

Drawing on indigenous governance and stewardship to build resilient coastal fisheries: People and abalone along Canada's northwest coast

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ABSTRACT

Small-scale indigenous abalone fisheries on the northwest coast of Canada persisted for at least two millennia prior to modern commercial and recreational fisheries that lasted for four decades before collapsing, causing a coast wide closure that remains today. What traditional governance and stewardship practices fostered resilient fisheries along Canada's northwest coast and how might they inform collaborative institutions that foster ecologically sustainable and socially just coastal fisheries in future? In collaboration with two coastal First Nations, a policy analysis of northern abalone (GaalGuuhlkyan –Skidegate Haida, ǵaṭǵṭíq –Heiltsuk, *Haliotis kantschatkana*) stewardship was conducted to assess where traditional and modern fisheries governance and management aligned or failed to align with seven theoretical principles of social-ecological resilience. The analysis revealed that traditional principles of reciprocity and contingent proprietorship of clan-based fishing areas aligned with resilience principles whereas contemporary centralized decision-making and region-wide management policies did not. Moreover, current issues of power asymmetry and lack of trust need to be addressed to build a future indigenous-state governance approach to coastal fisheries. This research demonstrates how indigenous resource governance and stewardship practices generated over millennia of social learning and experimentation offer insights that could be broadly applied to foster resilient coastal fisheries today.

1. Introduction

Building resilient and persistent coastal fisheries with local benefits is central to the well-being of coastal communities and ecosystems [15, 40,113]. This is particularly important for coastal indigenous communities who have relied on, and been stewards of, coastal resources for millennia [10,11,27,90,101,106,139,142,153]. Increasingly, indigenous communities throughout the world are successfully re-asserting their stewardship authority and responsibility over ocean resources (e.g., Ref. [145]). However, state-led governance and fisheries management institutions have often failed to accept and accommodate the changing roles and authority of indigenous communities [116,117,142], as well as new insights into factors that confer resilience in social-ecological systems (SESs) [20,58,59,61].

The concept of social-ecological resilience offers a theoretical basis for assessing the capacity of governance systems to achieve both social and ecological sustainability. Resilient SESs have the capacity to adapt or transform in the face of often-unexpected disturbances in ways that continue to support human well-being [19,32,59]. Over several decades, SES resilience theory (e.g. Refs. [17,44,58,147]), has been advanced through theory-testing and accumulated empirical evidence from which a comprehensive syntheses of seven resilience principles were generated [20]. These principles have been applied to analyze a wide variety of complex adaptive natural resource systems (e.g. Refs. [31,58,125,127,128]), and indigenous environmental governance along Canada's northwest coast (e.g., Refs. [140–142]).

Applying resilience principles to resource stewardship, particularly in collaboration with indigenous peoples, requires institutional

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approaches that can support indigenous intellectual traditions and worldviews [10,11,52,98,101] as well as meet multiple social and ecological objectives and achieve positive livelihood and compliance outcomes [33,112]. Among many governance models, adaptive co-management (ACM) is one such approach that embraces change and uncertainty, thereby fostering SES resilience [9,60,107,119,120]. As a context-specific and community-based approach, ACM incorporates the adaptive aspect of learning-by-doing [76] with cross-scale collaboration and co-management between governing authorities and resource users [115].

Indigenous peoples worldwide evolved natural resource stewardship practises that foster sustainable livelihoods and ecological well-being within their traditional lands and seas [7,10,24,28,101,142]. In many cases, indigenous values, stewardship protocols and fishing practises sustained local and regional resource use over centuries and millennia (e.g., Refs. [10,11,22,23,27,90–92,96,101,102,140,142]). Recent cases highlight the fundamental role of place-based indigenous knowledge and traditional stewardship in fostering SES resilience today. For example, indigenous management of arapaima in Brazil was key to recovery of this overexploited fish [30]. In the Canadian Arctic, indigenous co-management was critical to positive outcomes for communities, conservation of beluga whales and management of Dolly Varden char fisheries [8,86].

Here, the social-ecological resilience of northern abalone

(GaalGuuhlkyan –Skidegate Haida, ǵatǵǵı́q –Heiltsuk, *Haliotis kamtschatkana*) governance and stewardship systems of historical indigenous peoples in British Columbia (self-referred to as First Nations) was assessed and compared with the abalone governance system of Canada’s federal fisheries agency. Northern abalone (hereafter abalone) is a culturally important and economically valued marine snail that is now listed as an endangered species in Canada. Profound shifts in natural resource use and governance over the past 250 years have triggered fisheries and conservation conflicts involving abalone and its major predators, sea otters (*Enhydra lutris*) and people [87,126,133]. An ACM approach is proposed to chart a course towards more socially just and ecologically sustainable use and stewardship of abalone, with the potential for broader application to other coastal fisheries in Canada and internationally.

2. Social-ecological system description

... every spring time ... Ah, that rock ... the tide would come down that far and that rock would be there. Then my dad would say, ‘Okay, it’s time to go get abalone.’ (Stephen Hunt, Heiltsuk Nation, Jan. 2012)

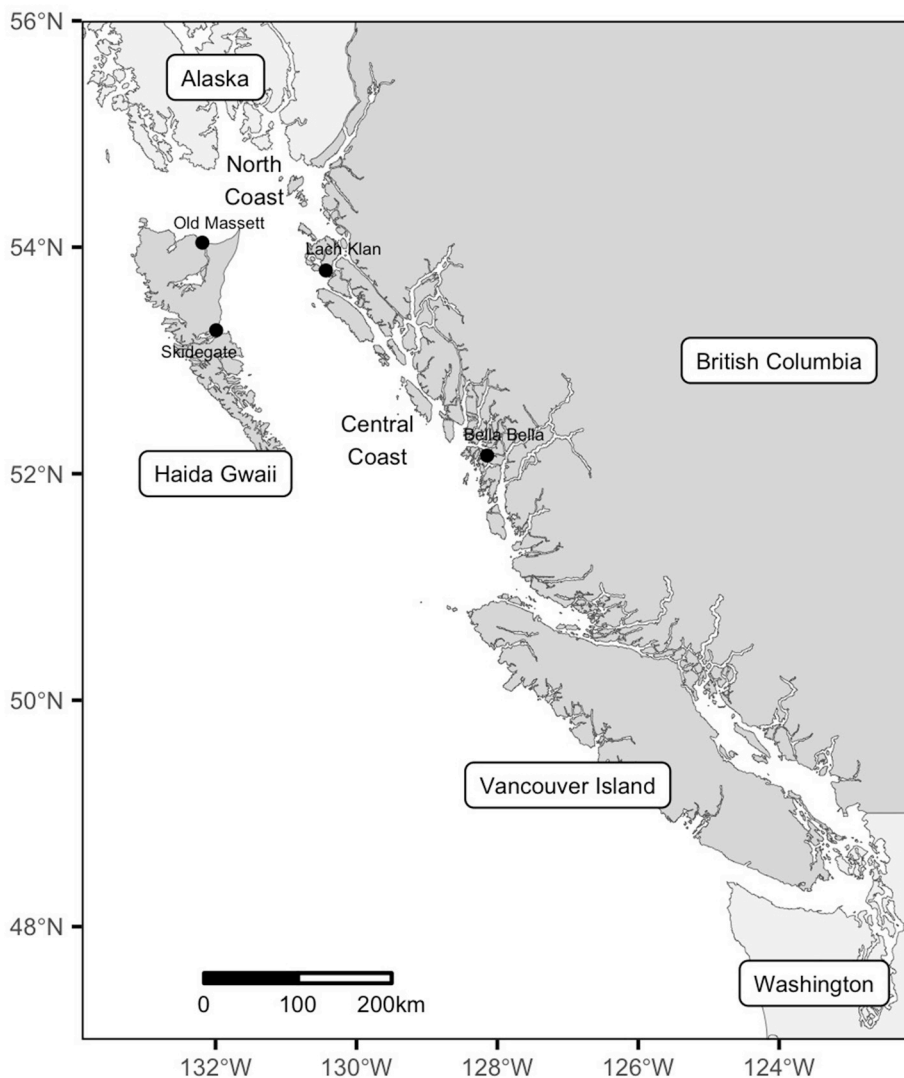


Fig. 1. Study area showing locations of communities in northern British Columbia, Canada, where abalone stewardship practices and protocols were investigated: Bella Bella where collaborative interviews were conducted with Heiltsuk Nation abalone experts; and Old Massett and Skidegate where the Haida Nation conducted interviews for the Haida Marine Traditional Knowledge Study [68]. The location of the village of Lach Klan in Gitxaala territory where published Gitxaala Nation knowledge was documented [99,100] is also shown.

2.1. Study area, components and interactions

Northern abalone range from California to Alaska and are highly valued by many indigenous people who occupy coastal British Columbia (BC), Canada [132,145]. This study primarily draws on expert knowledge from the Heiltsuk Nation with traditional territory on BC's central coast, and the Haida Nation with traditional territory on Haida Gwaii, on BC's north coast (Fig. 1). Archaeological and ethnographic evidence reveal that Heiltsuk and Haida are maritime cultures with persistent and strong ties to coastal resources, including salmon [153], Pacific herring [96], clams [78] and abalone [108], that stretch back at least 13,500 years [22,50,154]. Intercultural relationships that formed part of past governance institutions, including Peace Treaties between the Heiltsuk and Haida Nations, persist today [124].

Across the northeastern Pacific, abalone populations are strongly controlled by top-down forces of sea otter predation and human fishing. Following millennia of sustained hunting by coastal First Nations, sea otters were ecologically extirpated from much of the northeastern Pacific coast including parts of BC starting two centuries ago during the maritime fur trade [133]. Lack of sea otter predation allowed populations of their macroinvertebrate prey, including abalone and sea urchins, to increase greatly in abundance (e.g., Refs. [43,47,138]). Re-introduction of sea otters to BC from 1969 to 72 and their continued recovery today is again altering coastal food webs and ecosystems [26, 87,94,134,149,151]. Sea otter predation directly reduces total abalone densities and alters their behavioral patterns. Exposed abalone densities can decline by up to 16x after 30 years of sea otter occupation, yet densities of cryptic abalone can double [88]. By causing a well-known trophic cascade, sea otters can increase the spatial extent and depth of kelp forests [94] thereby increasing the depth range and spatial extent of abalone [88]. Recent evidence also hints at the complexity of sea otter-urchin-kelp interactions, revealing that environmental conditions can decouple this trophic cascade particularly after long periods of sea otter occupation [129].

The other dominant predator of abalone, humans, has a long history of fishing for this marine mollusc (Fig. 2). For millennia, First Nations traditionally picked (fished) northern abalone in the intertidal and shallow subtidal areas by hand-picking or using hand tools [56,69,99, 100]. As a cultural keystone species [64] for many coastal BC First Nations including Haida and Heiltsuk, abalone are important for food, local and regional trade and ceremonial regalia [69,99,100,130–132]. Following colonization, abalone were recreationally fished by people not of indigenous descent by intertidal hand-picking, and subsequently also by SCUBA diving from the mid to late 1900s. Commercial fisheries in the early 1900s through the early 1970s were small in scale using intertidal hand-picking and then SCUBA diving starting in the 1950s and 60s, with commercial fishery landings dramatically increasing in the mid-1970s [132]. First Nations traditional fisheries (specifically aboriginal food, social and ceremonial fisheries) are constitutionally protected in Canada and, after conservation, have priority over commercial and recreational fisheries. All abalone fisheries in BC were closed in 1990 due to abalone population decline (see section 2.2).

Abalone fisheries were shaped by interacting social and ecological forces including indigenous and colonial laws and governance systems, local and regional trade, national and international markets, and local to global scale environmental conditions (Fig. 2). Black markets at regional to global scales spurred illegal fisheries estimated at 2–4x the legal catch quota in later years of the commercial dive fishery [48]. In fact, small to large-scale illegal abalone fishing is considered the primary threat to abalone recovery today [56]. The decline in abalone abundances driven by formerly legal and continuing illegal commercial trade, and subsequent federal conservation policies restricting its harvest, has perpetuated the loss of First Nations cultural use and connections with abalone [69,87]: "... they [commercial abalone fishery] just annihilated the biomass ... after that my people were told that they couldn't eat that stuff [abalone] anymore." (William Gladstone Sr., Heiltsuk Nation, Jan. 2012).

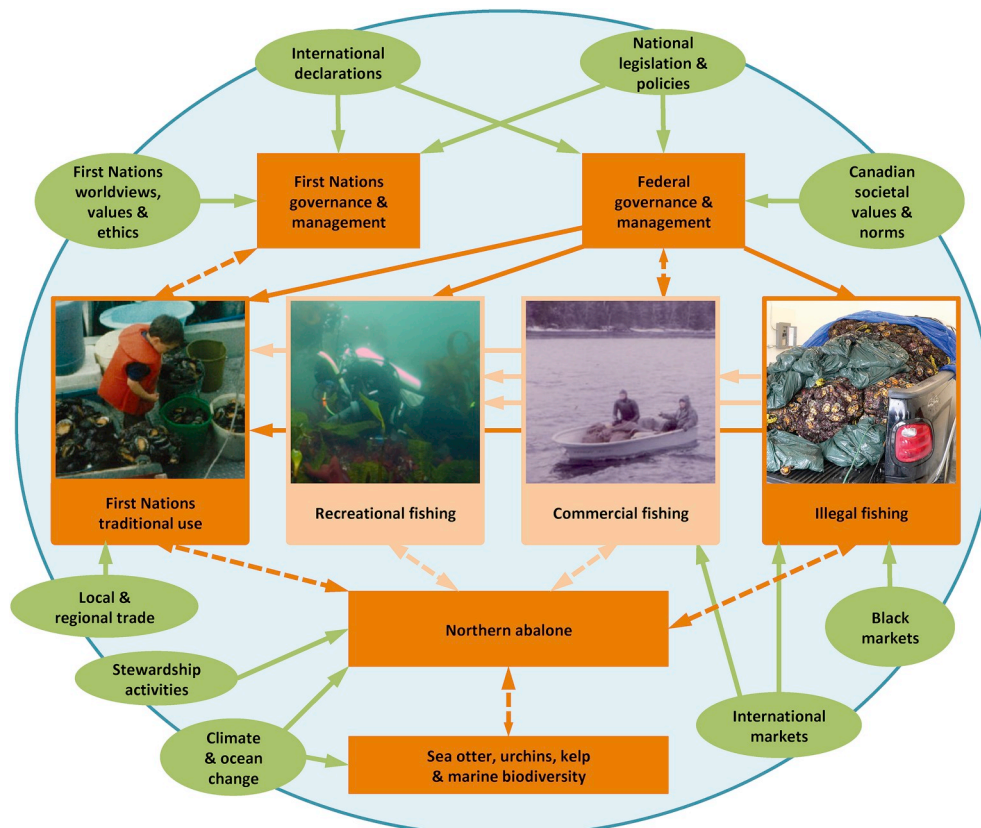


Fig. 2. Key components (orange rectangles), drivers (green ovals), direct linkages (solid arrows) and feedbacks (dashed arrows) of the northern abalone social-ecological system, including currently active (dark orange) and formerly active (light orange) components. Smaller arrows indicate less prominent feedbacks. Illegal fishing during and after the commercial fishery also affected the three legal fisheries, and commercial overfishing led to closure of the recreational and First Nations traditional fisheries. Diagram concept adapted from Salomon et al. [125]. Photo credits (left to right): McNeill family, Lynn Lee, Guy White, Fisheries and Oceans Canada. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.2. Governance regimes

Two major abalone fisheries governance regimes can be distinguished, driven by profound cultural and social change, leading into the current period of abalone recovery (Fig. 3). The historical First Nations governance regime maintained sustainable abalone fishing under traditional stewardship systems that persisted for at least 2000 years before European contact in the late 1700s [99,140,142]. European colonization initiated a period of rapid and unsustainable exploitation of natural resources and the decimation of First Nations populations by up to 80–90% through disease and conflicts throughout the 1800s [6,55,71, 108,123].

The Canadian federal governance regime, which undermined First Nations indigenous governance from the late 1800s and early 1900s to present [72], was characterized by continuing unsustainable resource extraction and colonial policies and laws intended to acculturate First Nations to “Canadian” society (e.g., foreign worldviews, residential schools, potlatch ban; [55,73]). Under this regime, management of traditional, recreational and commercial abalone fisheries was federally prescribed under Canada’s Fisheries Act [1] [[2]] and managed by the federal Department of Fisheries and Oceans Canada (DFO) in a centralized agency command-and-control management system [75]. The commercial abalone dive fishery was initiated under this regime in the 1950s and had low catch, little fisheries regulations (only minimum size limit of 90 mm) and no abalone population assessments. A greater than 10-fold catch increase starting in 1976 precipitated implementation of fisheries management measures including an increase in the minimum size limit, coastwide catch quotas and fishing season restrictions, followed by license-based quotas, and initiation of abalone stock assessments [132]. These measures did not halt the decline of abalone, finally leading to closure of all three legal abalone fisheries in 1990 [48].

As abalone fisheries were declining, coastal First Nations in BC were self-organizing into contemporary governance structures that included First Nations councils, constitutions and stewardship agencies with linkages to hereditary chiefs. Following the fisheries closures, abalone remained at low densities coast-wide for decades: “... you’d have to spend a lot of time walking the rocks the same areas where we used to ... know you’re going to get a bucket there ... If you go out to the same areas now ... you’re hoping to find one” (Gary Housty, Heiltsuk Nation, Jan. 2012). In 2000, abalone was the first marine invertebrate to be listed as *threatened* with subsequent uplisting in 2009 to *endangered* under Canada’s Species at Risk Act (SARA; [5]) due to lack of recovery since the fisheries closures [35]. Current governance (see Section 5) is characterized by a focus on abalone recovery and remains largely under federal authority, although First Nations are increasingly asserting

indigenous authority over coastal fisheries, including demands for collaborative management and litigation related to stewardship of the land and sea (e.g., Refs. [65,81,146]). Current fisheries reconciliation discussions in Haida and Heiltsuk traditional territory are led by contemporary indigenous governance structures such as the Council of the Haida Nation and Heiltsuk Tribal Council.

3. Methods

3.1. Assessing resilience of indigenous and federal fisheries governance regimes

To assess the degree to which historical First Nations and Canadian federal abalone fisheries governance regimes aligned with the seven theoretical resilience principles identified by Biggs et al. [20]; traditional knowledge interviews with Heiltsuk abalone experts were conducted, and published reports, technical reports, grey literature and peer-reviewed literature about Pacific Northwest coastal First Nations stewardship practices were synthesized (Section 4). The latter included articulation of fundamental truths, ethics and values underlying First Nations stewardship of natural resources [25,36]. In this paper, the term governance refers to broad environmental decision-making institutions and processes [89], and management systems refers to specific actions including practices and protocols for resource use and stewardship to achieve desired goals and objectives that are shaped by social norms and worldviews [93].

Collaboratively with the Heiltsuk Nation, ten semi-directed interviews [18,77] were conducted with indigenous abalone experts identified by the Heiltsuk resource management department to document traditional management, use and stewardship of abalone (see Ref. [87] for details). Participants included 14 abalone experts – one woman and 13 men – from 39 to 90 years of age. For similar Haida knowledge of traditional abalone stewardship and use, this research drew on a summary from the Haida Marine Traditional Knowledge (HMTK) Study that interviewed 47 men and seven women between 29 and 95 years of age [68,155].

3.2. Evaluating conditions for adaptive co-management

To apply resilience principles in future abalone use and management via adaptive co-management with the ultimate goal of restoring traditional abalone fisheries, the occurrence of 10 key conditions needed to foster this management approach was evaluated [9]. From this evaluation, information sources listed above and federal and community-based species at risk recovery strategies and action plans for abalone, recommendations were made to outline changes required in Canadian fisheries

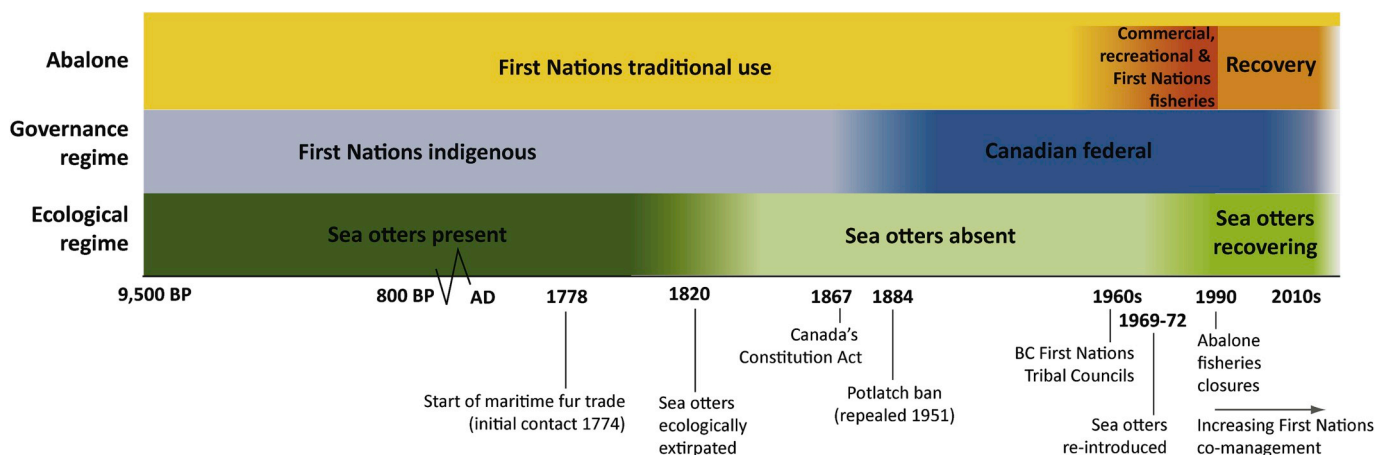


Fig. 3. Timeline of key events and changes in the northern abalone social-ecological system, including abalone use, major fisheries governance regimes, and ecological regimes (also see Ref. [87]).

governance to support successful ACM of abalone with coastal First Nations (Section 5).

4. Resilience assessment of abalone fisheries governance regimes

Characteristics of traditional indigenous and Canadian federal abalone fisheries governance and management systems were assessed relative to how they aligned, or failed to align, with seven theoretical principles of SES resilience [20] (Table 1). Examples were included under the principle where they best fit, recognizing that some governance characteristics are illustrative of multiple resilience principles and vice versa. This paper focuses on evaluation of a complex, multi-dimensional pre-colonial indigenous governance system using SES resilience theory. Other theories and worldviews could equally be applied including boundaries and territoriality (c.f., [105]), recognition of the agency and status of animals as non-human persons (c.f., [53,70,104]), and indigenous intellectual traditions and worldviews (c.f., [10,98,101]). Multiple causal links likely contribute to produce sustainable SES regimes.

4.1. Maintain diversity and redundancy

Options for responding to change are fostered by maintaining diversity and redundancy in SES components, interactions, and responses to disturbance [20,45]. A diverse fishing portfolio, including abalone, was characteristic of historical First Nations SESs [78,95]. Heiltsuk predominantly picked abalone and black seaweed together in spring and also picked abalone for fresh eating while fishing for other coastal species, including salmon, herring, halibut, seagull eggs, crabs, urchins, gumboot chiton and black katy chiton (Table 2). Similarly, Haida picked abalone with seaweed, clams, cockle, mussels, halibut and rockfish, among other species [69]. This diversity in catch allowed fishing of alternative species when the target species was in low abundance: "... the old people called them *hamúlis* [red turban snails] ... when they can't find abalone, they pick all the *hamúlis* ... it's like same taste as abalone" (Fred Reid, Heiltsuk Nation, Jan. 2012).

More broadly, diversity and redundancy were evident in 'houses', the fundamental social unit of northwest coastal indigenous governance systems that encompassed family and clan relationships with kinship connections to other houses through hereditary chiefs [99,141,142]. For example, Haida hereditary chiefs led larger social units such as lineages, clans or villages and were the trustees of lineage properties [21]. The head titleholder of each house or chief held proprietorship over specific fishing sites and reciprocity among houses by way of potlatch ceremonies and feasts fostered response diversity to local disturbances for many resources including herring spawn areas [65,121], clam beds [78] and salmon streams [25,141,142] such that if a local population failed, title holders could acquire access or fisheries from other areas. In Heiltsuk territory, families had designated fishing areas where they were responsible for ensuring local-scale persistence of coastal resources: "I think it was ... our way of keeping it ... stable. We didn't just run all over an area, harvesting wherever we could. We went to one area and we harvested there and then we didn't bother with any other particular areas, so that other families could harvest there. A lot of different families go to different areas to harvest seaweed, to harvest everything else" (Howard Humchitt, Heiltsuk Nation, Jan. 2012). Local-scale house or chief-based governance and use matched the local spatial scale of abalone population dynamics (likely ~1–10 km larval dispersal; generally <100 m adult movement) and likely fostered spatial heterogeneity and genetic diversity due to short larval duration (~1 week) and likely limited larval dispersal (Table 3).

In contrast, a centralized Canadian federal fisheries department managed for maximum sustainable commercial yield of single species, in this case abalone, often along the entire BC coast (~25,000 km; [132]) without considering fishing effects on other species in the

Table 1

Key characteristics of traditional First Nations and Canadian federal fisheries governance regimes for abalone in relation to seven theoretical principles identified to enhance the resilience of social-ecological systems [20].

Resilience principle	
First Nations traditional governance	Canadian federal governance
Maintain diversity and redundancy <ul style="list-style-type: none"> • System of family-based houses and chiefs with designated fishing areas maintained diverse and redundant stewardship areas • Fishing and stewardship of multiple species occurred together 	<ul style="list-style-type: none"> • Maximum yield-oriented outcome occurred for a single species at a time • One federal decision-making body issued species-specific licenses with coast-wide regulations
Manage connectivity <ul style="list-style-type: none"> • Worldview of <i>Everything depends on everything else</i> strongly connected people, place and a diversity of interacting species • Trade and reciprocity connected local and regional interactions • Traditional fishing practices maintained ecological connectivity 	<ul style="list-style-type: none"> • No ecological monitoring created few feedbacks for over two decades • Fisheries regulations and some population monitoring developed feedbacks for final 12 years • Little to no meaningful communications with indigenous or other local coastal communities minimized social feedbacks
Manage slow variables and feedbacks <ul style="list-style-type: none"> • Intergenerational ethics and teachings of <i>Stewardship, Respect, Responsibility and Reciprocity</i> guided continuity of use over millennia of dynamic environmental change 	<ul style="list-style-type: none"> • Intensive commercial fishing of high abalone abundance from ecological regime without sea otters caused rapid abalone decline leading to fisheries closures in less than four decades
Foster complex adaptive thinking <ul style="list-style-type: none"> • Worldviews of <i>Adapting to change and Balance</i> inherently acknowledged uncertainty, disturbance and surprise as part of the system • Regular physical connection between people and place created tight internal feedbacks 	<ul style="list-style-type: none"> • Primary goal of maintaining relatively constant abalone catch ignored ecosystem complexity • Centralized decision-making and lack of monitoring created lags and inability to respond to local-scale changes in a timely manner
Encourage learning and experimentation <ul style="list-style-type: none"> • Ethics of <i>Seeking wise counsel</i> and <i>Knowledge</i> reflected intergenerational learning by youth practicing with elders and knowledge holders • Experimentation with diverse resource management tools facilitated social learning 	<ul style="list-style-type: none"> • Coast-wide implementation of management measures limited experimentation and learning • No effectiveness monitoring of local-scale fisheries closure areas limited learning from management actions
Broaden participation <ul style="list-style-type: none"> • Ethics of <i>Sharing</i> and <i>Seeking wise counsel</i> encouraged participation through sharing knowledge and resources • Learning-by-doing fostered participation of whole community in fishing and processing • Public exchanges at potlatches promoted transparency and public accountability 	<ul style="list-style-type: none"> • Little to no resource users in management process for over two decades limited participation • Formation of commercial fishing association in last decade of fishery created some participation • Some limited participation by First Nations and recreational interests informed local-scale fisheries closures in last decade of fishery
Promote polycentric governance <ul style="list-style-type: none"> • Nested system of houses and chiefs created multiple governance authorities with no centralized regional governance • Local spatial scale proprietorship responsibilities matched to local-scale ecological processes 	<ul style="list-style-type: none"> • Centralized, top-down federal decision-making limited polycentric management, except for limited local-scale fisheries closures • Coast-wide regulations created scale mismatch between large-scale governance and smaller-scale ecological processes

ecosystem. Unless they held multiple different commercial licenses, abalone commercial fishers could not shift their efforts to fish other species should abalone become locally depleted. Following collapse of the abalone fisheries and growing conservation issues related to other

Table 2

Traditional indigenous abalone stewardship protocols and management practices revealed by Heiltsuk First Nation experts, highlighted with representative quotes. Experts are identified in the acknowledgements. Equivalent contemporary fishing regulations in *italics*.

Stewardship practice or protocol and representative quotes	Experts
Only fish during daytime lower low tides in spring by hand-picking [<i>Season and gear restrictions</i>]	
<ul style="list-style-type: none"> “... we go out is May ... in seaweed picking time.” (William Gladstone Sr.) “... we used to go there for seaweed, and if we see abalone we used to take it.” (Gary Housty) Hand-pick in different ways: grab fast by hand with no tools, knock off with yew wood club into a basket, pop or pry off with tool (butter knife in recent times) Fish with a gaff or spear at low tide (less common than hand-picking) 	MR, DW, WGSr, GB, HH, FR, AR, HER, SH, GEH, GGH, 3 anonymous
Only pick abalone that are out in the open or on kelp	
Take only the larger abalone [<i>Size restrictions</i>]	
<ul style="list-style-type: none"> “Gran would get mad, Grandpa would get mad ... they wouldn't just let it go. Like, when I was a little boy, ...first time – it was okay. Tried it again? They were mad, because it's too small.” (Howard Humchitt) Minimum acceptable size for picking ~80 mm shell length (larger medium-sized shells) 	MR, DW, HH, FR, HER, SH, 2 anonymous
Take only what you need [<i>Total allowable catch restrictions</i>] and share what you have	
<ul style="list-style-type: none"> “But you know my grandfather always said, ‘Don't take more than what you need.’ You know, that's what, that's all I ever heard.” (William Gladstone Sr.) “I don't think there was ever really a set amount, because when he got in, he shared ... And the people that didn't have the boats, they were able to share with the guys that had boats.” (Hazel Emma Reid) 	DW, WGSr, GB, HER, GGH, 1 anonymous
Designated family fishing areas [<i>Designated access privileges, Territorial Use Rights for Fishing</i>]	
<ul style="list-style-type: none"> “I went to this one particular place, another family went to another place and another family to another place.” (Mike Reid) “You know ... each family ... had their own, real own places to go to.” (Gary Housty) 	MR, DW, HH, AR, GGH
Take only a portion of what is there [<i>Minimum density restrictions</i>]	
<ul style="list-style-type: none"> “... if this whole rock was filled right up, I'd only take a portion of that rock ... Then I look for another rock to get on. Make sure there's enough, so they'll recover again.” (Davie Wilson) 	MR, DW, SH
Picking associated with fishing other species [<i>Diverse portfolio of fished species</i>]	
<ul style="list-style-type: none"> Abalone and seaweed often picked together on low tides in spring 	MR, DW, WGSr, GB, HH, FR, HER, SH, 2 anonymous
Many pick abalone to eat while out fishing other species including black katy chiton, red urchin, herring, halibut, salmon, crabs and seagull eggs, and while fur trapping	
<ul style="list-style-type: none"> “Yah, we just row around the island and pick enough to eat and all these reefs outside here ... ” (while trapping river otter in the 1940s and 50s; Fred Reid) “Well it was like what the old people say ‘Once the tide goes out, the table's set!’” (Fred Reid) 	
Transplanting abalone [<i>Enhancement strategies</i>]	
<ul style="list-style-type: none"> “... they'd just take the small ones and transplant them into the area where they'd be able to go – once they're big enough – they could go out and harvest it.” (Davie Wilson) 	MR, DW, WGSr, 1 anonymous

Table 3

Spatial and temporal scale of ecological features for northern abalone compared with scale of stewardship and management practices [132,48,88].

Ecological feature and description	First Nations traditional stewardship practices	Canadian federal management practices
Depth distribution		
<ul style="list-style-type: none"> Majority distributed lower intertidal to 10 m chart datum depth Densities decrease with depth down to >10 m without sea otters Densities increase with depth as sea otter occupation time increases 	<ul style="list-style-type: none"> Fished only at lower low tides in spring and summer by hand or with hand tools, sometimes including a spear or gaff that could reach up to 2 m into the water Fished only within a portion of total depth range for abalone providing depth refuge 	<ul style="list-style-type: none"> Commercially fished by SCUBA diving at any time Fished throughout entire depth range for abalone providing no depth refuge
Fecundity		
<ul style="list-style-type: none"> Larger mature abalone have exponentially higher number of eggs 	<ul style="list-style-type: none"> Fished larger mature abalone >80 mm 	<ul style="list-style-type: none"> Minimum size limit of 90 mm, then 100 mm Illegal fishing fished all sizes
Spawning, larval dispersal and spatial distribution		
<ul style="list-style-type: none"> Broadcast spawning with ~1 week larval period, likely limiting larval dispersal to short distances (likely within ~1–10 km) particularly within kelp forest habitat Highly variable densities over small spatial scales Adult movement generally limited to <100 m 	<ul style="list-style-type: none"> Local-scale family-based fishing areas Took only what was needed for food and trade (limited scale compared to modern trade) Took only some in an area, leaving others to spawn Transplanted abalone from one place to another 	<ul style="list-style-type: none"> Coast-wide open access fishery for over two decades across ~25,000 km of the BC coastline Maximum annual and then license-based catch quotas later in fishery Intense fishing left few larger abalone in fished areas Illegal fishing further limited abundance, size and distribution

commercial fish and shellfish species, more recent federal legislation (i. e., [3]) and associated policies related to ecosystem-based management of fisheries and equitable access to diverse fishing licenses may provide avenues for restoring diversity and redundancy in future fisheries management.

4.2. Manage connectivity

Connectivity between nodes (e.g., species, habitats, actors, institutions) through linkages (e.g., species interactions, communication channels) facilitates exchange of goods and information that alter (increase or decrease) the spread of disturbance effects and facilitate recovery afterwards [20]. Traditional indigenous abalone fishing practices likely maintained ecological connectivity of abalone populations between habitat patches (Table 3). Fishing primarily took place in the low intertidal during the spring and summer by hand-picking and occasionally with a gaff or spear, leaving an extensive depth refuge for abalone and thus insurance against overfishing: “... we were told by the elders that you can't go and pick abalone when it's underwater ...” (Stephen Hunt, Heiltsuk Nation, Jan. 2012). “We used to just go pick what was above ... the water line, because they'd be crawling around in the kelp” (Martin Williams, Haida Nation, HMTK, Feb. 2009). Both Heiltsuk and Haida were also taught: “... we weren't allowed to take the small ones. We had to just take the big ones and you had to do it fast” (Fred Reid, Heiltsuk Nation, Jan. 2012). Heiltsuk experts confirmed that ‘big’ abalone were at least 80 mm in shell length and often bigger. Many abalone are mature by 50 mm shell length and all are mature by 70 mm, therefore this practice ensured opportunities for abalone to spawn before being picked.

Interconnectedness between people and place are acknowledged in the Heiltsuk truths of *Connection to nature, Creation, and Balance* [25]

and the Haida worldview that *Everything depends on everything else* [80]: “We’re probably responsible for both the sea otter population and the abalone population as people, so we need to recognize the need to bring a balance to them” (Mike Reid, Heiltsuk Nation, Jan. 2012). Trade between houses and villages within and among First Nations would have fostered strong horizontal linkages with regional connectivity supported by trade networks between coastal and interior First Nations [123,142]: “... we give [abalone] to the people inland for ... moose and all the other stuff. Trade and barter.” (Gus Brown, Heiltsuk Nation, Jan. 2012). Current evidence for pre-contact northern abalone economies suggests predominantly local and regional use and trade, with some evidence for shell trade of California abalone species into northern BC and Alaska, particularly post-contact [130]. During the First Nations indigenous regime, vertical linkages among governance structures were limited to levels of house-based social hierarchy due to a lack of broader central governance [141,142]. Although lack of a broader governance structure could have led to resource depletion should external demand outweigh local supply and breach stewardship protocols, overall markets and trade were much smaller in quantity, rate and geographic area compared to the latter part of the commercial abalone fishery. Pre-contact abalone fisheries were not subject to the same magnitude of external and often volatile national and international markets that drove high demands in modern commercial abalone fisheries [38,46,49].

In Canadian federal management, institutional connectivity between decision-making authorities, resource users, and resource conditions, was limited. Regional fisheries offices that implemented federal decisions had little communication with indigenous or other local communities. For almost four decades (1950s-1990), the modern commercial dive fishery occurred throughout the abalone depth range [48], leaving no depth refuge and reduced potential for ecological connectivity. No abalone population assessments were conducted until 1978, resulting in lack of connectivity between management decisions and ecological consequences until the last 12 years of the fisheries. These later feedbacks formed some vertical linkages between local-scale conditions and federal decision-making, but lags in management actions meant regulations were instituted too late to sustain the abalone fisheries. More recent inclusion of indigenous and conservation interests in abalone recovery processes offer potential for increasing and managing connectivity at local scales that better match abalone population dynamics (Table 3).

4.3. Manage slow variables and feedbacks

Variables in SESs change and interact at different timescales with slow variables underlying interactions of faster variables and affecting system resilience [20]. For the abalone SES, slow variables include sea otter range expansion, ocean conditions and climate change. The temporal continuity of abalone and sea otter use over millennia provided indirect evidence that indigenous systems accounted for slow variables and feedbacks, although direct evidence was lacking to show how they considered long-term changes in ocean conditions. The overarching Heiltsuk truth of *Stewardship* [25] and Haida ethics of *Respect, Responsibility, and Reciprocity* [36,80] helped foster the sustainable resource use protocol of ‘Take only what you need’ and maintained stewardship practices: “One of the things I remember when we were picking abalone is when either one of them [parents] would say, ‘That’s enough now’ ... that’s a real important, important thing to say, because that’s how we conserve.” (Gary Housty, Heiltsuk Nation, Jan. 2012) and “... grandmother used to say, ‘Only take enough for what you need. You don’t need to take any more than that’ ... ‘If you look after it, it will always be there’” (Herb Jones, Haida Nation, HMTK Mar. 2007). Heiltsuk were also taught to take only a proportion of what was available in any location (Table 2).

Slow variables are capable of creating regime shifts when they reach certain thresholds [20], such as ecological regime shifts triggered by the depletion or recovery of sea otters. These shifts dramatically changed

the ecosystem’s ability to produce and sustain abalone, likely affecting how much abalone was picked through time (Fig. 3; [87,150]). For example, more recent traditional abalone catch was likely greater than in pre-contact times when abundant sea otters reduced overall abalone density and size [87,88,150]. However, even in pre-contact times with sea otters, alternative hypotheses suggested that First Nations hunting pressure and human presence created areas with low to no sea otters near villages [34,126], potentially facilitating higher localized abalone abundances [126,135]. More extensive kelp forests associated with sea otters far from human occupation sites [94,151] would also have improved overall abalone habitat conditions and productivity during this time [88]. Ecological conditions under this regime could have fostered small-scale sustainable abalone fishing, although present-day experience of abalone declines related to sea otter recovery has precluded abalone fisheries in some areas of southeast Alaska (S. Ibarra, personal communications, 05 Nov 2018) while other areas are able to sustain higher abalone densities (M. Miller, personal communications, 06 Nov 2018). Underlying these ecological interactions, large-scale oceanographic regimes also likely influenced annual kelp production and abalone recruitment [41,111], in turn affecting abalone population dynamics.

No evidence was found to show consideration of slow variables in Canadian federal abalone management. The extirpation and subsequent re-introduction and recovery of sea otters was not considered in abalone management decisions and is acknowledged without associated management actions in the current federal abalone recovery plan [56]. The high abundance of abalone being fished that had accumulated over a century without sea otter predation or significant levels of fishing [87,137] was removed in less than two decades of intensive commercial fishing [48]. First Nations traditional and recreational fisheries with much lower fishing rates and spatially-restricted fishing practices may have remained sustainable in absence of the modern intensive commercial dive fishery.

4.4. Foster complex adaptive thinking

Understanding SESs as complex adaptive systems (CASs) can foster resilience by promoting holistic approaches to management that acknowledge uncertainties in system understanding and therefore the need for adaptive management [20]. Haida and Heiltsuk worldviews recognized the need for *Adapting to change* and *Balance*, understanding coupled human-ocean ecosystems as being prone to uncertainty and change [25,36,80]. A degree of ecological variability was expected: “One of the things he [father] mentioned ... which keeps triggering to me how important it is ... you go out, you don’t expect to get seaweed in that same place every time. And the reason for that is seaweed are so delicate, they don’t grow in certain ocean conditions” (Gary Housty, Heiltsuk Nation, Jan. 2012). For abalone, “You knew that when you were going there in that particular area, there would be populations of abalone there and you would be going home with some ... Some years some of the rocks had lots of populations on them and other years they didn’t” (Mike Reid, Heiltsuk Nation, Jan. 2012).

Close and regular physical connection between the well-being of people and places they lived created tight internal feedbacks such as learning from management actions. For example, if salmon abundance in one titleholder’s/chief’s rivers declined, negative effects would be immediate (e.g., hunger and/or starvation, loss of respect and titleholder/chief status). Yet the potlatch system provided some insurance against localized declines through gifts and trade between clans as the mechanism underlying the traditional principle of reciprocity [141,142]. Management errors were also made with consequences that could be long-lasting. Haidas have a story about how eulachon used to be abundant on Haida Gwaii in the past but “The eulachons were insulted and moved to the mainland, never to return ... That’s one story of where the respect wasn’t followed and we paid” (Haida Marine Traditional Knowledge Study participants et al., 2011a, p.23). For Heiltsuk today, “I

know our community is in ... dire need of sustenance from the sea. Our economy is crashed; we don't have a base economy anymore. Our base economy used to be the sea ... And when more of the food source disappears, it's harder to stay healthy" (Mike Reid, Heiltsuk Nation, Jan. 2012).

In contrast, the primary goal of Canadian federal abalone management was to maintain a relatively constant commercial production of abalone [14], thereby minimizing variability. Moreover, the inability to respond quickly to changing conditions limited effectiveness of management actions. For example, Heiltsuk reports of local abalone decline did not result in management actions and closed areas were ineffective due to lack of enforcement capacity. Failure of federal management to recognize the properties of CASs is evident in the lack of experimentation with alternative management tools and persistence of a centralized single species management approach with regional catch quotas.

4.5. Encourage learning and experimentation

Social learning, the modification of existing or acquisition of new and improved perspectives through social interactions, is a key process that enhances SES resilience [20]. Experimentation is an active form of management that can specifically enhance learning [66,144,148]. The Heiltsuk fundamental truth of *Knowledge* and Haida ethic of *Seeking wise counsel* reflect the importance of learning by experience and through intergenerational knowledge transmission [25,80]. In practice, Heiltsuk abalone experts learned abalone picking and stewardship protocols by going out to pick abalone with their grandparents, parents, aunt, uncles, siblings, elders and/or other community members: "Yeah, we have the punt, so ... we load the kids up and away we go" (H. Emma Reid, Heiltsuk Nation, Jan. 2012) and "... the whole family can work there [jarring abalone and processing other seafood]. And they all know what to do too, if we get lots of fish" (George Housty, Heiltsuk Nation, Jan. 2012). Regular observations of the land and sea while engaging in fishing activities facilitated intergenerational learning about ecological structures and processes (Table 4) that could then inform management practices. Heiltsuk experts were also taught about translocating abalone from one area to another to enhance access (Table 2) and potentially to restore locally depleted areas.

Learning and experimentation appeared to be limited under Canadian federal abalone management. When abalone monitoring and fisheries regulations were implemented in the last 12 years of the commercial dive fishery [132], they occurred without explicit learning opportunities. For example, fisheries closures for First Nations and recreational fishing, and for localized areas of low abalone abundance, were implemented but not monitored and therefore data was not available to inform future management actions [14].

4.6. Broaden participation

Active engagement of relevant actors in governance processes ranges from information exchange to co-production of knowledge, to sharing of decision making authority, facilitating adaptive response to surprise and uncertainty [20]. The Heiltsuk fundamental truth of *Sharing* [25] and Haida ethic of *Seeking wise counsel* encourage participation by sharing knowledge and resources in everyday life: "... depending on how many sacks of abalone we got, once it was taken in, a lot of it was given out to the people that couldn't make it out or especially with the elders – a lot of the abalone was given to the elders" (Davie Wilson, Heiltsuk Nation, Jan 2012). Heiltsuk experts learned to fish abalone as youth by picking abalone with more experienced family and community members. Many talked about working together to process seafood including abalone: "... it was an annual thing – abalone time, when you go out deer hunting – just about anything ... halibut ... beach line in Bella Bella, smokehouses were going, and everybody was down doing their fish. After school, that's where every, everybody would go." (Stephen Hunt, Heiltsuk Nation, Jan. 2012). Specifically for abalone processing, "... it was the

Table 4

Examples of traditional ecological knowledge about abalone shared by Heiltsuk experts, highlighted by some representative quotes. Experts are identified in the acknowledgements.

Ecological knowledge	Experts
Distribution and behavior	
<ul style="list-style-type: none"> Most abalone found at or below kelp line at very low tides on the rocks, sometimes under kelp and sometimes on the kelp itself: "I don't [know] why they'd know, but most of them were just under ... there's very few that you'd get above tide, and if they were in and above tide, they'd be in gullies." (Stephen Hunt) Abalone used to be commonly found on the kelp at low tide: "Well, we used to get them on kelps. It was so hot up there they lay on the kelps and you could just pick them. Don't have to pull them out." (Anthony Reid) Abalone moved up into shallower water when the temperature was warmer in spring and summer: "In the summer time they come quite a ways up." (Heiltsuk expert) Larger abalone more commonly found at the very low tide line Abalone commonly found in patches and clumped: "... some areas where they're real close together ... other areas would be a little bit farther apart ..." (Heiltsuk expert) Abalone used to be abundant in inside waters during grandparents' time Juvenile abalone in the intertidal mostly noted under kelp or in crevices 	WGSr; GB; HH; AR; SH; FR; HER; DW; 3 anonymous
Interactions with other species	
<ul style="list-style-type: none"> Abalone expected to be found with sea urchins: "... you can tell how close the abalone are to the surface by the urchin because the urchin are just below them all the time ... if you watch, if you look, the urchins are always just below the abalone." (Mike Reid) Kelp forest recovery would provide more shelter for fish and food for shellfish that grow faster when there is more kelp: "And they're finding that the animals that hang around ... the kelp forests are creating a lot of nutrients for the shellfish." (William Gladstone Sr.) Sea otters eat urchins, abalone, clams and Dungeness crab; Larger kelp forests noted where urchin abundances are low River otters and eagles also eat abalone, with river otters leaving shells in the shoreline forest: "We used to walk inside the bushes a bit and we used to find a whole bunch of abalone shells in there." (Davie Wilson) 	DW; WGSr; HH; HER; FR; MR; 2 anonymous

whole family. Go in and you clean them and then you used to go and get the old wooden fingernail brush ... And you grab the meat there and scrub ... It was all black on the abalone but when you were finished scrubbing it you'd get down, and you'd clean it, it looked like that [tan-coloured]. And then they used to jar them ..." (Stephen Hunt, Heiltsuk Nation, Jan. 2012). Participation from diverse interests can increase legitimacy and transparency, leading to greater cooperation, compliance, stability and resilience [20,114].

Outside of the federal agency, the only significant participation in Canadian federal fisheries management occurred when local community members discussed the locations of proposed local-scale commercial fishery closure areas with fisheries managers. In the last decade of the fishery, commercial fishers formed the Abalone Harvesters Association to communicate with and lobby the fisheries agency [48,132]. This relationship created power asymmetries in that commercial interests could influence management decisions, while First Nations and recreational interests had less influence.

4.7. Promote polycentric governance

Polycentric governance systems, in which nested governing authorities have some degree of independent management authority within a specific geographic area, can confer resilience and reduce management mistakes by better matching the scales of management with ecological and social processes of concern [20]. They can also enhance opportunities for participatory learning and experimentation across scales [20]. Traditional indigenous governance systems based on hereditary chiefs and/or multiple governing houses within each Nation were inherently polycentric. Local place-based proprietorship rights distributed governance authority among head titleholders or chiefs, providing insurance against local-scale effects of broad-scale disturbances or management errors (see Section 4.1). Contemporary indigenous governance structures involved in management of communal fisheries continue to recognize these traditional structures in decision-making through indigenous laws such as the Constitution of the Haida Nation. This polycentric governance system matched well with the spatial and temporal scales of ecological processes fostering abalone persistence (Table 3; see Section 4.1) and had potential to promote learning from local-scale experimentation with different management strategies such as translocations (see Section 4.5). Sharing of knowledge and lessons from different management practices within and among chiefs, houses and First Nations would have promoted social learning (see Sections 4.5 & 4.6).

In contrast, under centralized federal decision-making, coast-wide fishing regulations were mainly developed and instituted far from abalone fishing areas and coastal communities, creating scale mismatches with the smaller scale of dominant ecological processes (Table 3; *sensu* [39]). However, unlike the indigenous governance systems, regional regulations conferred potential ability to address broad-scale disturbances such as impacts of oceanic decadal oscillations and climate change. In the later years of the fishery, local federal representatives were given the authority to implement local area fisheries closures [14], representing limited power sharing within the federal fisheries agency, but not to external institutions or individuals.

5. Informing adaptive co-management for abalone

Given the high degree of alignment between characteristics of historical First Nations governance systems and theoretical resilience principles (Table 1), incorporating First Nations stewardship practices and protocols into contemporary fisheries governance could facilitate greater sustainability and resilience (also see Refs. [82,83,112,143]). Of course, the socio-economic context has changed substantially since pre-contact times when interactions were largely linked horizontally at local and regional scales with some wider trade networks. The maritime fur trade introduced the dramatic influence of global markets that remain relevant today, imposing new vertical linkages and strong external drivers (e.g., Ref. [74]). The challenges associated with the legacy effects of colonial dispossession [72,145], the move towards neoliberal privatization in Canadian fisheries [113] and current aboriginal rights regimes [106] all present very real challenges to designing and implementing a hybrid First Nations-Canadian federal governance model for abalone specifically, and Canadian fisheries more broadly. While these challenges should not be underplayed, the discussion below highlights recent changes in the institutional and governance arrangements for abalone in BC that signal potential for positive change through co-management approaches such as adaptive co-management.

Taking an ACM approach is one avenue to address the need to share power and responsibility between the state and First Nations who have constitutional rights to increased control over natural resource decisions in their traditional territories (c.f., [9,16,29]). This approach would be founded on collaborative joint decision-making between First Nations and the Canadian federal government. It could facilitate multi-scale

management using multiple knowledge sources including indigenous knowledge, and address the complex adaptive nature of SESs that is recognized in indigenous governance. Since the listing of abalone as a federally endangered species, innovative management institutions have developed for abalone recovery that could form a starting point for future co-management systems such as ACM. The conditions for successful ACM identified by Ref. [9] are drawn on to highlight critical considerations for building future environmental governance with First Nations in western Canada that is socially just and ecologically sustainable.

5.1. Current conditions that can foster successful adaptive co-management

Eight of the ten conditions for successful ACM [9] have largely been met or can be readily addressed in the contemporary abalone SES, particularly in relation to restoring small-scale traditional fisheries. The abalone SES is a *well-defined resource system* [1] centered on a relatively sedentary marine snail with limited larval dispersal [132] (Table 3), and traditional abalone fisheries are *small-scale* [2] in nature. Within this well-defined small-scale system, First Nations have *reasonably clear property rights* [3] to abalone and other coastal resources that are being leveraged in court cases and policy arenas (e.g., Refs. [65,81,136,146]). Examples of current co-management in northern BC include the Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site [37], Heiltsuk intertidal clam fishery [156], razor clam fishery on Haida Gwaii [157], Marine Planning Partnership between 16 BC coastal First Nations and the Province of BC [158], and Great Bear Rainforest Agreement [159,160].

Increasing co-management arrangements have led to increased *provision of training, capacity building, and resources* [4] particularly for coastal First Nations and also at provincial and federal scales. Many cross-scale relationships continue to support abalone recovery, including local partnerships and collaborative research projects. To foster resilience, First Nations traditional management can draw on an *adaptable portfolio of management measures* [5], including identified Heiltsuk fishing protocols and stewardship practices (Table 2) that are consistent with Haida and other coastal First Nations (e.g., Gitxaala Nation) practices for sustaining traditional abalone fisheries (Fig. 1; [69, 99,155]).

Within the current abalone SES, *clearly-defined social entities with shared interests* [6] in promoting abalone recovery are working together (Fig. 4; e.g., Haida Gwaii Marine Stewardship Group, Heiltsuk Sea Otter-Abalone Stewardship [57]), although specific definitions of recovery and local-scale livelihood objectives may differ. For example, many First Nations have objectives to restore abalone populations to self-sustaining levels that can support a traditional fishery [67], whereas federal recovery objectives are mainly ecological and currently defined only for areas not re-occupied by sea otters [56]. Furthermore, recovery is federally assessed based on population trends over a relatively short timeframe that is pre-defined as either 10 years or the timespan of three generations for the species, whichever is greater (SARA; [5]). The abalone generation time is 10 years therefore species status is gauged over the previous three decades, thus discounting profound effects of the ecological regime shifts that have occurred over the last two centuries (Fig. 3; [74,87]).

Actors within abalone recovery institutions *share and draw upon a plurality of knowledge systems and sources* [7] recognizing that complementarities between indigenous and western science knowledge can contribute to system understanding, trust-building and learning (e.g., Refs. [87,124]). Heiltsuk and Haida, among other First Nations, have documented traditional knowledge and supported and conducted research in ecology, archaeology, and social sciences focused on culturally important species including abalone [69,87,88,108,131]. Although federal legislation requires inclusion of Aboriginal Traditional Knowledge (ATK) in species at risk processes [5] and the Haida Nation

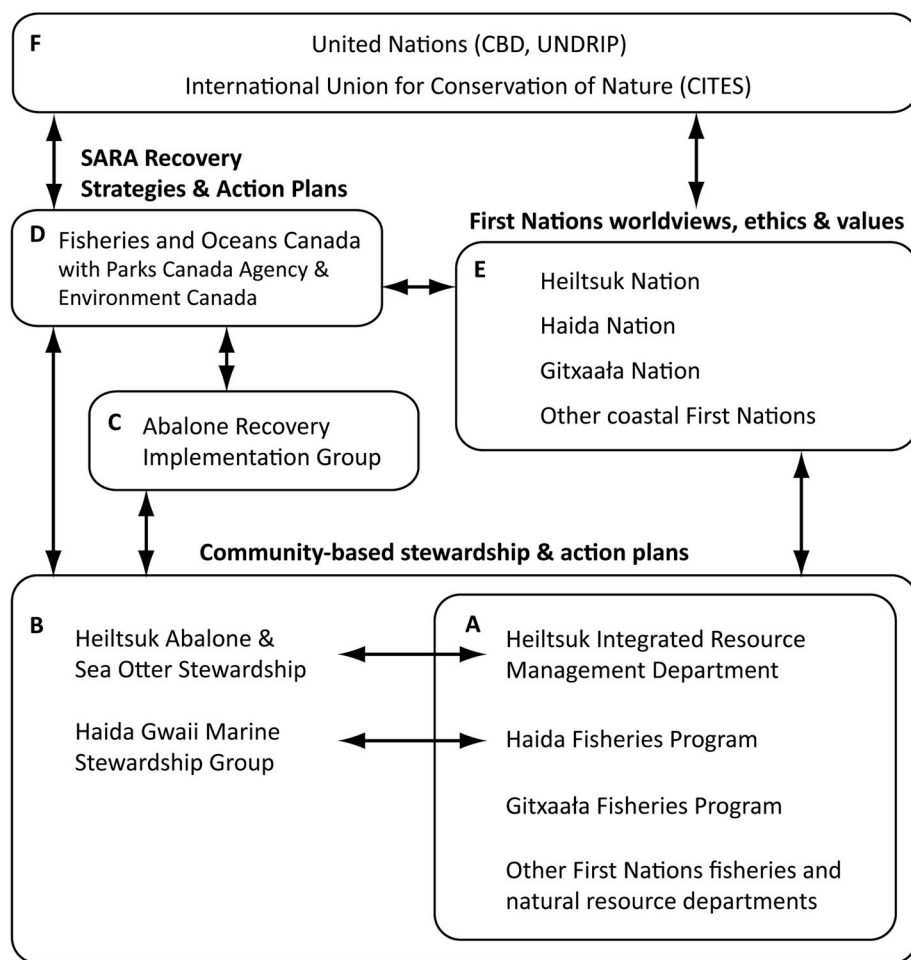


Fig. 4. Actors, institutions and multi-scale linkages governing abalone recovery in coastal BC: (A) Locally, First Nations laws and governance oversee abalone recovery initiatives and First Nations natural resource organizations communicate and learn within and among each other; (B) Local-scale multi-interest and/or multi-species working groups led by First Nations organizations develop and implement community-based action plans; (C) Regionally, a technical advisory group initiated by Canada's federal fisheries agency engages in regional learning by sharing knowledge, expertise, and information; (D) Nationally, Canada's federal fisheries and other agencies are mandated to protect and conserve abalone under Canada's Species at Risk Act (SARA); (E) First Nations governments communicate and learn between and among nations, guided by their respective worldviews, ethics and values; and (F) Internationally, Canada's endorsement of the Convention on Biological Diversity (CBD), Convention on the International Trade of Endangered Species (CITES) and United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), establish overarching expectations for Canada's decision-making related to species conservation and First Nations.

contributed ATK to federal abalone recovery plans [56], overall implementation to include ATK has been slow. A few *key leaders prepared to champion the process* [8] have emerged in some Nations, including Haida Nation representatives who have championed continuous engagement in abalone conservation with government and community partners since 2000. For the most part, however, representatives of governing institutions at all scales are frequently changing, requiring continual relationship building (c.f., [152]).

The final two conditions, *national and regional policy environment explicitly supportive of collaborative management efforts* [9] and *commitment to support a long-term institution-building process* [10], are currently two key barriers to overcome because they require short- and long-term shifts in abalone management authority and explicit transformation of a centralized federal governance system to one that is polycentric. Although some longer-term policy frameworks for fisheries co-management institution-building currently exist, such as DFO's Aboriginal Aquatic Resource and Oceans Management Program [161] and Aboriginal Fisheries Strategy [162], political will to fully implement fisheries co-management in Canada is lacking. In our remaining discussion, we highlight considerations that address power-sharing, trust and restoration of traditional abalone fisheries in relation to current governance institutions for abalone recovery.

5.2. Addressing underlying power dynamics

Coastal First Nations in BC are re-asserting authority to make resource stewardship decisions within their traditional territories, including for abalone (e.g. Refs. [65,67,81,146]): "The big thing, like we say all over on First Nations within BC, we have to be able to manage it"

(Stephen Hunt, Heiltsuk Nation, Jan. 2012). Thus, underlying power dynamics and biases may be the most critical challenge facing development of effective forms of equitable management including ACM. In spite of its promising structure, decision-making authority in contemporary governance of abalone recovery largely remains federal, limiting the ability of First Nations to enact 'legal' change. Shifting management authority to appropriate spatial scales with First Nations (e.g., traditional territories) through negotiated agreements is required to move beyond the *status quo* and could be enabled through existing Canadian legislation (i.e., [1–5]; c.f., [12]). Finer spatial scale management has been implemented for some shellfish fisheries such as sea cucumber, sea urchin and geoduck clams, as well as co-management arrangements with First Nations for some intertidal clams (see Section 5.1). Coastal First Nations are in the process of carving out these co-management initiatives for fisheries, demonstrating how the well-being and values of coastal communities can be incorporated into local-scale management in spite of the contemporary neoliberal fisheries management context [113].

In Canada, movement towards power sharing and co-management with indigenous peoples by territorial, provincial and federal agencies has been evident since the 1980s in the Arctic [8,86] and 1990s in BC (see examples in Section 5.1). However, the natural resource institutions within which decisions are implemented remain largely operationalized under state policies, regulations and bureaucracies. For example, an integrated fisheries management framework for new proposed commercial fisheries within the Beaufort Sea allows joint decision-making by indigenous Inuvialuit, federal agencies and multiple interests in the western Arctic, but these new fisheries would follow established federal policies [12]. Indigenous co-management of commercial fisheries

globally, including in New Zealand and Australia, face similar issues of power-sharing by state agencies [97,145]. Canadian federal agencies continue to resist coastal First Nations' constitutional rights to decision-making authority over many marine resources within their traditional territories, spurring multiple legal challenges (see Section 5.2). On the other hand, there are signs of progress in some natural resource institutions that could increasingly support and facilitate community-driven decision-making such as in Canada's Northwest Territories (NWT). Two examples include changes in the Statutes of NWT Wildlife Act and territorial approval of a community-based conservation plan for caribou [42].

In some cases, indigenous communities have enacted indigenous laws to implement management actions where state policies have failed to conserve or monitor species at the local-scale. For example, First Nations on the BC central coast, including the Heiltsuk Nation, designed and implemented Dungeness crab fishery closures and surveys, and rockfish surveys to monitor effectiveness of area closures in deliberative experimentation and learning [13,62,63]. Creative solutions that circumvented centralized governance institutions via direct negotiations between First Nations and commercial fisheries resource users enabled stronger conservation actions, such as for sea cucumbers on the BC central coast [85] and herring on Haida Gwaii and the BC central coast [65,81]. Negotiated agreements and management plans (e.g., Gwaii Haanas Gina 'Waadluxan KilGulhGa Land-Sea-People Management Plan [37]) can provide decision-making structures and objectives that make progress towards ACM in fisheries and other marine management issues.

5.3. Building trust for hybrid governance

Participation and trust building towards true hybrid governance must overcome a long history of deep mistrust between actors and institutions (c.f., [122]). Despite best intentions, differing perceptions about the validity of traditional and western scientific knowledge by different actors have often led to mistrust that limits the effective use and synthesis of knowledge sources to inform stewardship actions. For example, these undercurrents limited progress for Dall's sheep conservation by co-management boards in the Yukon territory in northwestern Canada [103] and herring co-management in northern BC [65,81,121,146]. Trust-building and a commitment to overcome power asymmetries is required at all scales of management, even locally where dominant voices and power relations in a community can marginalize others [29,33,54]. In academia, research projects like these collaborative abalone SES interviews can build trust by co-designing and co-implementing research projects that are based on free, prior and informed consent of participants, and community control of the co-produced knowledge [13,51,87,124]. Similarly, collaborative initiatives between academic institutions, management agencies and the Haida Nation (e.g., Ocean Tipping Points [163] and Ocean Modeling Forum [164]) provided opportunities to explore solutions to issues such as management of herring.

Building trust takes time and lack of long-term funding committed to institution and capacity building within and across all governance scales will be an on-going challenge. For current abalone recovery, institutions at all scales are primarily supported by short-term federal funding sources. This situation reinforces underlying power asymmetries, undermines trust-building and creates funding instability at the whim of changing government priorities. For example, reduced federal priority for marine conservation from 2011-2015 resulted in loss of regional capacity and funding that led to a hiatus of the Abalone Recovery Implementation Group (Fig. 4). However, in spite of short-term cycles, federal sources have supported Haida-led community-based abalone stewardship activities on Haida Gwaii since 2000 [131]. Financially, sustaining long-term institution building, particularly to support on-going monitoring, assessment, experimentation and social learning, is needed for effective co-management including ACM, but has potentially high costs that may or may not be balanced by long-term SES

benefits [9,120].

5.4. Restoring traditional abalone fisheries

Restoration of traditional abalone fisheries is a key goal of many coastal First Nations including the Haida and Heiltsuk Nations [67]. Adaptive management is needed to support this restoration: "It's got to be managed so that it'll be there ... if there's plentiful enough for every homeowner to have a feed ... maybe once or twice a year ... Do a feed at a time. Yeah. And don't go overboard when you ... go out and get them" (Stephen Hunt, Heiltsuk Nation, Jan 2012). Heiltsuk experts emphasized that enforcement of fishing protocols and monitoring of both abalone populations and fishing activities were critical management measures: "We've got to let it come back first. How much is out there now? And when was the last poacher out there? We don't know that yet" (Stephen Hunt, Heiltsuk Nation, Jan. 2012). If a traditional fishery were opened, "... they would have to make sure that the fisheries guardians are out ... [while people are] harvesting ... And they've got to report in how much they took in altogether" (Davie Wilson, Heiltsuk Nation, Jan. 2012). In spite of the local nature of future traditional abalone fisheries, Heiltsuk experts forewarned about the need to mitigate against external pressures from high-value black markets: "Some people will go nuts out there on it. And then they will sell it, because they know it's valuable" (Heiltsuk expert, Jan. 2012).

Some Haida and Heiltsuk experts also recommended the need for abalone stewardship areas to support more intensive monitoring and research and potential establishment of areas where no abalone fishing would be allowed as insurance for continuing recovery. Haida have implemented Abalone Stewardship Areas since 2003 [67,131]. For Heiltsuk, contemporary implementation of area closures is considered challenging because people are now concentrated in one larger community versus smaller communities throughout the territory: "... it'd be really hard to try and pick an area to close because families went to certain areas. If we chose one area to close, it might be one whole family's area of normal harvest. I don't think I'd want to pick something that impacted a family because in today's day and age, the fuel costs are so high and forcing the family to go elsewhere looking would be very difficult" (Mike Reid, Heiltsuk Nation, Jan. 2012). Other management considerations identified were to retire the existing commercial abalone fishing licenses to exclude any potential for re-opening unsustainable commercial fisheries, and predator control specifically via restoration of sea otter hunting and river otter trapping.

Abalone stewardship and recovery strategies have already created new opportunities for ACM and other forms of co-management including experimentation and learning between First Nations and federal agencies. For example, abalone rebuilding strategies have been collaboratively tested, including aggregating mature abalone to enhance fertilization success, outplanting hatchery-raised juvenile abalone to enhance recruitment, and establishing stewardship areas that are closed to sea urchin commercial fishing to reduce potential for poaching [79,131]: "... when they're broadcasting their spawn ... that spawn has a chance to connect somehow - maybe that means intervening a little bit and bringing the abalone into a safe structure of some type that their spawn at least connects ..." (Mike Reid, Heiltsuk Nation, Jan. 2012). Current management experimentation in a collaborative Haida-federal pilot kelp forest restoration project [110] was inspired by recent ecological insights into abalone-sea otter interactions [88], and traditional management practices (Table 2) present alternative management strategies that can be experimentally tested for future coastal fisheries.

Future scenarios for polycentric governance of abalone with multiple centers of decision-making are possible (c.f., [107,109,115]). A key challenge will be to collaboratively determine the scope and mechanism (s) for shifting decision-making authority to coastal First Nations. For example, all scales of governance could collaboratively establish spatially-explicit abalone population thresholds within which First Nations would have decision-making authority in their traditional

territories. Reaching or crossing these thresholds could trigger management actions at different scales to minimize risks of scale mismatch for conservation actions [39]. Strong horizontal linkages and feedbacks between coastal First Nations and supporting regional and national bridging institutions could help mitigate these risks. Innovative institutional arrangements to support such scaled thresholds could promote management experimentation and social learning to foster resilience and sustainability of traditional abalone fisheries as the coastal seascape is altered by sea otter recovery, climate change and other disturbances. Lessons learned from this abalone fisheries 'management experiment' could inform development of future First Nations-Canadian federal governance and management of other coastal fisheries.

6. Conclusion

I took my granddaughter out with me one day and ... showed her abalone and she said, 'What do you do with these?' (Davie Wilson, Heiltsuk Nation, Jan 2011).

Canadian federal abalone fisheries governance led to an ecological and cultural conservation crisis for abalone and people in less than four decades of commercial fishing. Generations of coastal First Nations youth now have no cultural connection to abalone because they have not been able to learn how to care for, pick and use abalone from their elders. The damage due to loss of access to this cultural keystone species is immeasurable: "... everyone looked forward to the first abalone of the year. Ah, I have children now who haven't even had abalone and now I have grandchildren ..." (Mike Reid, Heiltsuk Nation, Jan. 2012). For elders: "... when older people were getting ready to move on to the next journey, they always wished for abalone ... I would've liked to ... say, 'Oh, no problem. I'll send somebody out and get one for you,' but you can't" (Diane Brown, Haida Nation, HMTK, May 2007). And disruption of intergenerational knowledge transmission is not limited to abalone: "How many kids do you think go out on the land today? Not very many" (Heiltsuk expert, Jan. 2012).

For abalone governance and stewardship, achieving social justice requires accounting for SES complexity and past regime shifts. Abalone today may actually be at similar or higher abundances than in pre-contact times when its primary predator, sea otter, was still present [87,138,150]. If we accept this interpretation to be true, we can and should work together to restore traditional abalone fisheries that strive to be resilient and sustainable for abalone and people into the future. This social-ecological condition motivates deliberate transformation towards a collaborative First Nations-Canadian federal governance regime for abalone specifically, and nearshore fisheries more broadly [85].

'Why are you letting the white man control you?' (Stephen Hunt, Heiltsuk Nation, Jan. 2012)

In indigenous societies throughout the world, close connections between people and place facilitated social learning and experimentation that informed sustainable resource use practices [16,24,144]. Finding ways to navigate beyond centralized state problem-solving and decision-making is needed for successful co-governance of coastal fisheries with indigenous peoples in BC and beyond. Concurrent with this re-assertion of indigenous stewardship is the need for innovative approaches to evaluate success at meeting ecological, cultural, social, economic, and governance goals and objectives, and to account for tradeoffs in alternative management decisions (e.g., Refs. [84,118]). Re-establishing indigenous authority to use, manage and conserve coastal and marine resources, embedded within coupled human-ocean systems, could help navigate towards a socially just and ecologically sustainable operating space for the world's oceans and humanity.

Declaration of competing interest

None.

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