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Re-imagining the precautionary approach to make collaborative fisheries management inclusive of Indigenous Knowledge Systems

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Abstract

Fisheries science uses quantitative methods to inform management decisions that reflect cultural preferences which, in turn, indirectly influence the states of ecosystems. To date, it has largely supported Eurocentric preferences for the commodification of marine organisms under the tenets of maximum sustainable yield, whereby abundances are intentionally maintained far below their historical baselines despite broader socio-ecological trade-offs. In contrast, Indigenous Knowledge Systems (IKS) adhere to the principle of "take only what you need and leave lots for the ecosystem," implementing lower fishery removals to support socio-ecological resilience. Despite the power imbalance favouring Eurocentric preferences in decision-making, fisheries scientists increasingly recognize that the pairing of IKS and Western science, or Two-Eyed Seeing, would lead to more holistic management goals. For recognition to transcend tokenism, meaningful collaborations and co-governance structures underlying knowledge co-production must carry through to legislated policy changes. Using recent co-governance developments for fisheries management and spatial protections involving federal, provincial and Indigenous governments in Pacific Canada, we illustrate how the precautionary approach, including reference points and harvest control rules broadly applied in international fisheries, could be revised to make collaborative fisheries management compatible with IKS and improve biodiversity and fisheries protections. Our recommendations may create socio-economic trade-offs at different timescales for commercial fishers. Pre-empting that challenge, we discuss IKS-compatible economic approaches for addressing shorter term costs arising from reduced exploitation rates. Although our case study derives from Pacific Canada, the insights provided here are broadly applicable elsewhere in the world.

KEYWORDS
biological reference points, ecosystem-based fisheries management, harvest control rules, indigenous co-governance, size and age structures, two-eyed seeing

1 | INTRODUCTION

1.1 | Positionality statement

The work we present here is an expression of pluralism: the idea that people of different beliefs and backgrounds can – beyond mere coexistence – collaborate in the coalescing of diverse knowledge and value systems to improve the common good. We have come together as a group of Indigenous knowledge holders who live in their traditional territories and have technical backgrounds in fisheries and marine spatial planning (MR and JW), and settlers with academic training in fisheries or ecology who work directly for Indigenous Peoples (AF, KLW) or Canada's federal government (RF). While most of our message is told in a Western scientific voice and follows academic conventions, some concepts are told in a voice which conveys the knowledge of the Indigenous authors, as acquired through lived experience and oral traditions; such content includes Section 3, Table 1, and two statements by JW which we present as quotes to highlight their intentional shift to an Indigenous voice.

The work sprung out of frustration about the current lack of legitimate and widespread inclusion of Indigenous Knowledge Systems in Canadian fisheries management. Over the course of the work, that impetus morphed into a positive vision upheld by the questions: What kind of world do we want to live in? How can we get there together?

1.2 | Background

Cumulative impacts from industrialized society imperil the oceans (Georgian et al., 2022), yet pluralistic approaches to managing human activities can help mitigate the problem (Gavin et al., 2018). Accordingly, fisheries scientists are learning that Two-Eyed Seeing – a term created by Mi'kmaw Elder Albert Marshall to encapsulate the pairing of Indigenous and Western knowledge systems – can better support the resilience of socio-ecological systems (Reid et al., 2021). Examples include collaborations to determine escapement levels for Pacific salmon (*Oncorhynchus* spp., Salmonidae) that allow bears and people to share a common resource along the same river (Adams et al., 2021), and collaborations identifying the best locations to spatially protect declining fish species (Aswani & Hamilton, 2004). When the Indigenous eye and the Western scientific eye look at the same problem together, they can create a much clearer picture. They can pair the holistic, place-based, deep-time-rooted knowledge of Indigenous Peoples with the technologies and methodologies of Western science to create a more ecologically balanced view of the world. Operationalizing these concepts into policies and legislation, however, can be difficult (Almack et al., 2022). This paper, therefore, examines potential pathways for meeting the challenge of collaborative fisheries management involving Indigenous and Western knowledge systems.

To begin, scientists and managers need to understand what Indigenous Peoples mean when they refer to Indigenous Knowledge Systems (IKS) – a concept that may vary between Indigenous cultures while maintaining key centralities (Kovach, 2021). Anishinaabe scholar Deborah McGregor (2021: 3) defines IKS as "the broader political, legal, economic, and cultural systems that enable the continued generation and renewal of Indigenous Peoples to ensure their well-being." Similarly, Potawatomi scholar Kyle Powys Whyte (2013: 5) refers to IKS as "the living environmental governance of indigenous peoples stemming directly from their cosmologies in relation to the environmental challenges they have faced over many generations." Both authors highlight the inseparability of IKS from the people and lifeways from which they originate (McGregor, 2021;

Whyte, 2013). We note that Whyte (2013) used the term "traditional ecological knowledge (TEK)" while McGregor (2021) advanced the analogous term "Indigenous Knowledge Systems (IKS)." Consistent with McGregor's more recent terminology, when referring to earlier works we sometimes use "IKS" as a substitute for what the authors termed "TEK" or "Indigenous Knowledge (IK)."

Western science is a positivist approach for gaining knowledge through hypothesis testing. Although empiricism characterizes both Western science and IKS (see Section 2), only Western science strives for objectivity, thereby attempting to separate knowledge generation from the cultures, governance and values of people who generate that knowledge (Berkes, 2018; Muradian & Gómez-Baggethun, 2021).

IKS have long managed relationships between humans and the ocean via spatial and aspatial approaches. These approaches interrelate, and their interrelatedness will frame several of our arguments. Spatial approaches include Hereditary Chief governance in Pacific Canada and marine tenures in Oceania, wherein specific individuals hold inherited rights and responsibilities for stewarding specific areas and the authority to close local harvests for conservation (Johannes, 1978; Trosper, 2003). Aspatial approaches include harvests that are (1) selective for species, size, sex, health status or other characteristics, (2) intentionally partial such that most harvestable biomass is left in the ecosystem and (3) distributed over space, seasons and a suite of species so that no locale or species risks overharvest (Johannes, 1978; Mathews & Turner, 2017; McKechnie & Moss, 2016). These and other aspects of IKS are informed by detailed observations of ecosystem change and imbued by worldviews in which humans are obligated to maintain reciprocal and respectful relations with all beings (Berkes, 2018; McAllister et al., 2023; Reid et al., 2022). The flourishing of populous, technologically advanced Indigenous societies over the centuries and the resilience of cultures and ecosystems under their care in the face of colonial disruptions attest to the long-term successes of IKS (McAllister et al., 2023; Trosper, 2003).

Western systems of fisheries management and marine conservation also apply spatial and aspatial approaches. Spatial approaches can include area-specific restrictions or closures, often temporary, to support recovery of specific taxa, and marine protected areas (MPAs) which permanently exclude some or all extractive activities for broader biodiversity and fisheries protection (Baskett & Barnett, 2015; Sullivan-Stack et al., 2022). MPA networks enhance these benefits by promoting connectivity between protected ecosystems, representing all known elements of regional biodiversity and protecting priority habitats and species across multiple MPAs (Carr et al., 2017). When involved from the outset in their governance, planning, scientific advice and development, Indigenous Peoples may view MPAs and other spatial protections as consistent with IKS (Ban & Frid, 2018; Jones et al., 2010; Reid et al., 2022).

Aspatial approaches in Western fisheries management, like those of IKS, aim to control fishing mortality and species selectivity, applying quota systems and gear, season, license and size restrictions. Although fleet industrialization and non-selective fishing gear have curtailed species selectivity by many commercial fisheries (Davies et al., 2009), bycatch mitigation measures are on the rise (Gale et al., 2022; Hannah et al., 2015; Sullivan, 2022), suggesting that species selectivity by commercial fisheries could eventually align with that of IKS.

Western and IKS approaches to biomass removals, however, have been largely unaligned. A primary goal of Western fisheries management is to manage most stocks for maximum sustainable yield (MSY) – the maximum exploitation rate that can be applied without compromising future exploitation while assuming steady-state ecological and environmental conditions – which requires fishing down stocks to the biomass level at which population productivity is theoretically maximized via density-dependent effects on recruitment success (reviewed in Punt et al., 2014). The biomass required to enable MSY harvests, B_{MSY}, averages ≈40% of a stock's unfished spawning biomass (Thorson et al., 2012). In contrast, for IKS a primary goal of fisheries management is to adhere to the principle of "take only what you need and leave lots for the ecosystem (Reid et al., 2022)," thereby ensuring protection of all resources for future generations (McAllister et al., 2023). Indigenous Peoples, therefore, often perceive the aspatial approaches of Western fisheries management as threats to their cultures and ecosystems (Silver et al., 2022). This perception does not necessarily reflect a mistrust of Western science (Reid et al., 2021). Rather, it reflects disagreement with the commodification of species underlying Western management whereby – in line with a Eurocentric axiology – ecosystem components either have commercial value or are deemed value-less (Kovach, 2021; Reid et al., 2022).

Consistent with IKS (Johannes, 1978), Western perspectives recognize that spatial and aspatial management approaches are complementary (Sullivan-Stack et al., 2022). For instance, MPAs may displace fishery effort and confine fisheries to a smaller footprint which, in the short term, may require quota or fleet reductions to prevent unsustainable exploitation in fished areas (Hilborn et al., 2004). In the longer term, increased production within MPAs may generate the spillover of larvae or adults into fished areas and enhance future catches (Barceló et al., 2021). More generally, MPAs can protect trophic structures and natural carbon stores, contributing to the resilience of ecosystems and fisheries in a warming ocean (Roberts et al., 2017).

Fisheries managers must consider economic trade-offs created by spatial or aspatial fisheries decisions (Qu et al., 2021; Sen, 2010; Sumaila, 2021). Western approaches to understanding these trade-offs typically involve cost–benefit analyses, which have often espoused shorter term perspectives and treated marine organisms as commodities while ignoring broader ecosystem perspectives (Sumaila, 2021). An improved fisheries economics would apply concepts compatible with the holistic and intergenerational perspectives of IKS, including "value-over-volume" in which market-based solutions can lead to increased profits from reduced catches

(Sullivan, 2022), intergenerational discounting, which accounts for the longer term economic benefits of marine spatial protections and stock rebuilding above MSY levels (Sumaila, 2021), and valuation of nature's benefits to people, including carbon stores (Luisetti et al., 2019).

1.3 | Case study and objectives

Recent developments in marine co-governance of the Northern Shelf Bioregion, British Columbia (BC), Canada, serve as a case study for deepening discussion on the complementarity of spatial and aspatial management and the role of Two-Eyed Seeing. Since 2015, the governments of 15 First Nations (a term identifying Indigenous groups in Canada who are not Métis or Inuit), the Provincial Government of BC and the Government of Canada have worked as co-governance partners to develop an MPA network for the Northern Shelf Bioregion (MPAN-NSB; see map in Appendix S1); the ongoing process includes consultation with commercial fishers and implementation is expected to begin in 2025 (MPA Network BC Northern Shelf Initiative, 2023). The primary federal partner is Fisheries and Oceans Canada (DFO), an agency tasked with ecosystem and resource management for marine waters. DFO plays a critical role: under federal law, they uniquely hold the authority to legislate MPAs that exclude or limit fisheries. Also, critical is the co-governance role of First Nations, who have applied Two-Eyed Seeing to support their proposed spatial protection zones (Reid et al., 2022; Watson et al., 2021).

The MPAN-NSB has six goals and the first two directly relate to protecting biodiversity and fisheries (Appendix S2). Goal 1 is "To protect and maintain marine biodiversity, ecological representation and special natural features." The seven objectives under Goal 1 (Appendix S2) collectively aim to protect biodiversity elements, including genetic and phenotypic variability, habitat heterogeneity and species interactions required to maintain ecosystem functions and resilience. Goal 2 is "To contribute to the conservation and protection of fishery resources and their habitats." The three objectives under Goal 2 (Appendix S2) collectively aim to protect the stability, productivity, habitats and size and age structures of fished stocks. Indigenous co-governance partners support these goals (Reid et al., 2022).

Alongside the MPAN-NSB process, in 2019, the governments of Canada and of eight First Nations within the Northern Shelf Bioregion signed the *Fisheries Resources Reconciliation Agreement* (FRRA; amended in 2021), which supports collaborative governance (i.e. shared authority) of fisheries by signatory First Nations and the federal government (FRRA, 2021). This agreement could support implementation of spatial and aspatial fisheries management approaches that better align with IKS.

Commercial fisheries in the Northern Shelf Bioregion target a large suite of finfish and invertebrate taxa. Groundfish are prominent in our case study; they include species that declined during the 1980s and 1990s due to overexploitation (Anderson et al., 2021; Yamanaka & Logan, 2010). Groundfish declines have been largely mitigated since the 2000s due to the introduction of individual transferable quotas (ITQs), comprehensive monitoring and enforcement, freezing of the trawl footprint and spatial fishery closures (Anderson et al., 2021; Davis, 2008; Wallace et al., 2015; Yamanaka & Logan, 2010). Indigenous Peoples, however, see these improvements as insufficient because, as detailed in Section 4, the management of commercial fisheries largely follows an MSY framework, normalizing a shifting baseline of biomass abundances and body sizes that are far below their historical values (Figures 1 and 2).

Indigenous Peoples in the region fish for food and cultural purposes, as regulated by traditional stewardship principles, and participate in commercial fisheries, as regulated by federal law. In remote Indigenous communities, store-bought foods are limited and expensive due to transport costs, making local access to traditional marine foods paramount to food security. Additionally, the hosting of Potlatch ceremonies, which fulfil many social, governance and economic functions, require hosts to feed and gift attendees generously with traditional foods, underscoring the importance of access to marine foods for cultural purposes (Reid et al., 2022; Trosper, 2003).

Since 2009, the management of all Canadian fisheries has been guided by the *Sustainable Fisheries Framework*, a policy umbrella that incorporates the precautionary approach (i.e. it implements science-based decisions cautiously to "avoid serious harm to fish stocks or their ecosystem"), strives for ecosystem-based management, and prescribes requirements for stock assessments (DFO, 2009c). The policy has been largely exclusive of IKS. Whether intentional or not, that exclusivity is no longer socially acceptable or even legal under the FRRA and MPAN-NSB co-governance agreements, prompting us to examine how the precautionary approach inherent to the policy, including biological reference points and harvest control rules germane to fisheries management internationally (Free et al., 2022; Froese et al., 2011), could be re-imagined to make collaborative fisheries management compatible with IKS.

Towards that end, we: (1) review complementary differences and overlap between IKS and Western science – emphasizing ecology, the closest scientific analogue to IKS – in understanding relations between people and the biosphere (Section 2); (2) provide a working definition for IKS-compatible fisheries management (Section 3); (3) examine one of Canada's key fisheries policies, highlighting why the MPAN-NSB and IKS-compatible fisheries management would compensate for its current shortfalls (Sections 4 and 5.1); (4) recommend a revised application of the precautionary approach in fisheries policy that would be compatible with IKS (Section 5.2) and (5) discuss IKS-compatible economic approaches for addressing socio-economic trade-offs arising from reduced exploitation rates (Section 6). Although our case study derives from Pacific Canada, its insights are broadly applicable elsewhere in the world.

2 | INDIGENOUS KNOWLEDGE SYSTEMS AND ECOLOGY: OVERLAP AND COMPLEMENTARY DIFFERENCES

Ecology is only one of several subdisciplines of Western science with applications to fisheries. Its focus on species interactions arguably makes ecology the closest scientific analogue to IKS. For these reasons, we focus on ecology as a vehicle for distilling core differences and similarities between IKS and Western science.

In both IKS and Western science, knowledge derives from cumulative and collective observations that are built and transmitted socially and intergenerationally. Premises shared by both knowledge systems include: (1) ecosystems are characterized by interconnections and synergies between component parts; (2) ecosystems can be resilient to external forces – they are dynamic yet, unless disturbed beyond a threshold, maintain essential structures and functions and (3) humans are ecological forces that can support or damage biodiversity and ecosystem resilience (reviewed in Ban et al., 2018). Both knowledge systems share at least two major goals: (1) to understand and predict the abundance and distribution of organisms, and (2) to use observations and codified approaches (e.g. traditional laws, ecological theory) to predict the ecosystem consequences of human behaviours (Ban et al., 2018; Berkes, 2018; Trosper, 2003).

Both knowledge systems have complementary differences. Western science can have a global scope and uses technology to extend the observable beyond human senses (e.g. satellite imagery, stable isotopes), which may expedite insights into novel phenomena at very large scales (e.g. climate change and ocean acidification). IKS are place-based – built on cultural connection to specific places – which deepens insights into local ecosystems and their variability at finer spatiotemporal scales and often have longer historical baselines. Importantly, IKS are adaptive. In addition to including governance methods designed to buffer against periods of local resource scarcity, such as the Potlatch system of reciprocal exchange in Pacific Canada (Trosper, 2003), IKS often adopt technologies, methods and insights from Western science. Reciprocally, practitioners of Western science may deepen their insights by meaningfully engaging with practitioners of IKS (reviewed in Ban et al., 2018).

In rarer cases, IKS and Western Science may fail to agree (Gilchrist et al., 2005), providing opportunities for Western scientists to rethink hypotheses. As stated by Ken Paul, IKS practitioner and Fisheries Negotiator for the Wolastoqey First Nation in New Brunswick, "When IKS and Western knowledge systems disagree, the hard work to find a resolution is where the true benefit of Two-Eyed Seeing comes into play to create new knowledge (pers. comm. to AF, Feb 15, 2023)."

Unlike Western science, IKS are embedded in values and systems of ethics that focus on respect, reciprocity and responsibility towards other-than-human beings (Housty et al., 2014; McAllister et al., 2023; Trosper, 2003). As Whyte (2013) states, such knowledge is "not just about understanding relationships, it is the relationship with Creation." Further, Western management approaches compartmentalize the knowledge-generating process (i.e. science) from the decision-making process (i.e. policy and governance), whereas both processes are inseparable and reciprocal in IKS (McGregor, 2021; Whyte, 2013).

3 | DEFINING IKS-COMPATIBLE FISHERIES MANAGEMENT

An explicit and succinct definition of IKS-compatible fisheries management cannot satisfactorily capture the holistic nature of IKS and the diversity of Indigenous cultures (Kovach, 2021). In the spirit of Two-Eyed Seeing, we offer a *working* definition and examples of inherent goals, as articulated primarily by Indigenous members of the author team and improved collaboratively with a working group from the Haíłzaqv, Kitasoo Xai'xais, Nuxalk and Wuikinuxv First Nations.

A working definition of IKS-compatible fisheries management has goals, objectives and decision-making that align with the following principles (quoted from Reid et al. (2022), except for square-bracketed text):

Respect – All living beings deserve respect and need to be cared for. Take only what you need and heal any damages that occur to the lands and waters. Be patient and go slow; consider the long-term sustainability of your plans with careful forethought.

Balance and interconnectedness – All living beings are interconnected and changes to one species can cascade through the natural world, which affects intergenerational equity [i.e. actions by the current generation should not compromise well-being of future generations].

Intergenerational knowledge – We learn from the past and adapt our knowledge and decisions based on experience.

Reciprocity – The natural world provides us with everything that is necessary; we take care of the natural world first and it takes care of us.

Operationalizing these principles requires management goals to shift from a focus on organisms as commodities for maximum sustainable exploitation to protecting the resilience of socio-ecological systems in the face of changing environmental conditions. IKS view all species, humans included, as intrinsically tied together. Accordingly, many goals of Ecosystem-Based Fisheries Management (EBFM) – a branch of Western fisheries management which considers biophysical and human interactions within ecosystems (Mangel & Levin, 2005; Pikitch et al., 2004) – align with principles of IKS (Table 1). What IKS can contribute and EBFM cannot is the *legal responsibility* to manage human activities for

TABLE 1 Examples of IKS-compatible management goals and their analogues under ecosystem-based fisheries management (EBFM; Mangel & Levin, 2005; Pikitch et al., 2004).

Management goals		
IKS	**EBFM analogue**	**Example objectives under IKS**
Take only what you need and leave lots for the ecosystem. Plan for predators, not just people. Protect the food that all species need. Every species has a place in the food web. If we do not understand what we are doing when we are having negative impacts on keystone species, then we should be more precautionary and leave more of them around	Maintain the biomass levels required to support species interaction and ecosystem functions	Limit harvests of Pacific salmon to support food for bears (Adams et al., 2021) and the availability of salmon-derived nutrients to rivers, forests and estuaries. Restore eulachon (*Thaleichthys pacificus*, Osmeridae) runs not only for people but also for salmon smolts to feed on while out-migrating to freshwater. Leave the biggest fish alone, which maintains balance in the ecosystem. For Pacific herring, harvest eggs rather than spawning adults, which is much more sustainable (Shelton et al., 2014)
Kill only what you need; do not cause undue harm. Do not waste what you catch. All "bycatch" is utilized. Avoid incidental harm. Select the smaller, less impactful fish. When you take the biggest fish, you remove the best part of the stock	Size and species selectivity. Maintain large size and old-age structures for population productivity and to not disrupt trophic interactions	Target the smaller adult sizes of Pacific halibut (*Hippoglossus stenolepis*, Pleuronectidae) or of other groundfishes. Trap eulachon while they drift downstream, rather than while swimming upstream, so that they spawn first. Fish Pacific salmon at the mouth of creeks (rather than intercepting mixed stock at sea) so that only strong stocks are harvested Our traditional salmon fisheries used fish weirs, which allowed us to select the smaller fish and let the bigger, better breeders proceed upstream (Atlas et al., 2020). Manage mid-water trawl to avoid eulachon bycatch (Hannah et al., 2015). Prohibit bottom trawling due to its lack of selectivity and damage to biogenic habitats (CCFN, 2012)
Na Kila: "to watch over someone and look ahead for them" (*W'uik'ala* language)	Maintain biomass levels and size structures that support resilience to climate change and other perturbations	Leave more fish in the water so that they may better survive climate change impacts

Note: Examples are also provided for objectives under IKS.

socio-ecological resilience, as supported by intergenerational, place-based knowledge that transcends the limitations of Western science (Housty et al., 2014; Kovach, 2021; McAllister et al., 2023).

4 | GAPS BETWEEN CANADIAN FISHERIES POLICY AND IKS IN PROTECTING BIODIVERSITY AND FISHERIES

DFO's *Sustainable Fishery Framework* (DFO, 2009c) contains policies that contribute to biodiversity protection via, inter alia, by-catch management and protection of sensitive benthic habitats. The framework also includes *A Fishery Decision-Making Framework Incorporating the Precautionary Approach* (for brevity, the PA): the policy which determines targeted fishery removals (DFO, 2009a).

The PA focuses on abundance and biomass metrics intended to sustain fishery yields for individual commercial stocks. It requires managers to strive to maintain abundances above an "Upper Stock Reference point (USR)", i.e., in the "healthy zone," where the largest catches are allowed. Catches are downscaled with declining biomass if abundance drops below the USR into the "cautious zone," and are most restricted if abundance drops below a "Limit Reference Point (LRP)" into the "critical zone" (Appendix S3), triggering the requirement for rebuilding plans (DFO, 2009a, 2022b). Importantly, the USR can be less than the target biomass, or "Target Reference Point (TRP)" (Appendix S3).

The PA provides default "provisional" values of 40% and 80% of biomass at MSY ($0.4B_{MSY}$ and $0.8B_{MSY}$), respectively, for the LRP and USR (Figures 1 and 2). Although not required by the policy, these values are used widely. Nationwide, the provisional LRP and USR have been applied, respectively, to 43% and 65% of 177 stocks, spanning finfish, invertebrates and marine mammals (Marentette et al., 2021). This usage is even higher for Pacific groundfishes, where the provisional LRP and USR were applied to 75% of 24 stocks assessed during 2011–2021 (Anderson et al., 2021) and to all rockfishes (*Sebastes* spp., Scorpaenidae) assessed in 2022 (DFO, 2022d, 2022e; Haggarty et al., 2022). The PA provides no justification for why $0.8B_{MSY}$, rather than the full value of B_{MSY}, is sanctioned as the provisional USR, which may promote risk rather than precaution given the lack of buffer surrounding uncertain estimates of MSY (Froese et al., 2011).

The PA policy is clear that the USR serves as an upper control point for reducing removals below the healthy zone to avoid the LRP with high probability. It remains unclear, however, how the dual roles of the USR as a control point for avoiding the LRP and as the boundary of the cautious and healthy zones interact, creating ambiguity about the role of the USR (Appendix S3).

For stocks in the healthy zone, the PA recommends that the provisional fishing mortality, F_p, be less than the fishing mortality required to enable MSY harvests, F_{MSY}. The policy does not, however, specify the proportion of F_{MSY} to which F_p should be set, implicitly allowing $F_p \approx F_{MSY}$. The policy does specify that F_p for stocks in the cautious zone should scale down with declining biomass and be set to "the lowest possible level" for stocks in the critical zone (DFO, 2009a), which may force fishers using unselective gear (e.g. trawl, longline) to avoid species in the critical zone that overlap spatially with healthy stocks (Forrest et al., 2020).

The PA policy's Annex 1b provides guidance on how to obtain provisional estimates of B_{MSY} and F_{MSY} when population models are lacking. Recommended proxies for B_{MSY} and F_{MSY} include, respectively, "biomass corresponding to 50% of the maximum historical biomass" and "fishing mortality equal to natural mortality inferred from life history characteristics" (DFO, 2009a). Marentette et al. (2021) review alternatives to these proxies that have been applied in Canada.

While the use of MSY-based reference points under the PA policy is consistent with international standards, the approach is increasingly criticized for failing to meet broader socio-ecological objectives (Pauly & Froese, 2021; Silver et al., 2022; Walters et al., 2005). Further, the PA policy states the need for "factoring in ecosystem considerations," citing a 2004 review of Atlantic Fisheries Policy which recommended a risk management framework that included reference points linked to stock and ecosystem indicators (DFO, 2004). Sub-components of the PA, including the "Policy on New Fisheries on Forage Species" (DFO, 2009b), also require consideration of ecosystem needs in decision-making. Furthermore, Canada's renewed *Fisheries Act* requires fisheries management and its elements, including reference points and rebuilding plans, to take into account "the environmental conditions affecting the stock" (Parliament of Canada, 2019). However, to date, there has been little guidance for including ecosystem considerations in reference points or advice, and these considerations have been operationalized infrequently (Pepin et al., 2022).

The following subsections examine shortcomings of the PA policy towards protecting biodiversity and fisheries. Each subsection reframes, in scientific terms, concerns that First Nations of the Northern Shelf Bioregion have articulated through the lens of IKS (Adams et al., 2021; Eckert et al., 2018; Jones et al., 2010; Reid et al., 2022).

4.1 | The PA policy may contribute to disruptions of ecological processes

The low biomass levels acceptable under the PA's criteria can destabilize food webs (Walters et al., 2005). B_{MSY} for marine fish occurs on average at ≈40% of the unfished biomass, $0.4B_0$ (Thorson et al., 2012). Under the widely applied provisional USR and LRP of $0.8B_{MSY}$ and $0.4B_{MSY}$, the average species would decline to $0.32B_0$ before dropping from the healthy to the cautious zone (triggering the initial downscaling of removals), and to $0.16B_0$ before dropping from the cautious to the critical zone (triggering the lowest catches and rebuilding plans; Figures 1 and 2). In contrast, biomass levels $\geq 0.5B_0$ could more fully allow species to maintain their functional roles in the ecosystem (Froese et al., 2016). Further, the policy implicitly allows exploitation rates for stocks in the healthy zone to be $\approx F_{MSY}$. For bony fishes, a meta-analysis found that F_{MSY} equates, on average, to ≈87% of natural mortality, M (Zhou et al., 2012). In contrast, long-term fishing mortalities $\leq 0.5M$ could help mitigate fishery impacts on food webs and size and age structure (Froese et al., 2016; Walters & Martell, 2002).

The PA policy does not provide safeguards against declines in size and age structure, despite these having been documented for Canadian stocks (McGreer & Frid, 2017; Shackell et al., 2010; Figure 2). Most fisheries are size- and age-selective, disproportionately removing larger and older individuals from the population, and these impacts are exacerbated under MSY-level harvest rates (Beamish et al., 2006; Berkeley et al., 2004). The consequences include truncated size and age structures, which may reflect phenotypic changes due to selection of faster-growing fish (Taylor & Methot, 2013) or reduced size- and age-at-maturity under fisheries-induced evolution (Heino et al., 2015; Pinsky & Palumbi, 2014). Given that maximum prey size and trophic position increase ontogenetically with body size (Juanes, 2016; Olson et al., 2020), truncated size structures may disrupt cascading predator effects that support biodiversity and ecosystem functions (Hammerschlag et al., 2019; Strong & Frank, 2010). While age and size correlate, age truncation can specifically affect food webs that encompass Pacific herring (*Clupea pallasii*, Clupeidae). As first observed by IKS, the loss of old individuals in Pacific herring may preclude transmission of learned migration patterns to younger fish (MacCall et al., 2019). Additionally, as taught by Haíłzaqv knowledge holders to one of us (MR), older fish teach predator avoidance behaviours to younger fish. Possibly linked to these mechanisms, the number and quality of spawning areas used by herring have declined in some areas (Gerrard, 2014), possibly disrupting food webs (Surma et al., 2018).

In summary, the PA lacks explicit safeguards for food webs and predator–prey interactions integral to biodiversity and ecosystem functions (Table 2).

4.2 | The PA policy lacks safeguards against reduced resilience to climate change

Reductions in abundance allowed by the PA's provisional reference points, coupled with the policy's lack of benchmarks against declining size and age structures, fail to support resilience to climate change via at least two sets of mechanisms. The first involves simplified food webs stemming from exploitation (Strong & Frank, 2010), which may be less able to withstand range expansions of warm-tolerant species with strong ecological effects (Ling et al., 2009). Also, simplified food webs may have fewer predator species or, within a species, fewer

TABLE 2 IKS-compatible management objectives contrasted against DFO's policy, *A Fishery Decision-Making Framework Incorporating the Precautionary Approach* (PA), and implications to biodiversity and fishery protections.

			Implication of PA objective		
Biodiversity component	**IKS-compatible objective**	**PA "provisional" objective**	**Diminished food webs**	**Lower resilience to climate change and fishery exploitation**	**Overall biodiversity loss**
Abundance	Maintain biomass of all species at or above $0.6B_0$ to support food webs, which requires $F \leq 0.5M$	Maintain biomass of commercial species above $0.8B_{MSY}$ ($\approx 0.32B_0$, on average); allows for $F > M$	*Expected* due to allowable biomass declines below $0.5B_0$ for predators, prey or both	*Expected*: Diminished food webs have lower redundancy and greater vulnerability to (1) invasion by climate immigrants and (2) declines of predator species impacted by warming	*Expected*: Weakened predator–prey interactions have cascading effects that affect diversity at lower trophic levels
Body size structure	Protect large individuals	None	*Expected*: fisheries remove bigger individuals that eat bigger prey and hold higher trophic positions	*Expected* due to (1) less resilient food webs (see above) and (2) reduced per capita fecundity	*Expected* due to weakened predator–prey interactions (see above)
Old age structure	Protect old individuals	None	*Expected* due to fishery removal of older individuals, which may (1) contribute to declines of species with high trophic positions and (2) disrupt learned migration of Pacific herring, diminishing abundance and food webs at specific spawning areas	*Expected* because older fish (1) store higher reproductive potential during poor years with low recruitment and (2) extend annual reproductive seasons to broader range of conditions for larvae	*Likely* due to weakened predator–prey interactions
Evolutionary processes	Avoid fishery-induced declines in size- and age-at-maturity	None	*Expected*: Fishery removal of older, larger fish may select for younger age and smaller size at maturity	*Expected* due to lost benefits of reproducing at older age and larger size (see above)	*Likely* due to weakened predator–prey interactions
Natural carbon stores	Maintain high fish abundances as natural carbon stores	None	*Expected* indirectly (see above)	*Expected* indirectly (see above)	*Likely indirectly* due to increased warming and ocean acidification

Note: See text (Section 4) for details and references.

individuals occupying high trophic positions (i.e. due to size declines). Reductions in functional redundancy can diminish food web resilience against warming impacts, such as enhanced vulnerability to disease for individual predator species (Eisaguirre et al., 2020).

The other set of mechanisms involves reduced reproductive potential. As documented for species in at least six orders, including Gadiformes, Clupeiformes and Scorpaeniformes, the timing of annual reproduction may vary with maternal age and size (Hixon et al., 2014). Maintaining old age structure for these species increases the length of the annual reproductive season, enhancing the probability that some individuals will reproduce when environmental conditions favour larval development (Hixon et al., 2014). For long-lived species in general, protection of old age structure provides insurance against multi-year periods with poor environmental conditions and low recruitment (Beamish et al., 2006). During poor years, the reproductive potential of the stock can be "stored" in older age classes, potentially allowing for strong recruitment pulses during rare years with favourable environmental conditions. By truncating age structure, fisheries can diminish the stored potential for strong recruitment pulses and for extended reproductive seasons within a given year (Beamish et al., 2006; Berkeley et al., 2004; Hixon et al., 2014). Declines in old age structure for species with high trophic positions (McGreer & Frid, 2017) may also exacerbate fisheries' impacts on food webs. Additionally, body size declines expected under MSY harvest rates (Froese et al., 2016) can cause non-linear reductions in per-capita fecundity (Marshall et al., 2021) and larval survival (Berkeley et al., 2004), potentially reducing resilience to climate change or other perturbations (Le Bris et al., 2015; Micheli et al., 2012). The importance of protecting large and old fish, however, is not exclusive to the need to protect the entire range of size and age classes; in some cases, the collective reproductive output of smaller and younger females may surpass that of the less abundant females that are larger and older (Lavin et al., 2021).

Most stock assessments and management decisions operationalized under the PA have yet to explicitly account for uncertainty in species productivity trends due to climate change (Pepin et al., 2022). Climate change can amplify recruitment variability and drive non-stationary regime shifts and uncertain stock trends (Szuwalski et al., 2015). Although stock assessments can account for extreme recruitment events through heavy-tailed probability distributions, which adjust the expected recruitment produced under stationary assumptions, most do not account for uncertainties arising from climate-induced non-stationarity (Anderson & Ward, 2019). While these problems are not unique to Canada (Link et al., 2021), they do weaken the precautionary intent of the PA policy.

Bocaccio (*Sebastes brevispinus*, Scorpaenidae), a species listed as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2013), is an example. In 2019, bocaccio was assessed at 3% of the unfished biomass, placing the species in the critical zone (DFO, 2020a). Following the subsequent growth of a cohort associated with an extreme recruitment event in 2016 (44 times greater than the long-term average, with causal mechanisms still unknown), bocaccio biomass was reassessed in 2021 at 36% of the unfished biomass (DFO, 2022d), placing the stock in the healthy zone. Given the revised stock status based on projections of steep stock increase due to the growth of the 2016 cohort, managers increased the mortality cap 24-fold, from 75 tons in 2019 to 1800 tons in 2022 (DFO, 2022c), largely to prevent bocaccio from becoming a choke species in the multispecies groundfish trawl fishery. Rare recruitment events, however, may not necessarily lead to sustained stock recovery due to uncertainty from climate change (Szuwalski et al., 2015; Szuwalski & Hollowed, 2016), and truncation of size and age structures exacerbates that uncertainty (Beamish et al., 2006; Marshall et al., 2021).

Additionally, standard stock assessments operationalized under the PA policy do not account for increasing hypoxia in deep waters (Jackson et al., 2021) nor for climate-induced shifts in species distributions (English et al., 2022). Both drivers increase uncertainty on how fisheries might impact stocks and ecosystems (Link et al., 2021), which may disproportionately impact Indigenous communities trying to access traditional foods (Whitney et al., 2020). For instance, groundfish fishers from the Wuikinuxv Nation associated declines in their local catch rates (JW, pers. obs.) with hypoxic events documented in the inlet's deep waters during 2009–2019 (Jackson et al., 2021).

In summary, the PA policy lacks safeguards against reduced resilience to synergistic effects of climate change and fisheries on commercial stocks and their ecosystems (Table 2).

4.3 | The PA policy may not adequately protect unassessed species

The percentage of Canadian fish stocks assessed within the previous 5 years declined from 65% in 2018 to 55% in 2022 (Schijns & Rangeley, 2022). There is a risk that impacts from non-directed fisheries on species without a recent stock assessment may go undetected. Synopses of available indices of abundance and other biological data, such as those recently developed in the Pacific region (DFO, 2022a), could help mitigate the problem.

4.4 | The PA policy indirectly contributes to ocean warming and acidification

Marine fish have an average carbon composition, by weight, of 12.5% (±2.5%; Mariani et al., 2020). When fished, 94% of that carbon is released as greenhouse gases via human digestion and excretion or offal decomposition. When fish die naturally, much of their carbon content is sequestered in sediments (Mariani et al., 2020). Due to metabolic scaling, larger individuals store carbon more efficiently and their potential contribution to carbon sequestration exceeds that of an equivalent biomass of smaller fish (Falciani et al., 2022). Biomass reductions allowed by the PA's provisional reference points, coupled with the lack of benchmarks against declining body sizes, likely diminish fish contributions to natural carbon stores, indirectly contributing to ocean warming and acidification (Falciani et al., 2022; Mariani et al., 2020).

5 | APPLYING TWO-EYED SEEING TO OFFSET CURRENT GAPS IN THE PA POLICY

The following subsections offer Two-Eyed Seeing approaches for filling gaps in biodiversity and fisheries protection that currently exist under the PA policy.

5.1 | Spatial protections and their linkages to aspatial approaches

MPAs are a type of spatial protection that can link Western science and IKS, supporting a collaborative EBFM framework. The MPAN-NSB illustrates this point, as First Nations and their co-governance partners collaboratively drafted the network's goals and objectives (Appendix S2), insuring their compatibility with IKS (Reid et al., 2022).

MPAs that are well designed and enforced for compliance can promote higher species diversity, greater abundances, larger body sizes, older age structures and reduced rates of fisheries-induced evolution. In combination, these benefits can mitigate fisheries' impacts on food webs and carbon sequestration processes (Baskett & Barnett, 2015; Roberts et al., 2017; Sullivan-Stack et al., 2022). Although these effects may be highest for sedentary species, more mobile species also benefit from spatial protection (Claudet et al., 2010). MPAs can indirectly benefit fisheries through spillover effects (Barceló et al., 2021) and by providing insurance against uncertainty in ocean productivity and recruitment rates associated with climate change (Berkeley et al., 2004; Hixon et al., 2014; Marshall et al., 2021). Further, because MPA protections (even if partial) apply to all species within a defined three-dimensional space, they may protect unassessed and data-poor species within that space. Well-designed MPA networks account for movement connectivity between individual MPAs and incorporate representation of ecological features, which further protects biodiversity and pre-empts some concerns about changing species distributions under climate change (Carr et al., 2017).

Given that MPAs and fisheries management are interlinked (Sullivan-Stack et al., 2022), there is a need for monitoring designs to adapt to MPA restrictions of trawl and longline fishery-independent surveys. Stock assessment models are fitted to surveys of population biomass and species life histories, which often come from trawl, longline or other capture-based methods that can be lethal or destructive in implementation. As many MPAs preclude that kind of sampling, alternative assessment methods are required (Field et al., 2006). Non-destructive sampling methods that can be used in MPAs include stereo cameras that systematically record fish abundances (e.g. volumetric density) and body sizes with high precision (Williams et al., 2010, 2018). Stereo camera surveys also record key habitat variables for correcting abundances. Their selectivity has been estimated for several species with ranges that extend into the Northern Shelf Bioregion (Rooper et al., 2020). Size frequency distribution data collected by stereo cameras or other visual methods (e.g. divers at shallower depths) can be used to estimate relative natural mortality and relative fishing mortality, and therefore to estimate exploited and unexploited biomass (Cope & Punt, 2009; White et al., 2021).

5.2 | Aspatial approaches: re-imagining the PA policy so that it may become inclusive of IKS

The need for solutions to the chronic and systemic problems outlined in Section 4 is consistent with legal frameworks that seek to uphold the rights of Indigenous Peoples, both internationally (e.g. United Nations Declaration on the Rights of Indigenous Peoples) and in Canada (FRRA, 2021). Therefore, we suggest the following revisions to the PA policy, which would increase the compatibility of aspatial management approaches with IKS:

1. Shift the provisional reference points from MSY-based, which reflect the premise that marine organisms are commodities to be exploited at the maximum sustainable rate, to depletion-based reference points, which are more easily interpreted and consistent with notions of ecosystem stewardship and resilience. (Depletion-based reference points currently are applied to only a few Canadian stocks [Marentette et al., 2021], such as Pacific herring [DFO, 2020b]).
2. Increase the provisional USR (i.e. lower bound of the healthy zone) to $0.6B_0$ and decrease the provisional fishing mortality to the equivalent $\leq 0.5M$ to protect size and age structures and food webs (Figures 1 and 2; Froese et al., 2016; Pauly & Froese, 2021; Walters & Martell, 2002). The value of $0.6B_0$ suggested for provisional USR has been quantitatively vetted primarily for forage fishes (Pauly & Froese, 2021), yet its application to other taxa would be minimally consistent with "leaving lots for the ecosystem," and therefore warranted. Ecosystem models could refine the USR for specific cases (see below).
3. Increase the provisional LRP (upper bound of critical zone) to $0.32B_0$, the average equivalent value for $0.8B_{MSY}$ (Thorson et al., 2012; Figure 1). This is consistent with recommended international best practices as a threshold for preventing serious harm (Forrest et al., 2023; Sainsbury, 2008).
4. Implement additional reference points for size and age structures and use them as complementary criteria for delineating the healthy, cautious and critical zones (Figure 1). These reference points can be derived theoretically (Gedamke & Hoenig, 2006; Then et al., 2018; White et al., 2021) or from historical baselines (Eckert et al., 2018; McGreer & Frid, 2017).
5. Specify steps, requirements and timelines for a rapid transition to assessment models or decision-making frameworks that account for non-stationarity associated with ocean warming and related changes to species productivities and distributions (Link et al., 2021; Szuwalski & Hollowed, 2016). Policy developments in the USA (Busch et al., 2016) already illustrate pathways to that transition.

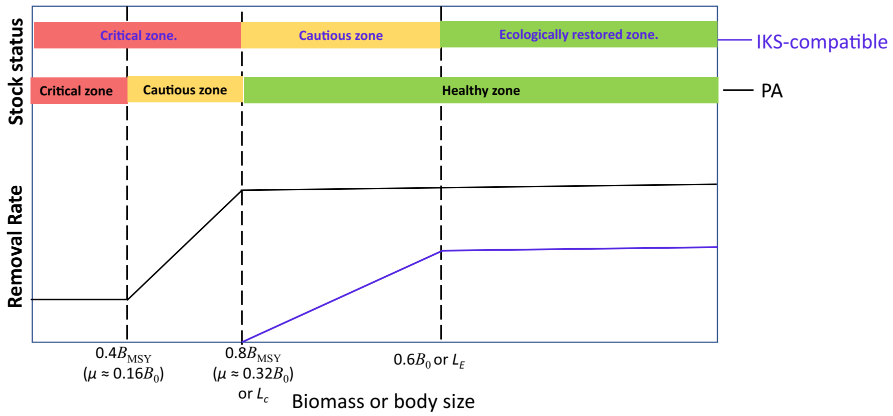

FIGURE 1 Conceptual model comparing provisional reference points established in the Sustainable Fisheries Framework's Precautionary Approach (PA) policy, which delineates the maximum removal rates for a given harvest control rule, and IKS-compatible reference points. Stock status zones and their corresponding removals under the PA (black font and line) are delineated only by biomass ($0.4B_{MSY}$ and $0.8B_{MSY}$, or their average proportion of B_0). IKS-compatible stock status zones and their corresponding removals (blue font and line) are delineated by reference points based on both biomass ($0.32B_0$ and $0.6B_0$) and body sizes, (L_c and L_E, which mark, respectively, the lower bounds of the critical and ecologically restored zones). The x-axis is scaled to baseline biomass (B_0) but not to body size, for which values may be derived theoretically or from historical baselines. The proportional difference in removals assumes peak harvests of F_{MSY} ($\mu \approx 0.87M$, teleosts) under the PA and of $F = 0.5M$ if IKS-compatible. See text for details.

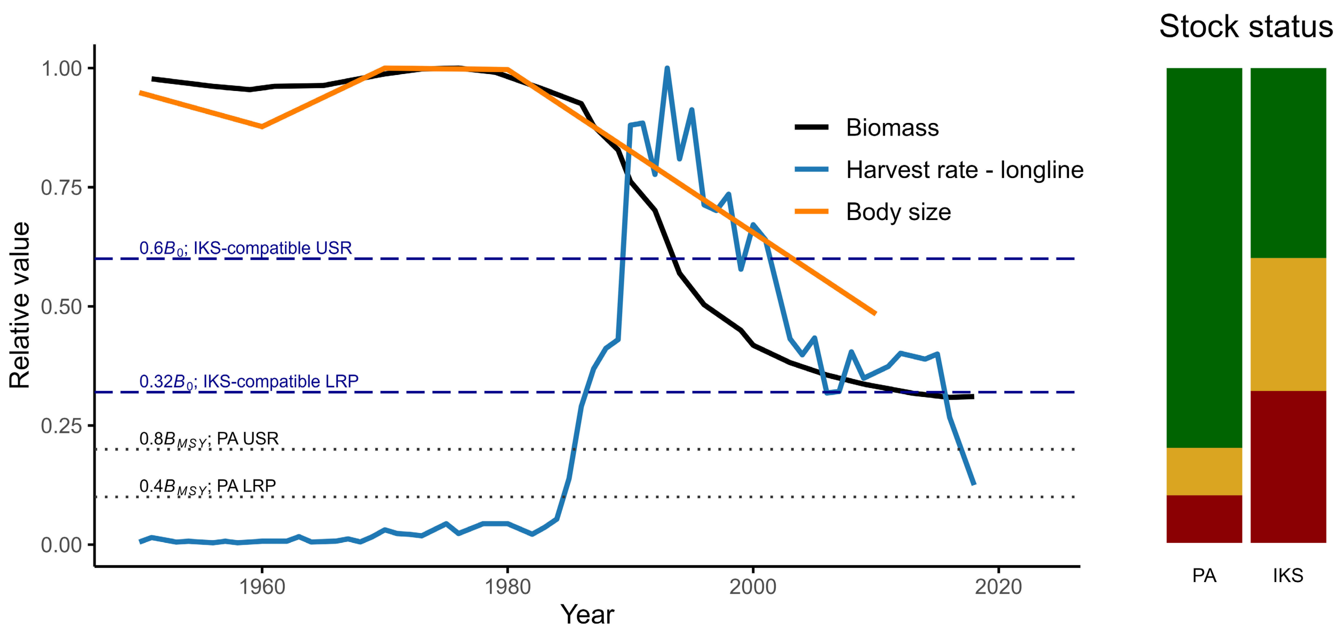

FIGURE 2 Relative change over time for biomass, longline harvest rates and body sizes for the northern substock of the outside population of yelloweye rockfish (*Sebastes ruberrimus*, Scorpaenidae), a culturally and ecologically significant species of the Northern Shelf Bioregion. The Sustainable Fisheries Framework's PA provisional reference points (black font and horizontal dotted line) and IKS-compatible reference points (blue font and horizontal dashed line) are shown with their respective stock status zones (green = healthy, yellow = cautious, red = critical). Biomass and harvest rate are as analysed by Cox et al. (2020) and digitized from their figure 9. Body sizes are as observed by Indigenous fishers (Eckert et al., 2018). At the end of the time series (2018), biomass is at $0.31B_0$, above the PA's provisional LRP and USR of $0.4B_{MSY}$ ($\approx 0.10B_0$) and $0.8B_{MSY}$ ($\approx 0.20B_0$), respectively, and the stock is within the PA's healthy zone (note that $B_{MSY} \approx 0.25B_0$, below the average value of Thorson et al. [2012] and Cox et al. [2020]). Under IKS-compatible biomass reference points (blue broken lines), however, the stock is marginally into the critical zone due to a legacy of overfishing during the late 20th century. Though not developed here, body size criteria under IKS can further refine stock status.

6. Specify steps and requirements for management decisions to integrate information from ecosystem models– which explicitly consider multi-species interactions and oceanographic processes – with single-species stock assessments (Pepin et al., 2022). For example, Howell et al. (2021) outline a methodology applied to two case studies in which target fishery mortalities for individual stocks were first determined through single-species assessments and then scaled, from the output of ecosystem models, to support broader socio-ecological objectives. An approach like this may also use the output of ecosystem models to incorporate carbon

sequestration objectives into fisheries management (Falciani et al., 2022). Additionally, open source, state-of-the art stock assessment models that can incorporate environmental covariates are now available (Stock & Miller, 2021).

The potential willingness of DFO to improve the PA policy with an IKS-compatible framework is suggested by recent analyses and policies advanced by DFO personnel. These include: (1) scrutiny of reference points (Marentette et al., 2021) and criticism of lack of ecosystem considerations (including non-stationarity) in most stock assessments (Pepin et al., 2022); (2) nascent collaborations with First Nations (albeit with unresolved issues) on setting objectives for management strategy evaluations for Pacific herring (DFO, 2020b) and (3) the "Policy on New Fisheries for Forage Species," which includes among its objectives the "maintenance of ecological relationships [...] among species affected directly or indirectly by the fishery" (DFO, 2009b). While these points are encouraging, expansion of similar frameworks to other ecologically important species groups (e.g. upper-level predators) and inclusion of size and age reference points are still lacking.

The potential for stakeholder support of IKS-compatible fisheries management is suggested by changes collaboratively designed by the Pacific groundfish industry over the past two decades. These changes include shifting to 100% at-sea and dockside monitoring with ITQs, freezing the trawl footprint and introducing coral and sponge bycatch quotas (Davis, 2008; Wallace et al., 2015). These measures have largely reduced impacts on corals and sponges (Gale et al., 2022) and unintended catches of long-lived rockfishes (Branch & Hilborn, 2008; Forrest et al., 2020).

Nonetheless, reduced exploitation rates arising from our recommendations may create socio-economic trade-offs at different timescales. Pre-empting that challenge, the next section discusses IKS-compatible economic approaches for addressing shorter term costs to commercial fishers.

6 | IKS-COMPATIBLE ECONOMIC APPROACHES FOR ADDRESSING SOCIO-ECONOMIC TRADE-OFFS OF MPAS AND CATCH REDUCTIONS

In IKS, long-term ecosystem health supersedes short-term economic gains. As articulated by a member of our author team (JW), "If we must take a cut in our short-term economic profits for our long-term sustainability, we will. That is very much how we think about things."

Both MPA networks and IKS-compatible fisheries management would improve the long-term resilience of socio-ecological systems while generating trade-offs at different time scales. MPAs decrease the total fishing area and may necessitate reduced quotas to avoid overexploitation outside MPAs (Hilborn et al., 2004), where lower exploitation is an explicit objective of IKS-compatible fisheries management. In both cases, the short-term costs to commercial fishers might be immediate catch reductions (i.e. if abundance already is near the USR or exploitation near F_{MSY}; or if shifting reference points places stocks in the critical zone, triggering a rebuilding plan). The long-term benefits to fishers, however, include catch increases due to spillover from MPAs (Barceló et al., 2021; Qu et al., 2021) and improved catch stability under climate change if exploitation limits are set to maintain ecosystem functions (Holsman et al., 2020). Complementarity between IKS, which are rich with intergenerational perspectives founded on gratitude and respect for the organisms harvested, and Western science, which has developed optimization techniques to achieve predetermined goals, can guide trade-off analyses that address social equity at different time scales (Plagányi et al., 2013; Sangha et al., 2015; Sumaila, 2021). In this context, we define "social equity" as policy decisions that prioritize fairness across sociocultural groups while accounting for the historical process that has privileged or underprivileged such groups. The implication is that these policies should explicitly aim to right past wrongs to Indigenous Peoples (Silver et al., 2022) without unduly impacting other groups.

Approaches for mitigating shorter-term costs to commercial fishers have included financial compensation from governments (Sen, 2010), which might facilitate a just transition to non-extractive activities requiring similar skills. Just transition frameworks have been employed in other sectors, such as fossil fuel extraction, which are downscaling (in part) to mitigate climate change (Draeger et al., 2022).

For commercial fishers wishing to continue working in wild-capture fisheries, value-over-volume approaches can support incomes despite quota reductions. These approaches focus on increasing the per-unit value of products or services along value chains and have been applied to forestry, fisheries and other industries (Brown et al., 2019; MacKenzie & Bruemmer, 2009; Sullivan, 2022). When applied to fisheries, they shift the focus from increasing the biomass extracted from the ocean to increasing the value of each unit of extracted biomass via at least two approaches. The first involves extending the value chain with more secondary products. Typical fish utilization by processors is only ≈50% but this value is increasing for some fisheries. For example, processors of Icelandic cod have increased utilization to over 80% by turning skin, guts and other parts previously treated as offal into unconventional products – leather, pharmaceuticals, cosmetics and nutritional supplements – leading to fourfold increases in the value of individual fish (Sullivan, 2022). The second approach is to increase the value of each unit of product. For example, Ikejime is a Japanese technique for killing fish individually as they are landed. It involves driving a spike behind the eye socket. The instant kill prevents the lactic acid formation that degrades flesh quality; consequently, fishers trade off the cost of increased handling time for the benefit of 20%–400% increases in revenue per unit of flesh (Sullivan, 2022). The value-over-volume paradigm, if managed appropriately, allows for greater financial remuneration while reducing ecosystem impacts, thereby intersecting with the IKS principles of "take only what you need" and "do not waste what you catch".

In the Northern Shelf Bioregion, potential industry support for implementing these concepts is suggested by the trawl industry's existing underutilizing of their quota for many species (see data archived at https://www.pac.dfo-mpo.gc.ca/fm-gp/groundfish-poissons-fond/publications-eng.html), and by the collaboratively developed changes already supported by that industry to reduce impacts on corals and sponges and to manage and monitor groundfish fisheries (Davis, 2008; Wallace et al., 2015). Further, some longline fisheries for groundfish already apply Ikejime (I. Bryce, commercial fisher, pers. comm. to AF, December 2022), suggesting that the method could expand to other fisheries.

Stakeholder support for MPAs and IKS-compatible fisheries approaches may potentially also increase if trade-off analyses are inclusive of broader ecosystem benefits to people. Ecosystem models, for instance, can show trade-offs between carbon storage or other ecosystem functions and fisheries landings (Falciani et al., 2022), and methods are available for economic valuation of those trade-offs (Luisetti et al., 2019; White et al., 2012). Additionally, most economic analyses employed in fisheries valuation account only for benefits to current generations and discount these benefits through time, potentially biasing policy decisions towards those that favour increased consumption in the present. In contrast, as articulated by a member of our author team (JW), IKS uphold the principle that "we are affected by our forebearers actions, and our descendants rely on us to protect them through our actions today." To not shortchange future generations, discount clocks can be reset at the start of each generation (Sumaila, 2021), intersecting with the principles of long-term ecosystem integrity and intergenerational equity that are foundational to IKS (Reid et al., 2022; Sangha et al., 2015). Normalizing these approaches in fisheries economics would facilitate constructive synergies between spatial and aspatial management measures intended to mitigate cumulative impacts on marine ecosystems (Sumaila, 2021).

To not compromise food security, the scaling-down of wild capture fisheries may require increased reliance on mariculture (Costello et al., 2020). Although some aspects of mariculture have a troubled history of harming ecosystems, the current trend is for more sustainable and efficient practices, including kelp farms that sequester carbon (Sullivan, 2022). If policies and technologies continue to improve, total production of finfish and shellfish could increase, potentially without undue ecological harm, from a current 59 Mt to 103 Mt by 2050, with maricultural contributions increasing from a current 16% to 44% by 2050 (Costello et al., 2020). IKS have long implemented mariculture practices that support the abundance and diversity of native organisms (Mathews & Turner, 2017) and have much to contribute towards improved practices.

An important caveat is that economic valuation of fish and their ecosystems, even in the context of the above arguments, implies one-way benefits to people. Thus, even well-intended economic analyses risk promoting human exceptionalism, emphasizing "nature's contributions to people" over "people's obligations towards nature" (Muradian & Gómez-Baggethun, 2021). In contrast, IKS centres on reciprocal relationships between human and other-than-human beings (Ojeda et al., 2022). Consequently, economic approaches are more likely to address the root causes of ecosystem declines when paired with the relational values of IKS.

7 | CONCLUSION

Fisheries science uses quantitative methods to inform management goals and – as the current state of the oceans indicates – most goals it has supported require adjustment (Silver et al., 2022). The synergistic pairing of IKS and Western science can improve our understanding of ecosystems and the consequences of human interventions. IKS, however, has a stronger foundation for setting and meeting goals that maintain respectful and reciprocal relationships between people and other-than-human beings; a failure to support those relationships is to imperil humanity's future (McGregor, 2021; Ojeda et al., 2022; Trosper, 2003).

Using the literature and our combined experiences and positionalities in Two-Eyed Seeing, fisheries science and co-governance processes involving First Nations, we have illustrated how the precautionary approach, including biological reference points and harvest control rules broadly applied in Canadian and international fisheries (Free et al., 2022; Froese et al., 2011; Marentette et al., 2021), could be revised to make collaborative fisheries management compatible with IKS and improve biodiversity and fisheries protections. Our proposed revisions to the PA policy include higher biomass levels for reference points and objectives for maintaining large size and old age structures. To refine and implement these revisions, we envision working groups that include practitioners of IKS and of Western science which in the Northern Shelf Bioregion would be formed under the FRRA co-governance mandates (FRRA, 2021). More generally and as illustrated for Indigenous fisheries in Torres Strait (between Australia and Papua New Guinea), management strategy evaluations – which use simulation testing of alternative monitoring data, analytical procedures and decision rules to evaluate trade-offs between multiple objectives – may provide a forum for applying Two-Eyed Seeing in fisheries decision-making (Plagányi et al., 2013). DFO scientists have recently raised concerns that align with many of our arguments (Marentette et al., 2021; Pepin et al., 2022), which suggests plausibility for revising current policy.

Sullivan-Stack et al. (2022) stated that, "Perceptions of a false dichotomy between fisheries management 'vs.' MPAs impedes progress towards sustainable management, a common goal for people who identify as fishers, conservationists, or both." Accordingly, we have argued that the MPAN-NSB – which already reflects the pairing of IKS and science under a co-governance structure – would, if implemented, enhance biodiversity and fisheries protection, and that challenges to stock assessments imposed by MPAs are tractable.

We have been transparent about catch reductions necessitated by MPAs and by IKS-compatible fisheries management. Equity in the present and future matters, so we have described ways in which commercial wild-capture fisheries might remain economically viable despite quota reductions and suggested approaches for trade-off analyses that would better inform the costs and benefits of alternative management decisions to current and future generations.

The application of Two-Eyed Seeing in collaborative fisheries management can be challenging. For instance, federal fisheries managers must consider the nutritional and economic needs of large, highly diverse and jurisdictionally complex human populations, while IKS often emerges from smaller and more localized communities with higher degrees of cultural continuity, potentially making it difficult to find common ground. Yet a commitment to pluralism can surmount these sorts of challenges (Almack et al., 2022). The benefits of doing so are worthwhile: despite the place-based origins of IKS, the potential contribution of Two-Eyed Seeing to addressing global and local environmental problems is increasingly evident (Berkes, 2018; Gon & Winter, 2019; Hoffman et al., 2021).

Ultimately, management goals and objectives reflect cultural preferences that, in turn, indirectly influence the states of ecosystems (Silver et al., 2022). One preference may be for the commodification of marine organisms under the tenets of MSY, which necessitates maintaining fish abundances far below their historical baselines. Another preference may be for preserving reciprocity in relationships between people and ecosystems, which requires larger abundances and body sizes of organisms to support species interactions and other elements of socio-ecological resilience. Yet, the cultural component of management goals need not be static. Most modern cultures are adaptive, capable of evolving towards pluralism. In a pluralistic world that embraces co-governance, Two-Eyed Seeing will play meaningful roles in setting and meeting better goals and objectives for managing relationships between people and the biosphere (McGregor, 2021; Reid et al., 2021; Trosper, 2003; Whyte, 2013).

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

Not applicable, as no data sets were generated or analysed in the course of this work.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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