, D. R., Beaumont, J., & Gregr, E. J. (2016). The crossroads of spatial protection, central place fisheries, and indigenous rights. *Global Ecology and Conservation*, *8*, 170–182.

Gilchrist, H. G., Mallory, M. L., & Merkel, F. (2005). Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecology and Society*, *10*, 20.

Gutiérrez, N. L., Hilborn, R., & Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature*, *470*, 386–389.

Haggan, N., Neis, B., & Baird, I. (2007). *Fishers' knowledge in fisheries science and management*. Venice, Italy: UNESCO Publishing.

Haggarty, D. (2013). Rockfish conservation areas in BC : Our current state of knowledge. The David Suzuki Foundation.

Hallwass, G., Lopes, P. F., Juras, A. A., & Silvano, R. A. (2013). Fishers' knowledge identifies environmental changes and fish abundance trends in impounded tropical rivers. *Ecological Applications*, *23*, 392–407.

Heaslip, R. (2008). Monitoring salmon aquaculture waste: The contribution of first Nations' rights, knowledge, and practices in British Columbia, Canada. *Marine Policy*, *32*, 988–996.

Hilborn, R., Orensanz, J. M. L., & Parma, A. M. (2005). Institutions, incentives and the future of fisheries. *Philosophical transactions of the Royal Society of London. Series B. Biological Sciences*, *360*, 47–57.

Hixon, M. A., Johnson, D. W., & Sogard, S. M. (2014). BOFFFFs: On the importance of conserving old-growth age structure in fishery populations. *ICES Journal of Marine Science*, *71*, 2171–2185.

Huntington, H. P. (2000). Using traditional ecological knowledge in science: Methods and applications. *Ecological Applications*, *10*, 1270–1274.

Jarvis, E. T., & Lowe, C. G. (2008). The effects of barotrauma on the catch-and-release survival of southern California nearshore and shelf rockfish (Scorpaenidae, *Sebastes* spp.). *Canadian Journal of Fisheries and Aquatic Sciences*, *65*, 1286–1296.

Johannes, R. (1998). The case for data less marine resource management: Examples from tropical nearshore fisheries. *Trends in Ecology and Evolution*, *13*, 243–246.

Johannes, R. (2000). Ignore fishers' knowledge and miss the boat. *Fish and Fisheries*, *1*, 257–271.

Johannes, R. (2002). The renaissance of community-based marine resource management in Oceania. *Annual Review of Ecology and Systematics*, *33*, 317–340.

King, M., & Faasili, U. (1999). Community-based management of subsistence fisheries in Samoa. *Fisheries Management and Ecology*, *6*, 133–144.

Lavides, M. N., Polunin, N. V. C., Stead, S. M., Tabaranza, D. G., Comeros, M. T., & Dongollo, J. R. (2009). Finfish disappearances around Bohol, Philippines inferred from traditional ecological knowledge. *Environmental Conservation*, *36*, 235–244.

Lotze, H. K., & Worm, B. (2009). Historical baselines for large marine animals. *Trends in Ecology & Evolution*, *24*, 254–262.

Love, M., Yoklavich, M., & Thorsteinson, L. (2002). *The rockfishes of the northeast Pacific*. Berkeley, CA: University of California Press.

Mallory, M. L., Gilchrist, H. G., Fontaine, A. J., & Akearok, J. A. (2001). Local ecological knowledge of Ivory Gull declines in Arctic Canada. *Arctic*, *56*, 293–299.

Mangel, M., Kindsvater, H. K., & Bonsall, M. B. (2007). Evolutionary analysis of life span, competition, and adaptive radiation, motivated by the Pacific rockfishes (*Sebastes*). *Evolution; International Journal of Organic Evolution*, *61*, 1208–1224.

MaPP. (2015). Central Coast Marine Plan.

Martin, K. S., McCay, B. J., Murray, G. D., Johnson, T. R., & Oles, B. (2007). Communities, knowledge and fisheries of the future. *International Journal of Global Environmental Issues*, *7*, 221–239.

McClenachan, L. (2009). Documenting loss of large trophy fish from the Florida keys with historical photographs. *Conservation Biology: The Journal of the Society for Conservation Biology*, *23*, 636–643.

McClenachan, L., Cooper, A., McKenzie, M., & Drew, J. (2015). The importance of surprising results and best practices in historical ecology. *Bioscience*, *65*, 932–939.

McClenachan, L., Ferretti, F., & Baum, J. K. (2012). From archives to conservation: Why historical data are needed to set baselines for marine animals and ecosystems. *Conservation Letters*, *5*, 349–359.

McGreer, M., & Frid, A. (2017). Declining size and age of rockfish (*Sebastes* spp.) inherent to indigenous cultures of Pacific Canada. *Ocean and Coastal Management*, *145*, 14–20.

McKechnie, I. (2007). Investigating the complexities of sustainable fishing at a prehistoric village on western Vancouver Island, British Columbia, Canada. *Journal for Nature Conservation*, *15*, 208–222.

Mellado, T., Brochier, T., Timor, J., & Vitancurt, J. (2014). Use of local knowledge in marine protected area management. *Marine Policy*, *44*, 390–396.

Menzies, C. R., & Butler, C. F. (2007). Returning to selective fishing through indigenous fisheries knowledge: The example of K'moda, Gitxaala territory. *The American Indian Quarterly*, *31*, 441–464.

Morato, T., Watson, R., Pitcher, T. J., & Pauly, D. (2006). Fishing down the deep. *Fish and Fisheries*, *7*, 24–34.

Murray, G., Neis, B., & Johnsen, J. P. (2006). Lessons learned from reconstructing interactions between local ecological knowledge, fisheries science, and fisheries management in the commercial fisheries of Newfoundland and Labrador, Canada. *Human Ecology*, *34*, 549–571.

Myers, R. A., & Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. *Nature*, *423*, 280–283.

Nair, R. (2017). Archeological find affirms Heiltsuk Nation's oral history. *CBC News*.

Parker, S. J., Berkeley, S. A., Golden, J. T., Gunderson, D. R., Heifetz, J., Hixon, M. A., … O'Connell, V. M. (2000). Management of Pacific rockfish. *Fisheries*, *25*, 22–30.

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution*, *10*, 430.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., & Torres, F. (1998). Fishing down marine food webs. *Science*, *279*, 860–863.

Pinheiro, J., & Bates, D. (2000). *Mixed effects models in S and S-Plus*. New York, NY: Springer.

Pitcher, T. J. (2004). *Back to the future: Advances in methodology for modelling and evaluating past ecosystems as future policy goals*Fisheries Centre University of British Columbia.

Poe, M. R., Norman, K. C., & Levin, P. S. (2014). Cultural dimensions of socioecological systems: Key connections and guiding principles for conservation in coastal environments. *Conservation Letters*, *7*, 166–175.

Poizat, G., & Baran, E. (1997). Fishermen's knowledge as background information in tropical fish ecology: A quantitative comparison with fish sampling results. *Environmental Biology of Fishes*, *50*, 435–449.

Service, C. N., Adams, M. S., Artelle, K. A., Paquet, P., Grant, L. V., & Darimont, C. T. (2014). Indigenous knowledge and science unite to reveal spatial and temporal dimensions of distributional shift in wildlife of conservation concern. *PLoS ONE*, *9*, e101595.

Snively, G., & Corsiglia, J. (1997). Knowing home: NisGa'a traditional knowledge and wisdom improve environmental decision making. *Alternatives Journal*, *23*, 22–27.

Thornton, T. F., Moss, M. L., Butler, V. L., Hebert, J., & Funk, F. (2010). Local and traditional knowledge and the historical ecology of Pacific herring in Alaska. *Journal of Ecological Anthropology*, *14*, 81–88.

Thornton, T. F., & Scheer, A. M. (2012). Collaborative engagement of local and traditional knowledge and science in marine environments. *Ecology and Society*, *17*, art. 8. https://doi.org/10.5751/ES-04714-170308

Thurstan, R. H., Buckley, S. M., Ortiz, J. C., & Pandolfi, J. M. (2016). Setting the record straight: Assessing the reliability of retrospective accounts of change. *Conservation Letters*, *9*, 98–105.

Turner, N. J. (2003). The ethnobotany of edible seaweed (*Porphyra abbottae* and related species; Rhodophyta: Bangiales) and its use by first nations on the Pacific coast of Canada. *Canadian Journal of Botany*, *81*, 283–293.

Turner, N. J., Ignace, M. B., & Ignace, R. (2000). Traditional ecological knowledge and wisdom of aboriginal peoples in British Columbia. *Ecological Applications*, *10*, 1275–1287.

Valbo-Jørgensen, J., & Poulsen, A. F. (2000). Using local knowledge as a research tool in the study of river fish biology: Experiences from the Mekong. *Environment, Developement and Sustainability*, *2*, 253–376.

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., … Jensen, O. P. (2009). Rebuilding global fisheries. *Science*, *325*, 578–585.

Yamanaka, K. L., & Logan, G. (2010). Developing British Columbia's inshore rockfish conservation strategy. *Marine and Coastal Fisheries*, *2*, 28–46.

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