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ORIGINAL ARTICLE

Resilience and vulnerability: perspectives of key informants on the uncertain future of Pacific salmon in British Columbia

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Abstract

A major challenge in contemporary aquatic environmental management is anticipating and responding to increasing social-ecological uncertainty and shifts in the health of managed species. Signals indicate that many wild North American Pacific salmon populations are in or at risk of decline, but the mechanisms affecting salmon resilience are not clear. There is a need to assess the resilience of species and stocks across the Pacific region from the perspective of groups involved in salmon work to direct effective management responses. Interviews were conducted with individuals ($N=32$) holding diverse knowledges and salmon expertise including employees of federal government fisheries management organizations, non-governmental organizations, Indigenous agencies, and universities, to understand how perceptions of salmon resilience in the Pacific Northwest are changing over time, the factors that positively or negatively affect vulnerability and resilience, and variations across Pacific salmon species and stocks. We find that Pacific salmon resilience is negatively affected by interacting biological, environmental, and social pressures, with life history, geography, and increasing water temperatures viewed as the most significant drivers of declining resilience. Chinook and sockeye salmon are perceived as the most vulnerable and the most socially valued species, compounding the challenges for fisheries management and conservation. Species seen as highly resilient (chum and pink salmon) are viewed as being at risk of future increases in vulnerability if increasing conservation measures for more vulnerable species shift harvesting pressures towards more abundant species. We conclude by outlining anticipated social-ecological changes facing Pacific salmon and discuss areas of consensus for salmon conservation needs.

Keywords Pacific salmon · Resilience · Vulnerability · Risk · Uncertainty · Fishery management

Introduction

Shifts in broader social-ecological systems manifest themselves in the form of changing hydrology, habitat loss, extreme weather, and more (Clarke et al. 2022; Thonicke et al. 2020). Environmental challenges, exacerbated by human development and an increasing demand for Earth's resources, place more pressure on non-human species as well as on resource users and management agencies alike (Vitousek et al. 1997; Ripple et al. 2017). Efforts to resolve multi-scale dilemmas require environmental managers to balance heightened social-ecological uncertainty and the interests of different user groups (Perry et al. 2010; Whitney & Ban 2019). Fisheries, particularly Pacific salmon fisheries, exemplify the unprecedented changes and associated complexities facing managers in their effort to support the resilience of managed species in an evolving environment (Schindler et al. 2008; Vinagre et al. 2011). Resilience in social-ecological systems can be described as the capacity to

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maintain the structure of a system against disturbances (i.e., individuals can overcome or positively adapt in the face of significant adversity or impact) (Luthar & Cicchetti 2000; de Abreu-Mota et al. 2018), while vulnerability is the susceptibility to harm from external or internal disturbances (Gallopin 2006). Ebbin (2009) proposes a continuum marked at each end by resilience and vulnerability that represents the ability of a system to adapt or respond to heightened social-ecological uncertainty. Perceptions of resilience and vulnerability have been identified in prior studies as important to informing understanding of how people interpret ecological changes (Murphy et al. 2020; Satterfield et al. 2018). Information about ecosystem change is insufficient to predict support or opposition to conservation strategies. People's actions are guided by how they perceive the state of the ecosystem, how they regard uncertainty, and what they assess as more deserving of attention (Constantino et al. 2021). Incorporating perceptions studies into environmental management is increasingly important in the context of unprecedented climate change impacts (Schwoerer et al. 2023). While some species have long been understood as highly resilient, such perceptions may be changing within and across regions as ecosystem dynamics shift in response to climate change.

The ability to identify changes in species resilience and anticipate future scenarios is therefore highly valuable for decision-makers given the potential to reduce uncertainty (Quay 2010). However, there exists a critical knowledge gap related to how fishery decision-makers and practitioners assess and understand resilience, particularly across different knowledge backgrounds. First, as Bellwood et al. (2019) note, terms like biodiversity and resilience can suggest multiple goals that vary among groups and may change over time. Understanding variations in how decision-makers and practitioners understand resilience and vulnerability is necessary for informing strategic management plans that can respond to present and future trends in the health of fish populations. Second, certain species with similar life history characteristics and the fisheries (commercial, recreational, Indigenous) that depend on them may be more vulnerable to changing environmental conditions than others. For example, Kadykalo et al. (2022) found that rainbow trout *Oncorhynchus mykiss* in British Columbia are not perceived by decision-makers and knowledge holders as vulnerable, but steelhead trout (also *O. mykiss*) are. Surveying key informants across multiple knowledge backgrounds provides a richer understanding of the state of knowledge about present and potentially vulnerable species. Finally, a changing perception of species as increasingly vulnerable may elicit greater policy and management response than no shift in perception, especially if the potential losses of certain species are accompanied by social and/or economic losses. Changing views of vulnerability may introduce opportunities for transformation, creativity, and collaboration across different ways of knowing, interests, and priorities (Murphy et al. 2020; Chalifour et al. 2022).

The present study is focused on wild Pacific salmon *O.* spp., which are highly valued species that support marine and freshwater ecosystems, economies, and diverse user groups (Bottom et al. 2009).[1] Our research is centered on the Pacific region of Canada in the province of British Columbia (BC). This region is home to five species of Pacific salmon including Chinook (*O. tshawytscha*), sockeye (*O. nerka*), coho (*O. kisutch*), chum (*O. keta*), and pink (*O. gorbuscha*).[2] For many Indigenous Peoples in present-day British Columbia, wild Pacific salmon have been and continue to be woven into culture, human well-being, place, and relationality since time in memory (Atlas et al. 2020; Reid 2022).

The remarkable lifecycle and demonstrated ability of wild Pacific salmon populations to respond to environmental disasters and changes have contributed to perceptions of salmon resilience (Waples et al. 2008; Healey 2009; Schoen et al. 2017; King et al. 2023). However, many salmon populations in the Pacific Northwest (most notably at southern latitudes) have declined in abundance compared to historic averages (Beamish 2022; Price et al. 2019).[3] The precise causes and mechanisms of this decline are unclear (DFO, 2019; Oke et al. 2020; Schoen et al. 2017).

Understanding where and how salmon vulnerabilities are expected to change over the next few decades of anticipated rapid change is critical to supporting anticipatory and adaptive resilience-based management (Mcleod et al. 2019). By asking key informants from diverse knowledge backgrounds to look ahead to consider future scenarios, this study makes a novel contribution to research on fisheries conservation in the context of environmental change. We provide an assessment of and predictions about the current and future resilience of Pacific salmon, including variations across species, stocks (an aggregation of populations with similar characteristics and often considered a functional management unit), and geographical areas, and identify areas of consensus among participants to help inform comprehensive management of

[1] We define user groups as including consumptive users (e.g., commercial, recreational and subsistence groups), Indigenous rightsholders, settler governments, NGOs, and the general public.

[2] The present study focuses on these five species of salmon, as they are the Pacific salmon species managed federally in Canada. Steelhead (*Oncorhynchus mykiss*) are biologically similar to Pacific salmon but are managed primarily at the provincial level.

[3] While declines have only accelerated in the twenty-first century, no Pacific salmon populations have yet been listed under Canada's Species at Risk Act despite recommendations to do so by the Committee on the Status of Endangered Wildlife in Canada (DFO 2022; Gayeski et al. 2018). There are Pacific salmon populations, particularly in more northern latitudes, that are stabilizing or even thriving (Beamish 2022).

salmon fisheries and habitat. Through interviews with Indigenous and non-Indigenous decision-makers, practitioners, and knowledge holders, this study aims to (i) identify and compare the factors perceived to affect wild Pacific salmon species/stock resilience and (ii) discuss what this means for the resilience of species/stocks now and in the future. Although our focus is inherently ecological, given that Pacific salmon are intricately connected to the people and communities, our work has broader social-ecological system relevance.

Positioning of the authors

The co-authors, a group of non-Indigenous persons trained in Western science, acknowledge with gratitude that this paper was prepared from the unceded and unsurrendered territory of the Algonquin Anishinaabe Peoples (Ottawa, Ontario). Qualitative research (such as this) inherently involves the researcher's experiences, biases, and understandings. We recognize the relational responsibility to appropriately represent the views and perspectives shared by all research partners. The research team has sought to develop cultural competence and practice ongoing reflexivity throughout the study on how interpretation through the lens of the research team reflects the complexity and nuance of the data.

Methods

Participant recruitment

Interviewees ($N=32$) were recruited using purposeful sampling from four sectors of Pacific salmon science and/or management: federal government fisheries management organizations (GOV), non-governmental organizations (NGOs), Indigenous agencies (I),[4] and universities (U) (Table 1). Our selection process was conducted as follows.

Federal government participants were identified through Fisheries and Oceans Canada (DFO) and the Pacific Salmon Commission's publicly available contact lists. Potential NGO participants were identified through contact lists on websites of NGOs which are members of the Pacific Marine Conservation Caucus (MCC),[5] and individuals' backgrounds were reviewed to ensure at least 6 months of experience working with Pacific salmon management, harvest, conservation, or enhancement.

Table 1 Affiliations of interview participants

Affiliation	N	Total N
Federal government fisheries management organizations (GOV)	11	$N=32$
Non-governmental organizations (NGO)	10	
Indigenous agencies (I)	7	
Universities (U)	4	

Participants from Indigenous agencies were identified in two ways: (i) names were directly obtained from contact lists provided on First Nations websites, where available (e.g., Lower Fraser Fisheries Alliance), and (ii) First Nations fishery professionals known from prior work conducted by Dr. Scott Hinch were contacted. Individuals with experiences in Pacific salmon fishery science and/or management and interest in participating were selected to be interviewed.

Finally, academic sector participants were identified through searching peer-reviewed literature on the Web of Science, published between 2009 and 2019. Keywords included "Pacific salmon" and "fisheries" or "management," "policy," and "conservation." Authors from the first 50 publications of each search were compiled and their expertise reviewed. Those identified as key informants in the field of salmon science and/or management (i.e., having at least two relevant publications, employed in a tenured or tenure-track position at an academic institution, and still working in BC regions) ($N=4$) were invited by email to participate.

Interviews

Research procedures were approved by the Research Ethics Board of the University of British Columbia (Protocol # H18-00692). Participants were assigned code numbers to maintain confidentiality in transcription, analysis, and reported results. Prior to conducting the interview, written or verbal consent was obtained from each participant, including consent to audio recording. In instances of verbal consent, it was subsequently confirmed on audio recordings to ensure a record. Interviews were conducted between April and July 2019 in person or by phone. We employed semi-structured interview methods whereby participants were asked open- and close-ended questions to prompt responses to specific topics as well as digress to further discussion of related themes and issues (Table 2). Interviews began with general questions about each participant's experiences in Pacific salmon fisheries. We then asked questions focused on the following: (i) perceptions of resilience and vulnerability for Pacific salmon resources over time, (ii) perceptions of the

[4] Indigenous agencies include organizations representing First Nations' interests and people in fisheries roles who work for First Nation governments.

[5] The MCC is an independent organization that advocates for marine conservation and provides an avenue for interested groups to participate in formal consultation with management institutions. The MCC aims to represent the interests of the marine conservation community and to inform decision-making through development of policy and advisory positions in Pacific fisheries and marine conservation (Cohen 2012).

Table 2 Interview questions analyzed in this paper, organized by the following categories: perception of British Columbia's environment, Pacific salmon management institution(s), and Pacific salmon. Under each category, we indicate timescales, where applicable

Timescale	Question
BC environment	
Present	Are we currently in a time of environmental uncertainty? If yes, what concerns you the most? Is British Columbia's environment more unpredictable today (than before)? In what ways?
Institution	
Past	Can you describe some of the biggest changes you've seen over the years in how Pacific salmon are managed?
Present	What are the main sources of uncertainty in current in-season management models? Has this changed in the past 10-years?
Future	If you could choose one management action to be implemented tomorrow, what would you choose (i.e., what is the most effective management solution, now and in the future)? Looking further into the future, say 25, 50, and 100 years down the road, what do you think the greatest challenge(s) will be in managing Pacific salmon?
Salmon	
n/a	Do you think Pacific salmon are an inherently resilient species, capable of withstanding a robust fishery and significant environmental changes?
Present	What are your current perceptions on the state of Pacific salmon populations? Do you think this is the case for all populations and species? What are the contributing factors? On a scale from 0 to 10, with 0 being "highly vulnerable" and 10 being "highly resilient", how would you rate the status of the five Pacific salmon species in BC? What do you think makes some species more resilient or vulnerable than others? Salmon runs have healthy rhythms and fluctuations. However, fluctuations are seen to be increasing in variability. What is underlying this variability in salmon run fluctuations (as a sign of potential future difficulties)?
Future	What are the factors which limit the health and survival of Pacific salmon, and how likely are they to compromise the future resilience of Pacific salmon? What do Pacific salmon resources look like in 25 years? 50 years? 100 years? What changes to the Pacific salmon fishery do you expect to see in the next 10 years in terms of population abundances? Harvest levels?

future state of Pacific salmon resources, and (iii) perceptions of how uncertainty plays into existing management processes and necessary possible change.

Closed-ended questions required participants to choose from a range of provided answers. For example, when asked, "How would you rate the status of the five Pacific salmon species in British Columbia?", participants were required to use a scale of 0–10 to respond (with 0 meaning *highly vulnerable* and 10 meaning *highly resilient*) (Fig. 1). Open-ended questions do not have recommended answers (e.g., when asked, "Looking further into the future, say 25, 50, and 100 years down the road, what do you think will be the greatest challenge(s) in managing Pacific salmon?", participants were encouraged to provide any answers that they thought relevant to the topic).

Coding and analysis

Interviews were first transcribed by the software Trint, manually reviewed, and corrected by a research assistant. The corrected transcripts were re-read by Y. Wang to identify important and recurring themes in responses. A codebook was developed by Y. Wang using a general inductive approach, as described in Thomas (2006). As each interview was analyzed by the research team, codes were assigned to words or phrases that expressed essential concepts or ideas emerging from the text. Following a thematic analysis approach (Attride-Stirling 2001), H. Postma and V. Berseth read the responses to identify patterns and relations between the codes. Related codes were grouped into broader categories (e.g., factors affecting salmon resilience and future challenges) that were then organized according to three high-level organizing themes: (i) environment, (ii) institutional capacity, and (iii) salmon.

Thematic and inductive analysis inherently involves the researcher's experiences, biases, and understandings, making exact replication unlikely. To account for the potential differences that may arise in interpretation, the research team consistently discussed and resolved differences in the definition and applications of codes, as well as interpretations of the data. This required consistent critical reflection and

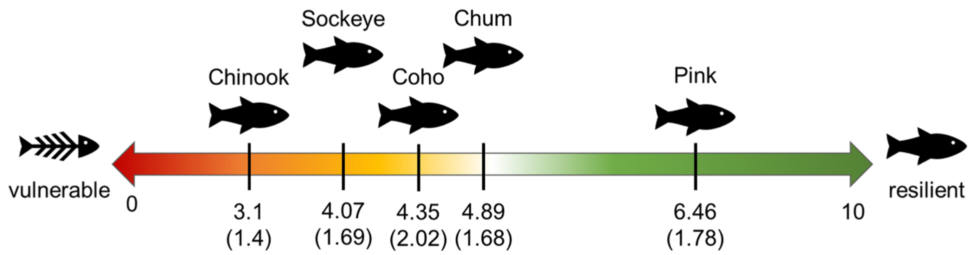

Fig. 1 Mean assessment of Pacific salmon species along a vulnerability-resilience continuum (0–10), standard deviation in parentheses

ensured that no single interpretation dominated the analysis. While acknowledging the limitations of qualitative analysis, this research holds value because of the diversity of the participants and the breadth and depth of answers provided.

Findings

We found widespread agreement among respondents (32 of 32) in their assessment of whether Pacific salmon are resilient and capable of withstanding environmental and fishery-related changes. There were no respondents who described salmon as simply "resilient." Instead, interviewees described salmon resilience as context-dependent and subject to change over time. Table 3 provides a summary of the factors respondents identified and contains illustrative quotes.

A minority of respondents ($N=3$) pointed to salmon's evolutionary capacity to adapt to their local environment as evidence that while some populations may become more vulnerable, others have the propensity to pass on beneficial adaptations (e.g., heat tolerance). One participant expressed surprise at the ability of salmon to withstand pressures from human activity, describing salmon as presently resilient, but "not because of management. If anything, they should be gone" (Participant 91, I). Interviewees identified a range of factors that positively or negatively impact salmon resilience, including biology, environment (e.g., changing climate, water conditions), human activities and management practices, and the interactions between them.

Factors affecting resilience

Biology

Salmon biology was a primary focus for participants in how they understood Pacific salmon resilience. The five species of Pacific salmon share a number of life history attributes, meaning that they all, to some extent, share a common vulnerability to particular stressors (Braun & Reynolds 2014). Pacific salmon are anadromous and are exposed at some point in their life cycle to stressors and changes in both marine and freshwater environments. However, each species has its own life history (Waples et al. 2008), and participants noted several important differences in the biology of each species that make certain stocks more resilient or vulnerable, including freshwater dependency, length of migration, lifespan and life cycle, and the ability to stray to non-natal streams to spawn.

Overall, when participants considered the resilience of the five Pacific salmon species, Chinook, sockeye, and coho populations were perceived to be more vulnerable because of their longer life cycles and freshwater dependency. Some Chinook, sockeye, and coho populations spend at least 1 year in freshwater before migrating to the ocean and returning to their natal streams. In general, participants described Chinook and sockeye stocks as the most vulnerable to freshwater conditions (e.g., species with philopatric life histories spend more time in and are more susceptible to changes in freshwater habitat). However, certain characteristics (e.g., differences in the timing of adult spawning migration and utilization of and access to freshwater habitat) have produced differing life history strategies among populations (e.g., ocean-type and stream-type Chinook populations, whereby juveniles of the former leave shortly after emergence to rear in an estuary while the latter spend a year in freshwater). Perception of certain stocks may differ depending on locale as ocean-type Chinook and sockeye are generally found along the coast, and stream-type comprise interior populations. Some stocks in British Columbia (e.g., Upper Fraser sockeye) travel far distances in their migration to and from the ocean. Species and stocks which have increased dependency on freshwater and freshwater habitats are perceived to be more vulnerable because of the changing, or loss of, optimal habitat. Across all life stages, good and accessible habitat is necessary for the health and resilience of Pacific salmon (Crozier et al 2021).

Longer life spans also mean that salmon spend more time in marine environments, increasing their exposure to fishing and predation pressures. As one participant (Participant 09, NGO) noted, Chinook have longer life spans, and an increased likelihood of "getting killed by somebody or something". Respondents ($N=6$) described pink and chum salmon as comparatively more resilient because of their lesser dependency on freshwater (e.g., juveniles migrate to the ocean immediately or shortly after emergence) and their

Table 3 Summary and illustrative quotes of the cumulative and overlapping factors identified by respondents as affecting salmon resilience

Main factors	Sub-factors	Quotes
Overall resiliency	Context-dependent	"I don't think they're doing poorly as a whole and I certainly don't think they're doing well as a whole. There's some runs that are doing okay, or do okay in most years, but … the fluctuations that we're seeing are increasing, and the overall trend is poor" (Participant 01, NGO) "When you talk to people like me, you have to break it down on a per species, per system basis because they all have challenges. I work in the Lower Mainland [region]. So our challenges are urbanization" (Participant 42, GOV) "They adapt to a whole lot of nasty stuff over the course of their evolution. They've adapted to more extreme climate changes than we're seeing now. I think there's natural selection that will produce a lot of adaptation, but there are limits to how that goes along. We're going to see a bunch of populations disappear but I think even after we've had a lot more global warming, there will be a large number of populations that will be healthy" (Participant 57, U)
Biology	Species Life history	"Interior Fraser Chinook and sockeye, and coho. Those ones would be highly vulnerable because they have a lot of migration distress" (Participant 25, GOV) "I guess I rank chum higher because they stray. They don't have to come back to the exact same river ... some portion of them will go elsewhere. They'll colonize to some degree. They're not as picky about returning, some percentage of them return to other locations" (Participant 03, NGO) "Chum don't get higher into the upper watershed. They're not able to get past Hell's Gate, really. So the chum are relegated to the Lower Fraser where there are a lot of habitat impacts on all the small streams that they use. But beyond that they could be quite resilient because similar to pink they're only in freshwater to spawn in the gravel and then the chum leave very quickly and they actually have four generations so they have a little bit more bet-hedging than the pinks do in that way. But they also kind of get more up in the little tributaries to spawn and those habitats are often affected" (Participant 02, NGO)
Environment	Habitat Food sources Predation Ecosystem-dynamics Climate change	"The general declines in productivity and fluctuations year-to-year that we're seeing is very troubling. And we know that the scientists within DFO and academic institutions, and elsewhere, are telling us it's heavily linked to climate change. The situation we're seeing around salmon currently is likely to get worse, not better" (Participant 61, NGO) "River temperature for sure, because fish really do not like going up the river unless the rivers have a certain temperature. And unfortunately, with the river heating up more and more every year… I mean, half a degree doesn't sound like much. But over five years? That's two and a half degrees, going from fifteen to seventeen and a half" (Participant 91, I) "[Chinook] seem pretty sensitive to the changes in the food web. I don't know if they're particularly more vulnerable, but they're more exposed to more stressors such as orca predation and fisheries" (Participant 60, U)
Human activities and management	Fishing practices Aquaculture Human interest (Mis)management	"They have a strong ability to bounce back because of their high fecundity. But I don't think that means that we can just do whatever we want to their habitat, and in terms of fishing pressure, there's a lot of change going on. A lot of habitat loss. They can probably tolerate it to a certain level, but there becomes a point when the combination of fishing and habitat becomes an issue. So, I think salmon could adapt to climate change if we rolled back all the other things we're doing to them" (Participant 02, NGO) "It's not whether salmon do good or bad from year to year … we have failed completely to manage our [fishing] behaviours to account for the need to get enough fish back to spawn. We have taken risks, way too many risks for way too much time. And we're at a point now where I don't think that we have the kinds of abundance and diversity to withstand our human footprint on their environment, let alone fishing" (Participant 89, I) "They're still allowing salmon to be farmed in open net pens despite the huge body of literature and evidence shown that this harms populations. That doesn't put conservation first in my opinion. I think that they are nowhere near where they need to be" (Participant 59, U)

putative increased ability to stray to non-natal streams. However, there were some differing opinions as to whether lesser freshwater dependency does in fact increase resilience for pink and chum salmon. One view expressed by respondents was that chum may be considered more vulnerable than pink salmon because chum often spawn in streams close to the ocean, and BC's largest salmon-producing rivers originate in southern regions of the province with increasingly concentrated urbanization (Maas-Hebner and Dunham 2014; Ettinger et al. 2021).

Environment

Participants described the climate in BC as increasingly unpredictable. $N=6$ identified the connection between climate change and current fluctuations in salmon runs as a troubling sign. Overall, participants shared a consistent concern that changes in environmental conditions across marine and freshwater ecosystems affect salmon resilience. For marine environments, participants identified ocean acidification, commercial fishing, prey availability, heat waves, warming waters, and changing food web dynamics to be considerable factors affecting perceived resilience. Freshwater environmental factors include loss of good, accessible habitat to spawn or migrate (e.g., habitat destroyed or altered by and for humans), and fishing and other predation pressures. These issues are cumulative and overlapping (Arlinghaus et al. 2016). Increasing ocean and river temperatures were described as key issues driving species to become more vulnerable over time.

Environmental changes were predicted to impact salmon differently depending on factors such as life history and geography (e.g., southern and interior vs. northern and coastal stocks). Moreover, the relative importance of certain factors will change over time, with some populations of species (pink salmon) benefiting from climate change, and others experiencing increased vulnerability (Chinook, sockeye, and coho).

Human activities

Participants shared multiple ways in which humans affect the resilience of Pacific salmon, including by harvest, habitat alteration, and salmon production. As outlined above, good habitat is critical to survival, and human activities have a direct impact on the quality and availability or accessibility of salmon habitat. Respondents also discussed the need to manage harvest activities (e.g., through assessing stocks, allocating fishing licenses, and enforcement of fishery regulations) to maintain a sustainable rate of exploitation of salmon stocks. Management was perceived to be challenged by the need to balance competing interests across user groups. Many ($N=12$) respondents, including ($N=3$) federal government staff, described current fisheries management as biased towards fisheries (e.g., harvest controls) and noted the need to increase the attention and resources given to conservation initiatives such as habitat restoration and efforts to rebuild populations. Overall, participants were critical of decisions that have undermined salmon resilience, though some ($N=4$) noted that decisions made about salmon have improved over the last 10 years.

Species such as Chinook, sockeye, and coho were perceived to be more vulnerable because they are more highly valued and targeted by recreational and commercial fishers, while chum and pink salmon are not considered vulnerable at present because they are not considered by these user groups to be a valuable trophy fish or as important for economic gain. However, even though some management practices have been employed to reduce fishing on certain vulnerable species or stocks, these fish are still made vulnerable to harvest by fishers intentionally or accidentally through mixed-stock fisheries.

Predictions about future salmon resilience/vulnerability

Participants spoke to variation across salmon populations in BC and to the growing complexities of salmon management in a changing environment. Most populations are expected to decrease over the next 10 years, with increased instability among others. Loss of good and accessible habitat (Finn et al. 2021) is predicted to drive some salmon populations further from dense human settlements (e.g., shift northwards), or disappear altogether. Most participants anticipate harvest levels to decrease across populations, particularly for Chinook and coho.

> "Overall it will remain very complex. I think some stocks will do okay. I think if we're lucky, some stocks might do well, and some stocks will do very poorly. I think certainly the ones that are in trouble now are in so much trouble that they're not going to rebound" (Participant 71, NGO)

Some participants ($N=4$) explained that sockeye harvest restrictions are already high, and populations could be expected to remain stable in the near future. However, even under current recreational and commercial harvest restrictions, populations are not expected to increase. Some species, such as pink and chum, may stay stable for now, though participants expect to see shifts in the future if fishers are required to reduce pressures on Chinook, sockeye, or coho, or if those populations extirpate or go extinct. In southern regions of BC, participants expect lower abundances to be defined as the new normal, and "harvest levels to be adjusted accordingly" (Participant 24, GOV). Another participant said that, "…some sockeye stocks are not recovering, even in the absence of fishing" (Participant 94, I).

The loss of some stocks through extirpation (e.g., stocks shifting northwards) or extinction, and the increasing fluctuations in salmon runs, are expected to have wide-reaching implications. Participants spoke to the fragmentation of habitat and its effect on ecosystem dynamics and lifeway for many who depend on and interact with salmon (e.g., as a vehicle of nutrients, an economic resource, and critically, for some, a cultural heritage).

Lessons learned and future directions

The present study invited decision-makers and knowledge holders to look ahead and consider the possible futures for salmon. There are several lessons that can be learned from the responses about how salmon resilience is viewed by people with a vested interest in salmon health, and who can influence the practices through which salmon are cared for.

Lesson 1: resilience is context-dependent and difficult to predict

Over time and across literature, Pacific salmon have been described as inherently resilient species, despite ongoing declines (Holt 2010; Schoen et al. 2017). However, as several scholars have argued, assuming that salmon are inherently able to withstand external pressures has contributed to a loss of salmon's capacity to be resilient (Bottom et al. 2009; Healey 2009; Waples et al. 2009). From this view, there is no guarantee that salmon will continue to be resilient within the context of an evolving and increasingly unpredictable climate. We found that while there are high-level concerns about the declining condition of Pacific salmon, not all salmon are assessed along the resilience-to-vulnerability continuum in the same ways. Rather, the health and sustainability of certain populations are affected, and increasingly so, by myriad complex and interconnected biological, environmental, and social factors. Moreover, as noted by participants, growing uncertainty presents a substantial challenge to decision-makers' ability to anticipate and respond to salmon vulnerability and resilience into the future.

Lesson 2: under climate change, salmon face several possible scenarios: extirpation, winners-and-losers, and adaptation

While some environmental changes have positively contributed to variation in salmon production in the past (Finney et al. 2002; Waples et al. 2008), Pacific salmon must now confront cumulative and unprecedented climate impacts (Crozier et al. 2021; Rust & James 2023). When asked to speculate about the future state of Pacific salmon, key informants spoke to three possible scenarios: (i) all salmon populations will experience a decrease in abundance; (ii) some species and populations will benefit from climate change, while others will not; and (iii) salmon can adapt to new climate realities.

All decrease/extirpate — no consensus

Emerging patterns in Pacific salmon abundance suggest that most populations are expected to decline or face increasing uncertainty over the next generations (e.g., Chinook, sockeye or coho stocks which may be extirpated or go extinct could result in the increased harvest of other species). While some species may have a greater capacity to withstand some external pressures, several participants raised concerns about large-scale oceanic and climatic regime shifts that are expected to have negative impacts on overall salmon productivity, consistent with existing literature (Price et al. 2017; Wilson et al. 2022). For example, a recent DFO technical report (Grant et al. 2019) found that the effects of climate change impact salmon at every stage of their life cycle and that general patterns in abundance are emerging concurrent with climate habitat changes. However, there was no shared consensus among salmon key informants that widespread extirpation was likely.

Winners and losers — strong consensus

The scenario most commonly suggested by participants was the potential for winners and losers. This view holds that, regardless of their ability to adapt, some species and populations will be more favored by changing environmental conditions than others (Farley et al. 2020; Schoen et al. 2017). Pacific salmon utilize both marine and freshwater habitats and the extent to which populations are exposed to environmental conditions is inextricably linked to life histories and spatial distribution (Braun and Reynolds 2014; Crozier et al. 2008). The vulnerability of salmon and the predictability of salmon runs are also strongly attributed to the loss of good and accessible freshwater habitat (Bisson et al. 2009; Gosselin & Anderson 2017), and populations with greater freshwater dependency, such as stream-type Chinook and river-type sockeye (where juveniles which spend a year in freshwater before migrating long distances to the ocean) (Beacham et al. 2004), are especially vulnerable to climate-related habitat impacts (e.g., earlier freshet events which can scour gravel-laid eggs) (Honea et al. 2016; Jeffries et al. 2014).

Population abundance was predicted by respondents to vary across species, stocks, and location. While some populations of Chinook, sockeye, and coho were predicted to decline or disappear in an uncertain environment, our findings are consistent with Farley et al. (2020) in that climate change may (at least in the near future) positively impact pink salmon. A warming ocean and northern hemisphere (including glacial retreat, longer periods of ice-free conditions, and warming freshwater habitat) are predicted to result in pink population expansions including into new northern ranges (Frommel et al. 2020; Pitman et al. 2021). These changes are linked to increasing interspecific competition, posing unique changes to ecosystem dynamics across the Pacific Northwest (e.g., Chinook, sockeye) (Connors et al. 2020; Ruggerone et al. 2023; Couture et al. 2024).

Salmon will adapt to new climate realities — low consensus, context- and species-dependent

There were varying views on whether salmon will be able to adapt and how the major factors identified above — biology, environment, and human activity — will alter salmon's adaptive capacity. Existing research has shown that salmon may adapt to changing climate realities, such as through increased straying (Bett et al. 2017), shifting geographic ranges from southern regions to more favorable conditions in northern regions (Nielsen et al. 2012), and changing dietary patterns (Kaeriyama et al. 2004). For some ($N=3$), the evolutionary capacity for salmon to adapt to their particular spawning grounds suggests that even a few surviving salmon will be sufficient to pass on genetic traits associated with greater survival. However, most respondents shared concerns about the rate and intensity of climate changes outpacing salmon's adaptive capacity or destroying vital ecological niches. Thus, climate change is similarly viewed by salmon key informants as contributing to the possibility for winners and losers as some salmon species and populations may be able to adapt, while others may not.

Lesson 3: there are some ways that humans can help support salmon resilience, but management faces several challenges

The present study of Pacific salmon in Western Canada exemplifies a social-ecological system in which salmon resilience is inseparable from human actions, from harvest and management to habitat (Waples et al. 2009; Woods et al. 2022). Yet, after decades of research, and the implementation of the Pacific Salmon Treaty and Canada's Wild Salmon Policy, most wild Pacific salmon stocks in British Columbia remain unquantified, and their conservation status remains unknown (Grant et al. 2019; Price et al. 2017). An uncertain environment and a shifting perception of salmon along the resilience/vulnerability continuum suggest that salmon are not being managed sustainably for use by the people and ecosystems that depend on them (Gayeski et al. 2018; Healey 2011; Walsh et al. 2020).

While commercial and recreational harvesting practices have been a focal point of debate around salmon management in Canada (Walters et al. 2019; Nguyen et al. 2016), the findings of this study suggest that there may be limits to the effectiveness of current federal government fisheries management to support salmon resilience. Key informants predict harvest restrictions will increase across all populations in correspondence with lower abundances (e.g., even with reduced fishing pressures, populations of Chinook, sockeye, and coho are not expected to increase), yet participants also expect populations to decline or become less predictable. As a result, simply adjusting harvest or catch may not be sufficient to reverse declines in struggling populations. We find these results particularly noteworthy as they suggest a change in the perception of salmon's ability to overcome the challenges posed by its changing environment, indicating a shift in how salmon decision-makers and practitioners perceive the placement of salmon on the vulnerability/resilience continuum. It also underscores the importance of addressing all three intersecting factors affecting salmon resilience.

At the same time, some respondents levied critiques at the general approach in management that, from their view, is biased towards the economic interests of fisheries. The interviews did not ask participants directly about these conflicting views (perceived favoritism towards fisheries and anticipated increasing fisheries restrictions). However, it is possible that the idea of Pacific salmon as perpetually characterized by "winners and losers" reinforces a sustainable harvest approach which maintains that harvest and conservation can coexist. In other words, there may be a normalized view that while salmon may be declining in some areas, there are other populations that are sufficiently abundant to support continued commercial and recreational harvest. This may suggest some degree of "shifting baseline syndrome," which Thurow et al. (2020) define as a paradigm whereby new population abundances and environmental conditions are accepted as normal (i.e., not a cause for regulatory change). Moreover, the salmon species identified as most vulnerable by key informants in this study (Chinook, coho, sockeye) are also the species respondents characterized as most valuable for commercial and recreational purposes.

These findings support previous research on other aquatic species (e.g., coral) that call for monitoring to expand beyond static measures of biodiversity such as abundance, which can be poor measures for resilience (Mcleod et al. 2019; Burgass et al. 2018). The present study shows that managing for resilient salmon will require simultaneously balancing trade-offs between social and economic values, increasing protections for vulnerable species (such as directing fishing effort towards more terminal fisheries) (Atlas et al. 2020), and substantially increasing investments into non-harvest management tools at multiple scales, such as biological monitoring and freshwater habitat restoration.

This study also points to several areas for further research to access gaps in current academic literature and federal government management/knowledge. First, while the present study focuses on the resilience of salmon, respondents also pointed to the challenges for management under conditions of uncertainty. There is a need to better understand whether current management and conservation plans are themselves resilient and capable of responding to increasing uncertainty. In particular, valuable contributions can be made by work that examines where there may be mismatches between the institution and the species they manage. Additionally, while the present study focused specifically on managers and academics, comparative analyses of perceptions among wider groups of fisheries and environmental interest groups would be valuable for expanding the diversity of knowledge and views that make up the social context in which salmon are managed.

Second, more detailed assessments of salmon resilience are needed within species (e.g., by population, by Conservation Unit). Overall salmon abundance has been in decline along Canada's West Coast since the 1990s (Noakes et al. 2000; Price et al. 2017), and the impacts of these changes (e.g., presence/absence of certain stocks and certainty of runs) have wide-reaching implications for many whose lives and livelihoods intersect with Pacific salmon. For many Indigenous Nations across the Pacific Northwest, uncertainty around annual salmon returns poses a significant concern (CRITFC 2021; Reid et al. 2022). By identifying key factors affecting populations that are critical to Nations, these findings can help salmon-centered communities prepare for anticipated shifts in abundance and distribution, as well as possible loss of valued stocks.

Finally, a related area for further research is the potential for changes in perceptions and social preferences for harvesting species and the fisheries (commercial, recreational, Indigenous) that depend on them. The prospect of winners and losers at the species level suggests that fisheries may shift towards pink and chum salmon, which are at present perceived to be more abundant and more resilient, though chum have also experienced declines in some areas (Atlas et al. 2020). However, as we note above, the interaction between biological, ecological, and harvesting pressures suggests that increasing harvest pressures on these species may impact their overall resilience. In other words, species that are presently resilient are not necessarily guaranteed to remain so in the future. Transformative management approaches that can respond to unpredictable shifts in vulnerability will be increasingly important in the future. We emphasize that what that transformation looks like will be up to each First Nation and will presumably require a fundamental shift in power dynamics (Reid et al. 2022).

Conclusion

The complex set of challenges posed to wild Pacific salmon and fisheries managers necessitate an approach which prioritizes collaboration and conservation (Bottom et al. 2009; Nyboer et al. 2022; Thompson et al. 2019). This study asked key informants to reflect over a long time horizon to make predictions about the future resilience of salmon and expected changes to this interconnected social-ecological system. However, it is important to consider that this work was conducted in 2019, and, as such, the findings need to be interpreted in that context given ongoing ecological change and socio-political dynamics. For example, the COVID-19 pandemic occurred shortly after the survey was completed (which caused us to re-evaluate our relationship with nature), and for some Pacific salmon stocks in BC, there has been evidence of both recovery and further decline. The specific details need to be interpreted in that context, but the broader perspectives and associated recommendations (e.g., to transform management systems) are germane and should have salience moving forward given that the status quo has failed to achieve resilience.

Foresight science such as this is being widely used in conservation and natural resource management as a means of ensuring that managers are prepared for different futures (Ednie et al. 2022). However, there has been a noted lack of reflexivity in foresight research about the values and political dynamics that frequently exclude or marginalize groups, including Indigenous Peoples (Rutting et al. 2022). We surveyed participants across a wide range of knowledge backgrounds, including decision-makers, practitioners, and knowledge-holders, on trends in the health and status of salmon populations, values, risks, and uncertainties. In doing so, we were able to determine areas of agreement and consensus about the challenges posed to the health and sustainability of salmon populations and what could be done differently by those involved in salmon decision-making to support salmon resilience now and in the future. We argue that assessments of species resilience and vulnerability can be strengthened by learning from areas of commonalities between complementary knowledge bases, which can in turn provide a more robust basis for more effective fisheries governance. Parliamentary governments struggle with how to bring qualitative data and perspectives into decision-making processes for Pacific salmon given the historic reliance on quantitative stock assessment. Transformation in management will also require ensuring that diverse knowledge forms, domains, and area of inquiry are considered together.

The overall consensus shared by study key informants is that salmon resilience is not immutable: there are limits to the extent to which salmon species can experience external pressures and persist or (ideally) rebound when conditions become favorable. Indeed, for several respondents ($N = 13$), Pacific salmon are past the point where adjusting harvest levels will be sufficient on its own to improve salmon populations into the future. This study raises questions about the tolerance of salmon to change, including the magnitude and diversity of changes that Pacific salmon withstand in order to adapt or maintain their health.

Author contribution Hinch, Young, and Cooke secured funding, conceptualized the study, and mentored students. Material preparation, data collection, and codebook generation were performed by Wang. Following a thematic analysis approach, Postma and Berseth identified and categorized organizing themes. The first draft of the manuscript was written by Postma and Berseth. All authors provided significant comment on previous versions of the manuscript.

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Data Availability You are welcome to contact the authors for any questions about the data used in this research.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval The questionnaire and methodology for this study were approved by the Research Ethics Board of the University of British Columbia (Protocol # H18-00692).

Consent to participate Informed consent was obtained from all individual participants included in the study.

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