Indigenous Systems of Management for Culturally and Ecologically Resilient Pacific Salmon (*Oncorhynchus* spp.) Fisheries

WILLIAM I. ATLAS, NATALIE C. BAN, JONATHAN W. MOORE, ADRIAN M. TUOHY, SPENCER GREENING, ANDREA J. REID, NICOLE MORVEN, ELROY WHITE, WILLIAM G. HOUSTY, JESS A. HOUSTY, CHRISTINA N. SERVICE, LARRY GREBA, SAM HARRISON, CIARA SHARPE, KATHERINE I. R. BUTTS, WILLIAM M. SHEPERT, ELISSA SWEENEY-BERGEN, DONNA MACINTYRE, MATTHEW R. SLOAT, AND KATRINA CONNORS

*Pacific salmon (*Oncorhynchus *spp.) are at the center of social–ecological systems that have supported Indigenous peoples around the North Pacific Rim since time immemorial. Through generations of interdependence with salmon, Indigenous Peoples developed sophisticated systems of management involving cultural and spiritual beliefs, and stewardship practices. Colonization radically altered these social–ecological systems, disrupting Indigenous management, consolidating authority within colonial governments, and moving most harvest into mixed-stock fisheries. We review Indigenous management of salmon, including selective fishing technologies, harvest practices, and governance grounded in multigenerational place-based knowledge. These systems and practices showcase pathways for sustained productivity and resilience in contemporary salmon fisheries. Contrasting Indigenous systems with contemporary management, we document vulnerabilities of colonial governance and harvest management that have contributed to declining salmon fisheries in many locations. We suggest that revitalizing traditional systems of salmon management can improve prospects for sustainable fisheries and healthy fishing communities and identify opportunities for their resurgence.*

Keywords: traditional knowledge, salmon, sustainable fisheries, mixed-stock fisheries, Indigenous governance

In an era of escalating anthropogenic threats to global biodiversity, there is a need to understand the diversity of human–nature relationships and identify stewardship practices and knowledge that can foster resilient social–ecological systems (Bennett et al. 2016). There is growing recognition that the ecological knowledge and stewardship practices of Indigenous peoples can offer pathways for effective and socially just conservation and resource management (Turner and Berkes 2006, Polfus et al. 2016, Ban et al. 2018, Artelle et al. 2019). For example, Indigenous peoples manage more than 40% of Earth's ecologically intact landscapes (Garnett et al. 2018), and Indigenous-managed lands have similarly high vertebrate biodiversity to parks and protected areas (Schuster et al. 2019). The knowledge and legal jurisdiction of Indigenous communities has also benefited conservation and recovery of species ranging from grizzly bears (*Ursus arctos horribilis*) to Dungeness crabs (*Metacarcinus magister*; e.g., Service et al. 2014, Frid et al. 2016, Kitasoo/Xai'xais First Nation 2018).

Pacific salmon (*Oncorhynchus* spp.) form the foundation of social–ecological systems encompassing communities from California to Kamchatka and Northern Japan (Yoshiyama 1999, Muckle 2007, Tabarev 2011). Indigenous peoples of the Northern Pacific Rim have harvested salmon for subsistence and livelihoods for more than 10,000 years (Cannon and Yang 2006, Muckle 2007). Archaeological and ethnographic evidence points to long-term intensive use of salmon (Campbell and Butler 2010, Cannon et al. 2011, Ritchie and Angelbeck 2020) with deliberate and well-honed systems of salmon management (Carpenter et al. 2000, Turner and Berkes 2006, Menzies and Butler 2007). Resource management systems are the sum of the social and cultural processes that encode norms for the use of natural resources, and the technologies and understandings that

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underpin management actions (Lertzman 2009). Indigenous management systems promoted the sustained productivity of precolonial salmon fisheries, which likely rivaled early colonial commercial fisheries in their scale (e.g., Craig and Hacker 1940, Glavin 1996, Meengs and Lackey 2005). These systems were rooted in traditional laws, cultural and spiritual beliefs, and management practices that promoted sustained abundance and access to wild salmon by limiting the risks of overharvest and population collapse (Swezey and Heizer 1977, Harris 2001, Haggan et al. 2006, Ritchie and Angelbeck 2020).

In Canada and the United States, Indigenous management of Pacific salmon was painfully and intentionally disrupted beginning in the mid-nineteenth century and replaced by colonial government authority. This transformation fundamentally altered the scales, methods, and locations of salmon harvesting, stripping rights and jurisdiction from Indigenous people and beginning a struggle for access and governance authority that continues to this day (Higgs 1982, Newell 1993, Harris 2001). However, many modern salmon fisheries are struggling to provide sustainable social, economic, and ecological benefits; for example, in Canada, the number of commercial licenses has decreased, catches have crashed, and many salmon populations face conservation risks (Price et al. 2017, Walters et al. 2019).

Despite the destructive impacts of colonization, Indigenous culture and knowledge are resurgent in Canada and the United States. Salmon remain integral to the food security, cultural practices, health, and economy of Indigenous peoples (Chan et al. 2011, Marushka et al. 2019, Steel 2020). Although different legal and societal circumstances have contributed to this resurgence across North America, Indigenous communities are increasingly responsible for the management of fisheries, and stewardship of lands and natural resources within their homelands. Amid this ongoing transformation there is increasing recognition that Indigenous knowledge and management systems can contribute to restoring the productivity and resilience of aquatic ecosystems and fisheries (Turner and Berkes 2006, Lepofsky and Caldwell 2013, Salomon et al. 2019). Fisheries science and management should therefore seek solutions beyond the bounds of fisheries science, learning from and empowering Indigenous knowledge to benefit salmon-dependent communities and ecosystems (Reid et al. 2020).

In the present article, we provide examples of Indigenous salmon management systems, discussing the scale, methods and values that guide Indigenous management of salmon and contrasting them with contemporary fisheries management. We also give examples of how these technologies are being brought back to life, highlighting opportunities for their application to contemporary management and cogovernance challenges (supplemental table S1). Having supported vibrant salmon-dependent communities for millennia before European settlement, we believe that revitalizing Indigenous salmon management systems can support long-term opportunities for equitable and sustainable harvest of wild salmon across western North America.

Contemporary salmon management: History and challenges to sustainability

The changes in governance, technology, and fishery management that began with European colonization of western North America in the nineteenth century gave rise to a commercial fishing industry that has shaped the economics and fate of salmon fisheries in profound ways. In the present article, we review some shifts in salmon management systems and the social and ecological issues they have posed. Given the diversity of modern and traditional salmon fisheries, it is beyond the scope of this article to provide a comprehensive analysis of their respective strengths and weaknesses. Indeed, there are commercial salmon fisheries that are archetypes of sustainable natural resources extraction and management, such as the Bristol Bay, Alaska, sockeye salmon fishery (Hilborn et al. 2003). Instead, we identify a set of frequent challenges to the sustainability of contemporary salmon fisheries and point to areas in which Indigenous management systems, knowledge, and harvest technologies can provide pathways to sustainability.

The commercialization of fisheries transformed the values and understandings guiding fisheries management, because colonial governments and fishing companies sought to develop and extract resources for global markets (Newell 1993, Yoshiyama 1999, Harris 2001). The rise of combustion engines, monofilament nets, and other fishing technologies powered increasingly effective salmon fishing, whereas canning and refrigeration allowed huge quantities of salmon to be packed and shipped to global markets (Newell 1993, Meggs 1991, Taylor 1999, Morishima and Henry 2000). In the rush to extract wealth from the watersheds of the Pacific Northwest, salmon habitats were damaged, sometimes irreparably, by logging, mining, diking, dam construction and other destructive land use (Baird 1875, Stone 1892, Miller 2010). Habitat destruction coupled with extreme harvest pressure precipitated declines in salmon populations from the Skeena in British Columbia (BC) to the Sacramento River in California (Ricker and Smith 1975, Higgs 1982, Ricker 1987, Yoshiyama 1999).

Among the most profound transformations in management brought on by colonization was the shift to mixed-stock ocean fisheries, which gradually replaced Indigenous in-river salmon fisheries as the primary method and scale of harvest (Cobb 1921, Higgs 1982, Morishima and Henry 2000). Mixed-stock fisheries intercept fish during their oceanic feeding migrations, harvesting salmon from numerous populations. Many salmon in the Eastern Pacific traverse US, Canadian, and international waters during their migratory life cycle, and fish are routinely harvested outside their country and Indigenous territory of origin (PSC 2020a).

Therefore, the migratory life cycle of salmon poses additional challenges to sustainability by creating mismatches between management decisions, fishery opportunities, and the biologically relevant processes that support salmon populations (e.g., river disturbance, rainfall and temperature, and ocean climate and productivity; Bottom et al. 2009, Malick et al. 2017). These mismatches have created adverse downstream consequences for people, ecosystems, and salmon through intensive mixed-stock harvest, resource development, land use, and overproduction of hatchery salmon by industrial nations around the Pacific Rim (e.g., Moore et al. 2015, Sexton et al. 2020, Vierros et al. 2020). Supporting greater engagement and participation in monitoring and management among Indigenous peoples and local communities is one avenue toward alleviating the negative impacts of these scale mismatches (Herse et al. 2020).

Managers have long recognized that mixed-stock harvest can undermine the sustainability of salmon fisheries, if smaller or less productive populations are harvested in fisheries targeting abundant stocks (Ricker 1973, PFMC 1978, Hilborn 1985). In these instances, overharvest can threaten the long-term viability of wild salmon populations and fisheries (e.g., Connors et al. 2019). Management measures to limit the impacts of these mixed-stock fisheries may also be harmful to fishing communities if they reduce fishing opportunity for locally abundant populations (Martin 2008, Langdon 2015, Walters et al. 2019). By the 1960s, concerns over declining salmon runs drove efforts to curb overcapitalization through license privatization, consolidation, and buybacks efforts in both Canada and the United States (Newell 1993, Brown 2005, Carothers 2010). Efforts to shrink the commercial fishing fleet ultimately reduced the number of commercial licenses and fishing boats in remote and Indigenous communities, undermining access to salmon-fishing livelihoods and food security (Carothers 2010, Langdon 2015, Angel 2017, Steel 2020). The social–ecological and economic viability of commercial salmon fisheries has been further undermined by infrequent or unpredictable openings (e.g., Martin 2008, Walters et al. 2019), fluctuations in prices driven by global markets, and management objectives that are often narrowly focused on maintaining maximum sustainable yields (Adkinson and Finney 2003, Bjorndal et al. 2003, Hilborn 2006, Healey 2009).

Responding to the need for cooperative management of ocean salmon fisheries between the United States and Canada, the Pacific Salmon Treaty (PST) was first ratified in 1985 and was updated in 2019 to enable bilateral management of salmon fisheries (PSC 2020b). Although the treaty seeks to foster equitable and transparent management of salmon between the two countries, the legal primacy of this agreement has shaped management objectives, allocation, and monitoring in both countries, often with limited input from salmon-dependent communities (Knight 2000, Vierros et al. 2020). Therefore, contemporary salmon management governs resource use across vast spatial scales, and decision-making flows downstream from centralized government authorities operating under bilateral treaty arrangements. Centralized systems of command and control resource management decouple local resource users from management decisions, limiting the ability of local knowledge and values to penetrate decision making processes (Holling and Meffe 1996), thereby reducing access and agency within local communities that depend on fisheries or other natural resources for their livelihoods (figure 1; Leal 1998, Healey 2009, Pinkerton et al. 2014).

The management of fisheries in both countries is challenged by a lack of baseline data on salmon abundance, run timing, and harvest rates in mixed-stock fisheries (Halupka et al. 2003, Malick et al. 2017, Price et al. 2017). Monitoring salmon populations across the vast western North American range of salmon is costly and logistically challenging, and in many regions most populations are currently unmonitored (e.g., Connors et al. 2018). Harvest rates, migration timing, and marine distributions for many stocks are inferred from nearby intensively monitored populations—often hatchery-reared salmon—that are marked with coded-wire tags and adipose fin clips and recovered during fishery monitoring and spawner enumeration (e.g., Morris et al. 2007, English et al. 2018, Shelton et al. 2019). However, given the limited number of indicator stocks in many areas of BC and Alaska, and evidence that migration timing, routes, and fishery interceptions may vary considerably between proximal stocks, estimates of harvest inferred from indicator populations may yield unreliable estimates of harvest for many populations (Beacham et al. 2020).

Habitat loss, climate-driven declines in ocean survival, and efforts to minimize impacts on populations with variable conservation status have eroded salmon fishing economies (Martin 2008, Angel 2017, BCWSAB 2018). Given these challenges and risks of mixed-stock fisheries, managers have recently prioritized precaution and reduced salmon fishery openings and harvest quotas (Walters et al. 2019, Fisheries and Oceans Canada 2019a). In fact, in 2019, the total quantity and landed value of salmon caught in the Canadian commercial fishery was the lowest on record and commercial fisheries were closed along much of the BC coast (Fisheries and Oceans Canada 2019b).

Traditional Management Systems

Indigenous management systems offer alternatives to contemporary resource management because of differences in cultural values and knowledge that have motivated their development. Whereas colonial societies have largely emphasized extraction of resources for short-term profit, resource management by Indigenous peoples has tended to emphasize multigenerational sustenance and reciprocity (Trosper 2002, Ban et al. 2019, Curran et al. 2020). Indigenous management systems, guided by traditional knowledge and law, also share several key attributes with contemporary resource management; for example, both are guided by knowledge gained through the continuous

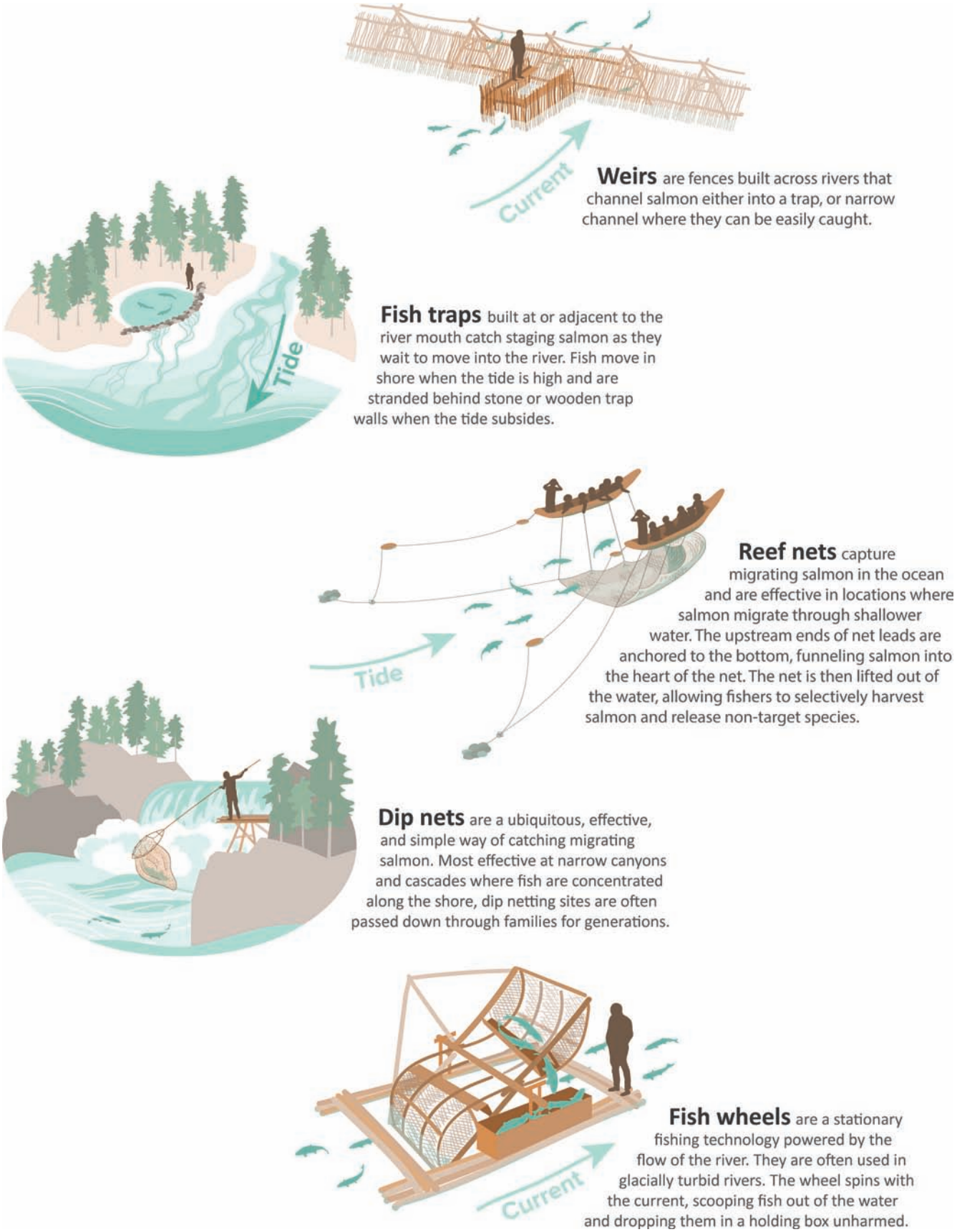


Figure 1. A variety of traditional Indigenous fishing technologies and details of their use.

observation of natural systems (Carpenter et al. 2000, Turner and Berkes 2006, Lertzman 2009). However, key differences exist in the scale, time horizons, and organizational hierarchies of Indigenous and contemporary resource management systems (figure 1).

Indigenous peoples of the Pacific Northwest have long established and complex institutions of governance that emphasize the conscious protection of the nonhuman world. Each nation or tribe possesses unique laws and stewardship practices. Despite their unique knowledge and traditions, Indigenous understandings of ecosystems, and the management systems that flow from traditional knowledge tend to incorporate a much deeper recognition of the connection between humans and ecosystems, placing humans within a broader family of life (Walens 1981, Berkes et al. 2000, Salmón 2000, Claxton and Price 2020). Indigenous laws are derived from millennia of experiences in very specific geographies that have shaped their morals, values, and traditional knowledge (Turner et al. 2000, Berkes 2012, Turner 2014). These laws have laid the foundation for Indigenous governance and decision-making.

Resilient resource management systems begin with governance structures that sufficiently address the health of ecosystems within legal and political institutions (Nadasdy 2003, Turner and Berkes 2006). On the Northwest Coast, high human population density created acute awareness among precolonial Indigenous peoples of the pressures their food and material resources faced, as well as the detriment of waste (Anderson 1996). In the case of salmon, this awareness guided stewardship and ceremonial practices that reflected the place of salmon as a vital economic and subsistence resource. Just as global economics shape the values and actions of colonial political institutions, salmon fisheries have shaped Indigenous institutions. Contrasting maximum sustainable yields–based fisheries management, Indigenous fisheries took what was needed for subsistence and trade, curtailed harvest when these needs had been met, and regulated access to reduce the risk of overharvest (Harris 2001).

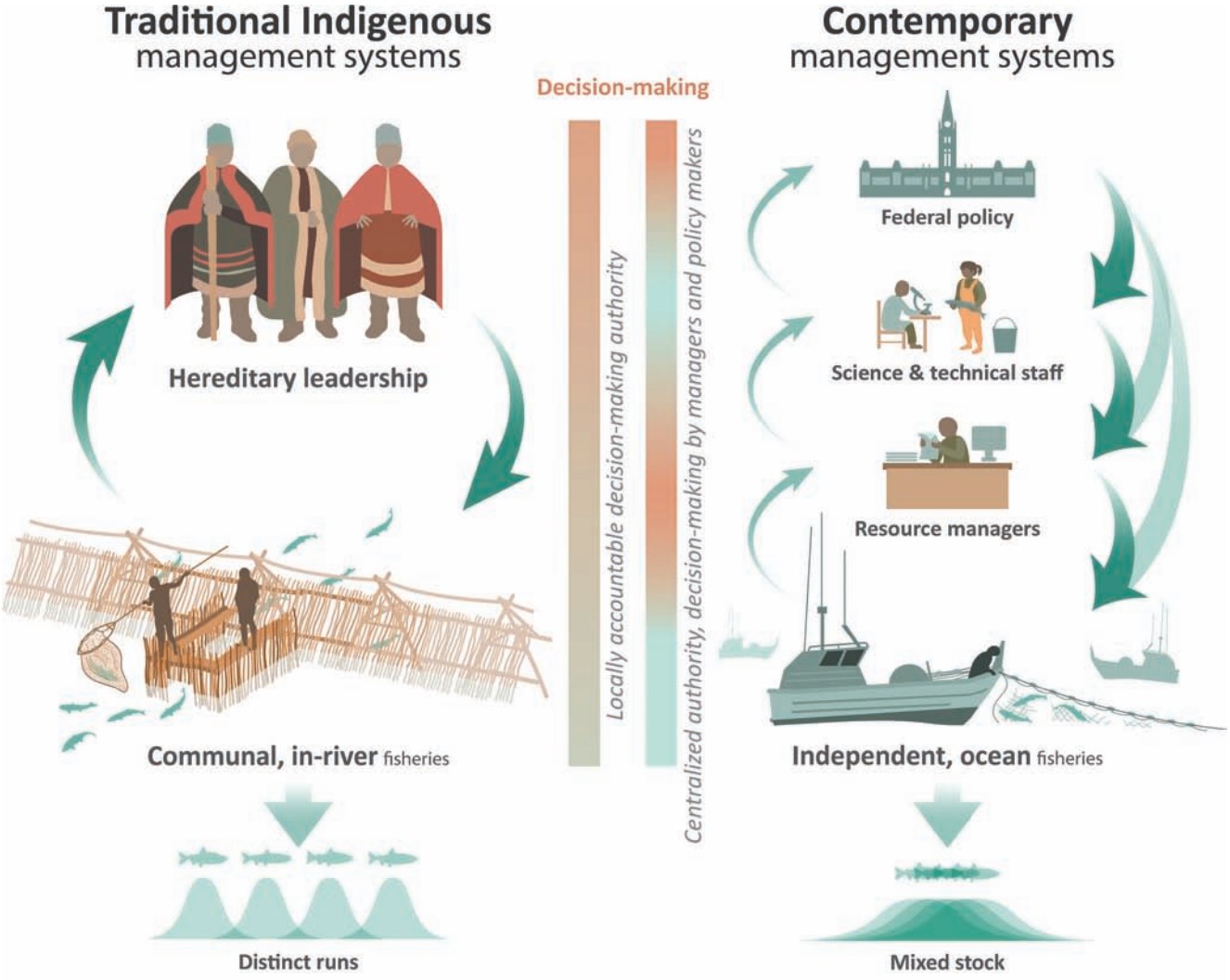
In each Indigenous community, oral histories about human and nonhuman relationships lay the foundation for how to conduct one's self in the natural world (Anderson 1996, Cajete 1999, 2018, Turner and Berkes 2006, White 2011). These stories provide "original instructions" for how to care and relate to the land (Nelson and Shilling 2018). Spiritual lessons and cultural beliefs act as the glue, holding together these systems and fostering direct emotional involvement with natural resources (Anderson 1996).

Indigenous management systems are placed based and typically govern resource management decisions locally, controlling resource access, land use, and stewardship decisions across ancestral territories (Leal 1998, Turner et al. 2000, Berkes 2012). These placed-based systems of Indigenous salmon management contrasts sharply with most contemporary sport and commercial fisheries (Gayeski et al. 2018b), where fleets or harvesters are highly mobile and can track changes in resource abundance, limiting their sensitivity to localized population declines (e.g., Schindler et al. 2010, Pitman et al. 2019). Proprietary access rights and hereditary management authority were traditionally upheld through family connections and systems of public reciprocity, which promoted equitable and sustained use of salmon. In addition to codifying the rights of chiefs or families to manage access and exclude outsiders, a clear set of responsibilities flowed from these rights, including the imperative to sustain the productivity of the resource and share the benefits within the community through reciprocal exchange (Trosper 2002, Brown and Brown 2009). From California to Alaska, these reciprocity-based world views center the responsibilities of rights holders to salmon and their community, and were perpetuated through ritual practices, taboos and laws that protected future abundance, and promoted the long-term stability of precolonial salmon fisheries (Swezey and Heizer 1977, Trosper 2002, Haggan et al. 2006, Menzies and Butler 2007, Johnsen 2009, Mathews and Turner 2017, Ban et. al. 2019).

At the forefront of any Indigenous management decisions are achievable and actionable principles. On the Central Coast of BC, the Haíłzaqv (Heiltsuk) Nation has was shown this in modern management plans, with simple but powerful legal principles guiding their work: "the right to use a river system comes with the responsibility to maintain a river system," or " the primary focus should be on what is left behind, not what is taken" (Housty et al. 2014). For example, among Indigenous salmon fishing communities from California to Alaska, the First Salmon Ceremony is a near-ubiquitous practice honoring and encouraging the life-giving return of salmon. This ceremony is followed by a short-term moratorium on fishing, allowing the first runs of fish to reach their spawning grounds before fisheries commence (Swezey and Heizer 1977, Amoss 1987, Jones 2000). Likewise, proprietary access rights limited fishing effort, and mandated weir openings allowed fish to escape upstream uncaptured (Swezey and Heizer 1977, Harris 2001, Ritchie and Anglebeck 2020). These cultural beliefs and practices not only regulated harvest impacts within biologically sustainable bounds but reflect a belief that salmon willingly gave themselves to support the survival of the people (Menzies and Butler 2007, Losey 2010).

Traditional technologies and approaches for sustainable salmon harvest

The methods employed by Indigenous salmon fishers varied widely, but very often included fishing technologies that support selective harvest and release of nontarget species (Stewart 1977). In addition, a large majority of fisheries were—and, in some cases, continue to be—conducted in terminal areas, targeting a single population of salmon with an in-river weir, trap, dipnet, or spear (Stewart 1977, Sweezy and Heizer 1977, White 2006, Menzies and Butler 2007). In the present article, we describe some of the common Indigenous salmon harvesting and management technologies (figure 2).



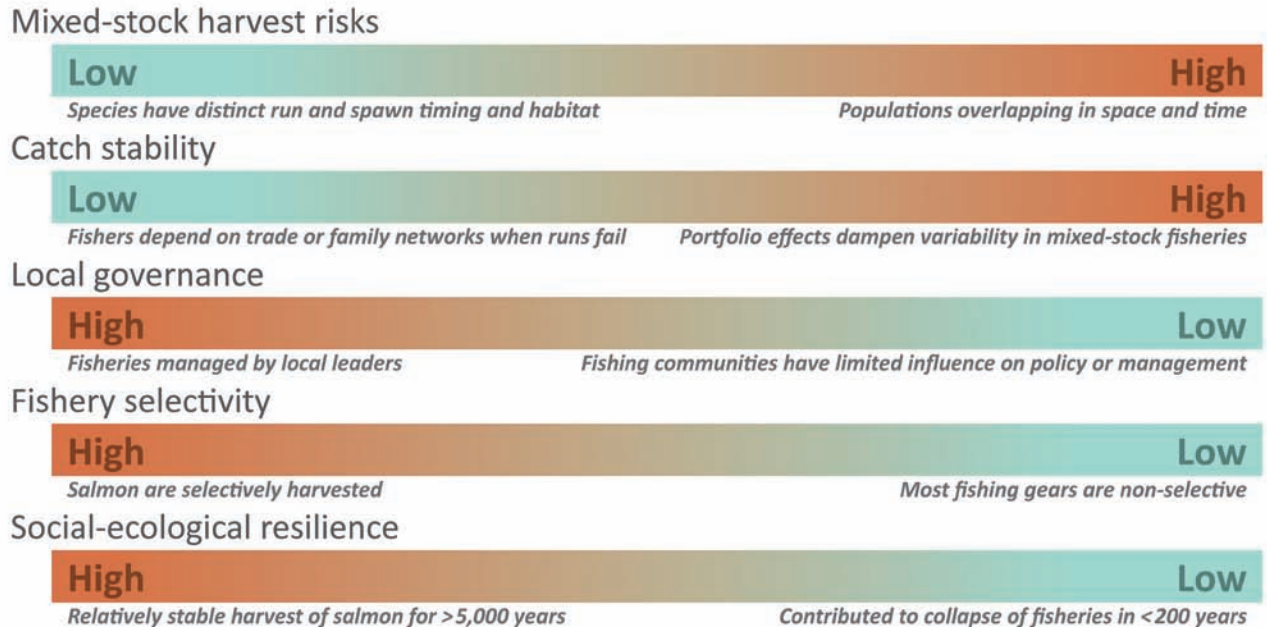


Figure 2. A comparison of Indigenous and contemporary fishery management systems depicting how decision-making authority is distributed within each system, with insights into their social–ecological performance across five key metrics.

Weirs. Fish weirs—river-spanning fences that channeled salmon into traps or fishways—were perhaps the most widespread salmon fishing technology employed by Indigenous people across the Eastern Pacific Rim from California to Alaska (Stewart 1977, Moss et al. 1990, Harris 2001, Moss 2013). Archaeological remains confirm their use at least 5,000 years ago (Moss and Erlandson 1998) and indicate widespread use over the last several thousand years (Swezey and Heizer 1977, Prince 2005, Nagata et al. 2012, Moss 2013).

Because weirs typically span the entire width of the river, they can fully obstruct upriver migrations of returning adult salmon. If used by fishers unaware or unconcerned about their impacts, a weir can quite easily wipe out a salmon population (Harris 2001, Ritchie and Anglebeck 2020). However, authority over a specific weir location was typically held by hereditary leaders who regulated access in accordance with Indigenous laws guiding reciprocal relationships, thereby promoting sustainability and ensuring access for the many upstream communities that depended on them (Swezey and Heizer 1977, Trosper 2002, Mathews and Turner 2017). The presence of thriving Indigenous societies and abundant salmon returns at the time of European contact is evidence of the deliberate management of salmon fisheries by Indigenous people, and the efficacy of weirs in place-based management systems (Copes 2000, Jones 2000, Johnsen 2009). Historical and ethnographic records of Indigenous management systems and beliefs highlight deliberate conservation measures that allowed returning salmon to pass weirs and reach upriver spawning areas, and strictly enforced rules that governed their use (Swezey and Heizer 1977, Berger 1982, Harris 2001, Ritchie and Anglebeck 2020). In many cases, multiple weir locations coexisted within a single river (Thomassen 1994, Harris 2001, Prince 2005), demanding cooperative management between numerous interconnected villages to ensure a mutually sustainable food supply. For example, salmon fishing on the lower mainstem Klamath River in Northern California was controlled by Yurok leaders who had been initiated into the role of overseeing weir construction and fishing. One weir, built each summer at Kepel during the height of the Chinook migration, was left open at night to allow unimpeded passage and was removed from the river after a period of 10 days, allowing the salmon to migrate freely into the territories of the upriver tribes on the Klamath and Trinity Rivers (Swezey and Heizer 1977). Weirs were therefore a primary instrument of precolonial adaptive management and fisheries governance.

In the Babine watershed a tributary of the Skeena River in BC, the Lake Babine Nation (LBN) practices ongoing salmon management and conservation. The watershed is the largest sockeye system in Canada (by area; Price and Connors 2014) and produces approximately 90% of Skeena River sockeye (Cox-Rogers and Spilsted 2012). Since time immemorial, LBN has managed and harvested Babine salmon using wood stake *k'oonze* (weirs) constructed at the outlet of Babine Lake (river kilometer [rkm] 96). The use of traditional weirs by LBN persisted into the early twentieth century, providing subsistence food resources and economic surplus to trade with nations in all directions (Fiske and Patrick 2000, Harris 2001). Matrilineal descent within clans determined resource allocation within LBN society and ensured that resource areas, including *k'oonze*, were managed sustainably (Earle and Ericson 1977, Bishop 1987, Rabnett 2000). Between 1904 and 1905, despite strong resistance, the weirs were forcibly removed by the federal government, disrupting thousands of years of Indigenous management of Babine salmon (Department of Marine and Fisheries 1905, Hackler 1958). In the years that followed, much conflict and disruption to LBN life has been documented, including extensive starvation among communities (Fiske and Patrick 2000).

Although Indigenous terminal fisheries were outlawed in the late nineteenth century, these technologies are currently undergoing a revival, with several examples of their reemergence informing our understandings of how they can be used in a modern context for monitoring and sustainable harvest. In 1946, the Department of Marine and Fisheries (now Fisheries and Oceans Canada) installed a weir at the outlet of Babine Lake to monitor the abundance of returning adult salmon (supplemental figure S1). Ironically, this weir closely resembled the traditional LBN weirs that spanned the entire width of the river, with multiple openings for fish passage. Since 2008, operations at the Lake Babine weir have been run by LBN, providing crucial data to support salmon management. Between 1965 and 1971, artificial spawning channels were added to two subbasins in the watershed by DFO, supporting additional spawning capacity in the Babine watershed (Ginetz 1977). Together, the weir and channels support terminal food, social, and ceremonial fisheries and commercial fisheries in years of abundant returns, creating sustainable local economic development opportunities for the nation and its communities. When Skeena River sockeye abundance is sufficient to trigger a commercial opening LBN members and other upriver nations conduct selective in-river commercial harvest. Likewise, when sockeye returns to Babine Lake exceed escapement goals, LBN conducts Excess of Salmon Spawning Requirements (ESSR) fisheries at the weir or at the mouths of the Fulton and Pinkut spawning channels (Fisheries and Oceans Canada 2019a). The reinstallation of the weir, including the data it generates to support management, and the employment, cultural wellbeing, and food security, and economic opportunity it provides to LBN, stands testament to the timeless ecological and cultural value of this traditional management system.

In 2013, the Haíłzaqv Nation revitalized traditional-style weir building in the lower Koeye River (rkm 3) to monitor returning sockeye abundance (figure S1; Atlas et al. 2017). Designs for the Koeye River weir were based on images in Stewart (1977). Archaeological and ethnographic evidence points to the use of weirs at larger creeks and rivers in Haíłzaqv territory including the Kunsoot, Neekas, and Kwakusdis Rivers (Carpenter et al. 2000, White 2006, HIRMD 2014). In the Haíłzaqv language the word *gvúláyu* refers to a fish trap made of saplings at the mouth of the

Table 1. A glossary of terms.

Term	Definition
First Nations	Indigenous people in Canada who are not Inuit or Métis. There are 630 million First Nations and more than 1.5 million Indigenous Canadians.
First generation story	A story originating from the first generation of Indigenous peoples, such as creation stories.
Food, social, and ceremonial fisheries	First Nations fisheries that are constitutionally protected in Canada as an inherent right.
Indigenous peoples	People descended from the original precolonial inhabitants of a particular place on earth. Indigenous people maintain connection to the lands, cultural practices, and traditions of their ancestors, and remain distinct from the dominant societies in which they live.
Indigenous management	Management systems grounded in the worldviews and daily practices of Indigenous people.
Management system	The social and cultural processes that encode norms for the use of natural resources, including the technologies and understandings that underpin decision making Lertzman (2009).
Mixed-stock fishery	A fishery that captures salmon from many populations.
Reconciliation	A government-to-government process undertaken by Canadian and Indigenous nations to reconcile historical harms done by colonization and foster more equitable relationships into the future.
Selective fishery	A fishery that captures target species but allows for the live release—with minimal harm—of nontarget species.
Social–ecological system	A system composed of interconnected biological, social and economic, and governance components.
Terminal fishery	Fisheries that catch salmon returning to a single river, typically with minimal bycatch of fish from other rivers. These fisheries may be conducted in river or at the head of an inlet where the river enters the ocean.
Wild salmon	Salmon born and reared in their natural habitat. By contrast salmon of hatchery origin or raised in fish farms are not wild.

river, which is distinct from *ckvá*, a trap made of stones on the beach (Carpenter et al. 2000). First generation stories confirm the existence and importance of weirs in Haíłzaqv Territory. In the story of Cúmqḷaqs, her son who was a supernatural carpenter, constructed the first salmon weir or trap in the lower reaches of the Tn̓ki River in Húy̓át. This salmon weir or trap was created to nourish the first ancestors of the village T̓iásu in Húy̓at (Boas 1932).

Despite evidence for their historical importance, there was no living memory of weir building among the Haíłzaqv when the Koeye weir project began in 2013, and in addition to population monitoring, the project has contributed to a revitalization of weir building among the Haíłzaqv people. About 500 sockeye are captured each year at the Koeye River weir and marked with PIT tags and visually identifiable tags for subsequent mark–recapture estimates of spawner abundance and survival to spawning (Atlas et al. 2020). In recent years the Haíłzaqv have also increasingly used the weir as a terminal fishing site for small-scale subsistence harvest, providing a few hundred sockeye annually for the community and youth at the Koeye River summer camp.

By fishing at the weir, Haíłzaqv managers can gauge the strength of the sockeye run in season and adjust harvest accordingly. Therefore, weirs offer a method to integrate monitoring and harvest. Given declines in productivity among BC sockeye populations (Peterman and Dorner 2012), high fuel costs, and mixed-stock harvest risks, this nascent community-run terminal fishery supports a cost-effective and risk-averse approach to harvesting sockeye for subsistence use (Steel 2020).

Fish traps. Like weirs, fish traps were widely used in traditional terminal fisheries (table 1, figure 1). Although many types of fish traps existed, stone fish traps built adjacent to river and creek mouths are a ubiquitous feature of the Northwest Coast intertidal landscape. From Washington State to Alaska, thousands of fish traps remain in estuaries of salmon-bearing streams, a living testament to the utility, durability and widespread application of stone fish traps (Langdon 2006, Menzies and Butler 2007, White 2011, Caldwell et al. 2012). These fish traps were built in numerous different configurations and shapes—depending on their location and target species—and were used for generations during the late summer and fall, because families and village groups visited seasonal camps to target specific salmon runs (White 2006, 2011). Typically, fish traps were built in river mouths and estuaries, although examples of in river traps have been documented (White 2006, Menzies and Butler 2007). In some instances, archaeological evidence suggests that both fish traps and weirs were used (Elroy White, Central Coast Archaeology, Bella Bella, BC/Canada, personal communication, 2 March 2020).

As salmon staging in the river mouth moved inshore with the tide they swam into the traps, and were captured as the tide ebbed, allowing fishers to harvest salmon and release those that were unwanted. Oral accounts from Haíłzaqv and other coastal Indigenous knowledge holders indicate selective harvesting of chum and pinks in more advanced states of maturation; their lower oil content made them suitable for smoking and long-term storage. Sockeye and coho were often eaten fresh (White 2006). Women led the smoking process, and supervised harvesting and fish selection (Jones 2000, White 2006). Trap walls were opened following harvest or during periods of inactivity to allow salmon to escape (Menzies and Butler 2007, White 2011).

The assertion of colonial jurisdiction and law increasingly excluded Indigenous fishers from the use of fish traps and weirs by the late 1870s. As opportunities for subsistence livelihoods declined and the imposition of the cash economy drove Indigenous people into the cannery workforce, discriminatory laws enabled adoption of fish traps by European settlers in the late 1800s (Boxberger 1989, Newell 1993). Incorporating technological innovations from the Great Lakes region and Scandinavia, the first European salmon traps were constructed on the lower Columbia River beginning in 1879 (Collins 1888). These traps consisted of wood pilings and attached cotton or wire mesh, which were effective in passively corralling large numbers of returning adult salmon for harvest or release (Cobb 1921). Salmon remained free swimming within a fish trap and were rarely entangled, giving the gear a product–quality edge (Buschmann 1903). Having demonstrated considerable success in Columbia River salmon fisheries, commercial trapping rapidly expanded to in-river and coastal fisheries on the Washington coast, Puget Sound, BC, and Alaska between the 1880s and early 1900s (Collins 1888, Cobb 1921).

Despite the fish trap's potential for selective commercial harvest and sustainability in rivers and estuaries of western North America, colonial fisheries were mostly unregulated in the early twentieth century, and fish traps became a destructive force to wild salmon populations (Cobb 1921, Boxberger 1989). With unlimited entry among white settlers to commercial fisheries, fish traps (favored by large salmon canning corporations because of the gear's remarkable efficiency) contributed to rampant overharvest and insufficient escapement to salmon spawning grounds (Johnson et al. 1948, Boxberger 1989, Lichatowich 1999). Overharvest prevented Indigenous people in the United States and Canada from accessing the resource for subsistence (Boxberger 1989, Taylor 1999, Harris 2001). Fish traps were eventually banned from Oregon to Alaska between 1934 and 1959, primarily for political reasons and the gear's perceived contribution to salmon decline (Johnson et al. 1948, Higgs 1982, Arnold 2011).

In 2016, the nonprofit organization Wild Fish Conservancy initiated a collaborative experiment with lower Columbia River commercial fishers in Washington State to revive the fish trap and evaluate the feasibility of trap for selective harvest (figure S1). Many salmon populations in the Columbia Basin are listed under the US Endangered Species Act (ESA). However, there are also abundant hatchery-produced salmon, and selective fishing gears are needed to reduce impacts on ESA listed wild salmon and enable harvest of hatchery fish (WFWC 2013, Gayeski et al. 2018a, Tuohy et al. 2019). Results from the Columbia River have shown the potential of fish traps to support a transition to selective fisheries; nontarget species have high rates of postrelease survival (94%–100%) when the gear is operated with a conservation-minded approach and regulated appropriately (Tuohy et al. 2019, Tuohy et al. 2020).

There is interest in revitalizing fish trap technology for subsistence and commercial use in Canada. For example, the Lax Kw'alaams First Nation has proposed using a modern fish trap in the tidal waters of the lower Skeena River (WFC 2019). The Skeena River is the second largest salmon producing river in BC, but salmon populations have declined by 56%–99% in the last 100 years (Price et al. 2019), and mixed-stock harvest poses challenges to the sustainability of fisheries targeting larger stocks (Walters et al. 2008). These declines combined with uncertainty in preseason and in-season escapement forecasts, precautionary management and commercial fishery closures have severely affected food security and economic opportunity for Lax Kw'alaams and other Skeena First Nations. Historically, Lax Kw'alaams people used selective fishing methods widely, including intertidal fish traps, and managed salmon resources according to culturally defined stewardship principals and traditional laws (Smethurst 2014, Letham et al. 2015, Ministry of Justice 2016). Modern fish trap technology will allow for selective harvest, capturing fish alive with minimal harm and reducing bycatch mortality of nontarget stocks (supplemental table S2).

The Lax Kw'alaams fish trap pilot project will provide research and monitoring opportunities, support the Lax Kw'alaams food, social, and ceremonial fishery and potentially support development of a sustainable high-value fishery (Gayeski et al. 2018a, Tuohy et al. 2019). By enabling sampling of salmon populations from across the watershed, it will create a platform for the development of collaborative research with upriver nations, governments, and other partners. There is a critical need to improve long-term and in-season knowledge of abundance and run composition among Skeena River salmon (Walters et al. 2008). The proposed fish trap technology will provide monitoring opportunities for earlier and later season sampling across various tide stages and river levels with minimal bycatch mortality, thereby addressing key challenges associated with the current gillnet test fishery used for in-season escapement estimates in the Skeena River (Tyee Test Fishery; Walters et al. 2008).

Reef nets. Reef nets are a sophisticated fishing technology invented by Straits Salish peoples. They have been used in fisheries along the tidal marine approaches to major salmon rivers such as the Fraser and Cowichan in BC, and the Skagit and Nooksack in Washington State, where modest depths and high concentrations of migrating salmon enable reliable fishing (Easton 1990, Claxton 2015). The long leads of the net are anchored at their ends, tapering back in a funnel shape toward a central net that is fished between two boats. Migrating fish are observed from an upright position, or from a raised platform in many modern reef net vessels. When fish have entered the heart of the net the sides are raised into the adjoining boats allowing the fish to be harvested selectively or released. Despite being protected under treaty agreements, reef nets were outlawed in Canada in the early 1900s (Claxton 2015), and reef net sites used by Indigenous peoples were appropriated in Washington

State to make way for commercial fish traps (Lummi Tribal Archives 1894).

Reef netting canoes were traditionally captained by individuals who held inherited rights to long-established reef netting locations. Sacred ceremonial rights accompanied initiation into the role, and reef nets were themselves sacred objects imbued with feminine life-giving qualities (Claxton 2015). The construction and use of reef nets was governed by the law and tradition of Straits Salish Indigenous peoples, and this technology was a major source of subsistence, wealth, and cultural stability for Straits Salish people in the precolonial era.

Today, reef nets are undergoing a renaissance among Indigenous and non-Indigenous fishers alike, because conservation concerns have increasingly necessitated selective harvest of abundant sockeye and pink salmon while limiting the impacts on ESA and the COSEWIC (Committee on the Status of Endangered Wildlife in Canada) listed populations of Chinook, coho, and steelhead in the Salish Sea. In 2013 the WSÁNEĆ Nation revived their reef net fishery in areas around the Saanich Peninsula on Vancouver Island in Southern BC (Claxton 2015). Likewise, in Washington Lhaq'temish (Lummi) fishers have partnered with distributors to market selectively harvested wild salmon as a value-added brand, and commercial reef net fishers have continued to operate reef nets in selective fisheries in the San Juan Islands, providing high quality, high value salmon for consumers. These fisheries exemplify the powerful transformations that can be achieved through the wider adoption of selective and terminal Indigenous fisheries, however the long-term viability of these fishing operations is threatened by ongoing declines in Fraser sockeye and the recent catastrophic impacts of the Big Bar slide on Upper Fraser salmon populations.

Seine nets. Numerous historical accounts document the widespread use of beach seines by Indigenous salmon fishers across the Northeast Pacific Rim. These nets, typically made from nettle fibers, spruce roots, or woven cedar bark, served as an indispensable tool for selective harvest (Stewart 1977). Stone seine weights have been found on the bottom of the Koeye River, and the remains of these nets are often found in archaeological excavations in wet sites in which the absence of oxygen slows decomposition of organic materials (e.g., Croes 1995). On the North and Central Coast of BC, seines were also used extensively during the smokehouse days in the first half of the twentieth century, when families would spend the fall season harvesting and processing fish at smokehouse camps (White 2006, Menzies and Butler 2007). In Southeast Alaska, small purse seines are still commonly used for subsistence fishing (Langdon 2015).

In watersheds in which nonselective mixed-stock fisheries pose conservation concerns, there are efforts to use beach seines and purse seines as tools for selective harvest. For example, the Confederated Tribes of the Colville Reservation began operating a purse seine for subsistence and commercial harvest, releasing ESA-listed steelhead and Chinook salmon, while harvesting marked hatchery fish (UCUT 2020). Similarly, First Nations on the Lower Fraser River in BC are evaluating and implementing selective harvest using beach seines to reduce bycatch impacts on endangered Upper Fraser coho stocks (Raby et al. 2014).

Dip nets. Dip netting is an ancient method of salmon harvesting, long practiced at specific locations where rapids, waterfalls and other constrictions facilitate use of the method. Very often, access rights to these locations are passed down through families who have used harvesting sites for generations. Perhaps the most famous example of the technology comes from Celilo Falls (rkm 302)—or *Wyam*, as it is called by the tribes of the Columbia Plateau—on the Middle Columbia River (figure S1). The falls were a major cultural site and gathering point for Native people who would fish for salmon in the rushing waters of the falls (Fisher 2004). With 15,000 years of human use, *Wyam* was among the oldest continuously occupied communities on the North American continent, which ended abruptly in 1957 when the construction of the Dalles Dam inundated the site. Among the tribes displaced from Celilo, dip net fisheries continue at many other locations in the Columbia River, including immediately below the Dalles Dam. Similarly, in BC dip net fisheries are important for the tribes of the Fraser Canyon (rkm 182 to 352). Prime dip net sites are often inherited and passed down through generations, and the tradition remains vibrant to this day despite years of harassment and arrest at the hands of fisheries officers during the twentieth century, and declining salmon returns in the Fraser (Harris 2001, Mack and Youngman 2020).

At Moricetown Falls on the Bulkley River (rkm 48), a major tributary of the Skeena River in BC, the Wet'suwet'en people have long harvested salmon using dip nets (Johnson Gottesfeld 1994). Since 1999, Wet'suwet'en Fisheries and Fisheries and Oceans Canada have worked collaboratively with fishers to monitor escapements of sockeye, coho, and steelhead in the Bulkley River. By seining and marking fish downstream of the falls and recapturing migrating fish in the traditional-dip net fishery at Moricetown, the nation and government partners are producing reliable mark–recapture estimates of abundance for these three culturally and economically important stocks (Gottesfeld et al. 2009). This project, which merges scientific mark–recapture with ongoing harvest and Indigenous management by the Wet'suwet'en is a powerful example of the opportunities that flow from linking traditional modes of harvest and management with scientific data collection.

Fish wheels. Fishwheels are an ancient fishing technology that Indigenous peoples have employed since precontact times (Cobb 1921, Menzies 2006). Originally constructed

from cedar wood and nettle fiber mesh, fishwheels mounted on floating platforms that included multiple revolving baskets (typically two or three large, flat dip net-like vanes) designed to catch fish and carry them into submerged holding areas unharmed (Menzies 2006). Much like watermills, the mesh vanes of fishwheels were turned by the current and so were best suited to shallow and swift-moving waters (Snively and Corsiglia 2001). As the baskets rose upward out of the water, they scooped up fish (principally salmon) ascending the river, and as the fish slid down the vanes toward the horizontal axle of the cylindrical fishwheel, they encountered wooden baffles that guided them into the submerged baskets (Corsiglia and Snively 1997). There they would remain until released unharmed or retained for food. In the words of Nisga'a Sim'oogit (Chief) Eli Gosnell, "the flowing river kept salmon alive until they were either harvested or released; we always took only the fish we needed and no more" (quoted in Menzies 2006). Over the course of the twentieth century, however, fishwheels have been employed throughout the Pacific Northwest for commercial, subsistence, as well as research and monitoring purposes (Meehan 1961), and their extreme efficacy eventually led to their prohibition for commercial purposes across many jurisdictions (such as in the Columbia River in Washington and Oregon; Aguilar 2005).

One of the most renowned contemporary uses of this in-river fixed gear involves the Nisga'a Nation, the people of the Nass River in northern BC, who have combined this traditional technology—now made of aluminum and nylon mesh (Alexander and Link 2001)—with modern analytical methods for fish stock assessment and monitoring, producing higher quality data and generating more accurate predictions about the fishery than had been previously available (figure S1; Link and English 2000, Snively and Corsiglia 2001, King 2004). Since 1992, the Nisga'a Lisims Government's Fisheries and Wildlife Department has conducted extensive fisheries research on the Lower and Upper Nass River using multiple fishwheels as a platform for fish counting, measuring, tagging, releasing, and recapturing (Link and English 1998). The Nisga'a fishwheel program has enabled the monitoring of salmon escapement and harvest, the study of factors limiting salmon production, as well as the participation of Nisga'a citizens in the stewardship of the Nass River (Link and English 2000, Nisga'a Lisims Government 2019). This highly successful program provides yet another example of obtaining otherwise inaccessible insights through the coupled usage of ancient and contemporary technologies and practices.

Cultural resurgence

For generations, Indigenous people across western North America have actively sought to counteract the effects of colonial dispossession of their lands, and to assert their sovereignty (Harris 2001, Fisher 2004, Claxton and Price 2020). Today, Indigenous people are working to rebuild institutions that were decimated by colonization, and communities continue to revitalize cultural and institutional resilience through self-governance, land-based learning, and intergenerational knowledge sharing (e.g., Beveridge et al. 2020). Across Canada and the United States, Indigenous people are actively shaping the future of their communities and homelands, successfully protecting and recovering ecosystems for the benefit of human and nonhuman life (Housty et al. 2014, Schuster et al. 2019, Curran et al. 2020).

The ability to harvest traditional foods, tell stories and pass on stewardship knowledge is fundamental to Indigenous identity and wellbeing (Alfred 2009). This sharing of culture through harvest and stewardship strengthens and affirms connections to identity and place. Through the practice of cultural reciprocity, Indigenous peoples perpetuate the vibrancy of communities, families, and placed-based ways of life (Trosper 2002, Artelle et al. 2018, Claxton and Price 2020). Salmon are emblematic of those connections to place, supporting food security, cultural identities and wellness that goes beyond meeting nutritional needs.

Among Indigenous peoples of the Pacific Northwest, harvesting salmon is inseparable from stewardship. With thousands of fish traps, weirs, and midden across the Northwest Coast, the history and connection between people and salmon remains powerfully visible on the landscape (White 2006, Caldwell et al. 2012). The use of these traditional harvesting technologies has been dormant in many places for more than a century but remains in some locations despite the concerted efforts of colonial governments in the nineteenth and twentieth century to extinguish Indigenous rights (Harris 2001, Mack and Youngman 2020). By revitalizing Indigenous technologies and management systems communities are reconnecting salmon stewardship with harvest, Indigenizing education, and perpetuating culture through intergenerational knowledge transfer (e.g., Claxton 2015). In doing so, they are reawakening relationships to places and cultural practices that supported vibrant communities and healthy salmon returns since time immemorial. The long-term success of place-based salmon management depends on uplifting this holistic vision for community participation in stewardship and governance.

Reconciliation and a changing landscape of cogovernance in Canada

For many Indigenous people, colonization severed access to sustainable and socially just salmon fisheries. Generally, in Canada, access to fisheries resources was not granted to Indigenous nations from the government despite repeated requests (Harris 2001). This exclusion from fisheries resources and decision making drastically undermined traditional livelihoods and created food insecurity among First Nations people (Eckert et al. 2018, Lee et al. 2019). As a result, Indigenous peoples' ability to transmit the knowledge critical to traditional management of fisheries was harmed. In turn, the sustainability of salmon fisheries suffered as long-standing systems of Indigenous fishery management

were replaced by industrial fishing fleets serving global markets (Higgs 1982, Newell 1993).

In addition to historic damage, contemporary salmon management policies have resulted in declining returns, further reducing First Nations' ability to perform a constitutionally guaranteed practice of harvesting salmon in Canada (*R v. Sparrow* 1 S.C.R. 1075 [1990]). Some settlements following litigation have resulted in financial compensation for a portion of these losses (e.g., *R v. Gladstone* 2 S.C.R. 723 [1996]), but rarely have the root causes of the damage—the imbalance of management authority between Indigenous people and the colonial state and the failures of current management systems—been addressed. To address these historic and ongoing injustices, colonial governments and First Nations are increasingly making agreements that contribute to reconciliation.

Effective resource management requires scientific, regulatory, political, and moral legitimacy (Pinkerton and John 2008), and new examples of fisheries reconciliation processes are emerging in Canada with the potential to strengthen the legitimacy of management frameworks. For example, Coastal First Nations, a group of nine nations in coastal BC, has recently negotiated a Fisheries Resources Reconciliation Agreement (FRRA) with Canada's Department of Fisheries and Oceans (CFN 2017). The agreement provides a process for participating nations to be true comanagers of fisheries, bringing together First Nations and DFO at regional tables and setting harvest management through a "strong collaboration" process. In addition, the participating nations will acquire commercial fishing licenses, and develop community-based commercial fisheries that support multispecies fisheries that are managed, permitted, and enforced under nation's fishing authority. This initiative will require access (licensing) reforms and has the goal of revitalizing local fleets and First Nations participation in fisheries. These agreements will likely make it easier to develop terminal harvest opportunities on the basis of observed in-season abundance.

Combined, these governance and policy advancements offer opportunities to support rebuilding salmon stocks and harvest in a socially just and sustainable manner. However, absent transformative changes in the modes of harvest and collaborative management processes for salmon, the opportunity presented by the FRRA may yield few benefits to communities. Although it is nonselective, mixed-stock fisheries remain the dominant mode of harvest, opportunities for sustainable salmon fisheries will very likely continue to dwindle under the weight of indiscriminate harvest of salmon populations and governance arrangements designed to enable extraction.

Returning to traditional scales and systems of management offers a positive step on the path of reconciliation. Although this process will not be the same for every nation, some likely commonalities and challenges emerge. First, depressed salmon stocks will need to be recovered to levels that enable long-term sustainable harvest opportunities. Second, expertise and interest in the use of terminal or selective fishing technologies will need to be rebuilt. Finally, fisheries managers will need to work with harvesters and community organizations to support implementation and management. In particular, revitalizing systems of contingent proprietorship whereby the individuals or groups interested in harvesting salmon are also responsible for monitoring escapement, managing fishery impacts, and redistributing some of their catch within their communities could empower local fishers or community organizations to help lead this transition (Greer 1993, Copes 2000, Johnsen 2009, Carothers 2011).

Finally, the reputation of many traditional fisheries technologies (e.g., weirs) have been tarnished by racist anti-Indigenous sentiment and legal frameworks, disrupting the transmission of cultural knowledge related to their use (Higgs 1982, Newell 1993, Harris 2001, Steel 2020). Correcting these harms requires that colonial management agencies acknowledge the efficacy of Indigenous salmon management and the harm that was done by banning these approaches. Thus far, the emergence of Indigenous leadership in monitoring and management of natural resources has been hindered by an imbalance of power in governance, and an unwillingness of governments to relinquish authority back to Indigenous communities (Thompson et al. 2020). By upholding the inherent rights of Indigenous people to manage natural resources within their ancestral territories and incorporating traditional knowledge and management systems into fishery management, colonial governments may begin to rectify that harm.

Biological realities, limitations and opportunities

The challenges facing salmon fisheries draw their origins in a multitude of historical and ongoing changes and are further compounded by the financial and logistical realities of managing salmon fisheries in remote regions of western North America. Climate change and habitat loss both pose existential threats to wild salmon populations, contributing disproportionately to their decline around the Pacific Rim (Lichatowich 1999, Gustafson et al. 2007, Katz et al. 2013). In recent decades wild salmon have experienced climate driven declines in survival at sea and in freshwater that have contributed to the collapse of many stocks that formerly supported major commercial fisheries (McKinnell et al. 2001, Peterman and Dorner 2012, Malick and Cox 2016). Declining abundance and productivity have led to lower sustainable harvest rates, limiting opportunities for commercial and subsistence fisheries (e.g., Fisheries and Oceans Canada 2019a). Marine heatwaves and drought are increasing in their frequency (Islam et al. 2017, Frölicher and Laufkötter 2018), causing acute short-term impacts on salmon survival (Rand et al. 2006, Daly et al. 2017). As anthropogenic climate change progresses, salmon returns are becoming more variable and less predictable (Grant et al. 2019).

Despite ongoing environmental changes and declining abundance, salmon populations remain resilient and often

highly productive. In many cases, there are opportunities for sustainable harvest if fisheries can be downscaled to target specific healthy populations. In the face of growing uncertainty and unprecedented environmental changes, in-season monitoring to support adaptive management is essential, allowing fisheries to harvest during times of unexpected abundance and to reduce impacts when conservation warrants precaution (Mantua and Francis 2004, Schindler and Hilborn 2015). Fisheries targeting single stocks may be a particularly valuable management tool when the status of individual populations is variable and management resources are limited. In cases in which circumstances necessitate mixed-stock harvesting, reef nets, seine nets and fish traps—centuries old technologies with deep roots in western North America—are already enabling selective harvest. By allowing fishers to harvest abundant populations or hatchery-origin fish, and safely release nontarget species, these technologies hold the potential for much wider application in selective fisheries.

Fisheries targeting mixed and single stocks balance tradeoffs between conservation and harvest opportunity differently. In general, mixed-stock fisheries tend to produce larger and more stable catches through time (Nesbitt and Moore 2016, Freshwater et al. 2020). Paradoxically, the stability conferred by harvesting multiple populations comes at the cost to small or depressed populations that comigrate with larger more abundant populations, threatening the very biodiversity that underpins stable catches (Connors et al. 2020). In some notable instances, networks of locally interconnected terminal fisheries have alleviated conservation risks and produced stable harvest opportunities. The Bristol Bay sockeye fishery—the world's largest wild salmon fishery—is managed using terminal fishery openings targeting specific population groups that meet in-season escapement targets (Hilborn 2006, Schindler et al. 2010). Similarly, most traditional First Nations' fisheries targeted fish returning to a single population, but the impact of natural fluctuations in abundance were damped by social connections, and kin-based networks of sharing and redistribution across villages and family groups (Suttles 1968, Trosper 2002, Prince 2011). Therefore, rebuilding networks of terminal fisheries that couple harvest and monitoring could increase salmon fishing opportunities, generate in-season information on escapement, and reduce conservation risks, while supporting resilient portfolios of salmon harvest.

Conclusions

Approaches to harvest and governance that are grounded in Indigenous knowledge can promote selective fisheries, local leadership of monitoring and management, and more equitable fishing opportunity for Indigenous and non-Indigenous communities alike. Adopting approaches grounded in traditional Indigenous management systems can catalyze long-needed transformations in salmon fisheries toward locally sustainable fishing opportunities (Greer 1993, Pinkerton 1999, Healey 2009). Numerous contemporary and historical examples of community-run fisheries have demonstrated the potential for local governance to maintain productive fisheries (Pinkerton and Weinstein 1995, Leal 1998, Pinkerton and John 2008, Johnsen 2009, Bavinck et al. 2015), and a growing body of evidence suggests that by integrating traditional and local knowledge into monitoring and management, fisheries can achieve greater social–ecological resilience (Berkes 2003, Lee et al. 2019, Salomon et al. 2019). Reconnecting salmon harvesting with stock assessment using terminal and selective in-river fisheries can unify monitoring, management, and harvest under the umbrella of local management, and encourage fisher participation in resource stewardship. This would bolster the legitimacy and resilience of fisheries management by emphasizing the observations and values of local communities, generating much needed biological data, and supporting governance frameworks that empower local decision-making (Moller et al. 2004, Augerot and Smith 2010, Angel 2017, Thompson et al. 2019).

There is an urgent need to realign the scales of fisheries with biologically relevant scales (e.g., salmon populations or watersheds) to reduce conservation risks, create opportunities for sustainable harvest, and support salmon-dependent species and ecosystem processes (Healey 2009, Ward et al. 2009, Gayeski et al. 2018b, Freshwater et al. 2020, Walsh et al. 2020). However, realignment of harvest toward greater terminal or in-river harvest will be of limited benefit if mixed-stock harvest rates remain high and fish are intercepted before reaching terminal fisheries, and terminal fisheries are not a panacea for sustainability if in-river fisheries overharvest returning salmon (Freshwater et al. 2020). For many species, allocation decisions driven by the PST remain a hindrance to recovery and limit the potential for transformation toward more locally managed fisheries. Therefore, mixed-stock ocean fisheries will likely need to forgo some harvest opportunity if the biological and social benefits of terminal and selective fisheries are to be realized (Connors et al. 2020). Including Indigenous people and local communities in future PST negotiations will therefore be essential, so that management of Pacific salmon fisheries can reflect their needs, aspirations, and understandings.

In the absence of transformation, salmon managers will continue to face a set of wicked tradeoffs posed by mixed-stock fisheries, where harvesting abundant salmon contributes to the long-term erosion of the biodiversity that underpins future fishing opportunity (Connors et al. 2020). Fortunately, solutions to these problems are not out of reach, and there is growing momentum toward transformative changes in the way that salmon are caught and managed. From weir and seine fisheries in Babine Lake, and nascent trap fisheries on the lower Columbia and Skeena Rivers, to selective reef net fisheries in the Salish Sea, these examples create growing momentum toward the revival of Indigenous harvest technologies that supported sustainable fisheries management over thousands of years.

We suggest that Indigenous salmon management practices offer lessons and options for fostering resilient salmon

fisheries as socioecological systems. Salmon possess biological traits that confer a remarkable ability to cope and recover from change (Waples et al. 2008, Healey 2009, Schindler et al. 2010). However, salmon are a part of a rapidly evolving socioecological system that has, at times, shown low resilience as evidenced by collapsed populations and fisheries (Gustafson et al. 2007, Bottom et al. 2009, Walters et al. 2019). Stories of Indigenous mismanagement or periods of scarcity, and contemporary examples of dysfunctional cogovernance do suggest the importance of not overeulogizing Indigenous management. However, from an empirical perspective, Indigenous salmon fisheries persisted for thousands of years, which speaks to their overall long-term resilience (e.g., Cannon and Yang 2006, Campbell and Butler 2010). Indigenous salmon management systems exhibit many of the principles that can promote resilience in social–ecological systems (Biggs et al. 2015). For instance, by fishing and managing at the scale of a single river traditional fisheries maintained biological diversity and limited the geographic scope of harvest impacts, garnered broad participation, and created diverse interconnected systems of governance. Indigenous fishery management is also grounded in multigenerational understanding of the links between salmon, people, and ecosystems, promoting adaptive learning that has fostered resilient human–salmon relationships for thousands of years.

Amid rapid and deep-rooted changes in ecosystems and fisheries, 10,000 years of Indigenous stewardship knowledge and growing scientific consensus tell us that revitalizing Indigenous systems of harvest and resource governance should be an urgent priority. Broader application of terminal and selective fishing technologies can help rebuild resilient locally managed salmon fisheries, and in doing so contribute to long-needed shifts in the balance of power, legitimacy, and opportunity in salmon fisheries. With humility and in a spirit of collaboration let us work together to bringing the story of salmon fisheries full circle, supporting the revitalization of Indigenous management systems that formerly supported sustainable fisheries for millennia. In doing so we will move closer to a goal shared by many Pacific Northwesterners; that wild salmon remain at the foundation of North Pacific cultures and ecosystems for generations to come.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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William I. Atlas and Katrina Connors are affiliated with the Pacific Salmon Foundation, in Vancouver, British Columbia, Canada. WIA and Natalie C. Ban are affiliated with the School of Environmental Studies at the University of Victoria, in Victoria, British Columbia, Canada. WIA and Matthew R. Sloat are affiliated with the Wild Salmon Center, in Portland, Oregon. Jonathan W. Moore is affiliated with the Earth2Ocean Group, Biological Science, at Simon Fraser University, in Burnaby, British Columbia, Canada. Adrian M. Tuohy is affiliated with the Wild Fish Conservancy, in Duvall, Washington, Spencer Greening is affiliated with the Faculty of Environment at Simon Fraser University, in Burnaby, and with the Gitga'at First Nation, both in British Columbia, Canada. Andrea J. Reid is affiliated with the Department of Biology and the Institute of Environmental and Interdisciplinary Science at Carleton University, in Ottawa, Ontario, Canada, and with the Department of Forest and Conservation Sciences at the University of British Columbia, in Vancouver, British Columbia, Canada. AJR and Nicole Morven are affiliated with the Nisga'a Nation, in British Columbia, Canada. Elroy White is affiliated with Central Coast Archaeology, in Bella Bella, British Columbia, Canada. William G. Housty is affiliated with the Heiltsuk Integrated Resource Management Department, in Bella Bella, British Columbia, Canada. Jess A. Housty is affiliated with the QQs Projects Society, in Bella Bella, British Columbia, Canada. EW, WGH, and JAH are affiliated with the Heiltsuk Nation. Christina N. Service, Larry Greba, and Sam Harrison are affiliated with the Kitasoo and Xai'xais First Nations, in Klemtu, British Columbia, Canada. Ciara Sharpe, Katherine IR Butts, and William M Shepert are affiliated with Lax Kw'alaams Fisheries, in Prince Rupert, British Columbia. Elissa Sweeney-Bergen and Donna MacIntyre are affiliated with Lake Babine Nation Fisheries, in Burns Lake, British Columbia, Canada.