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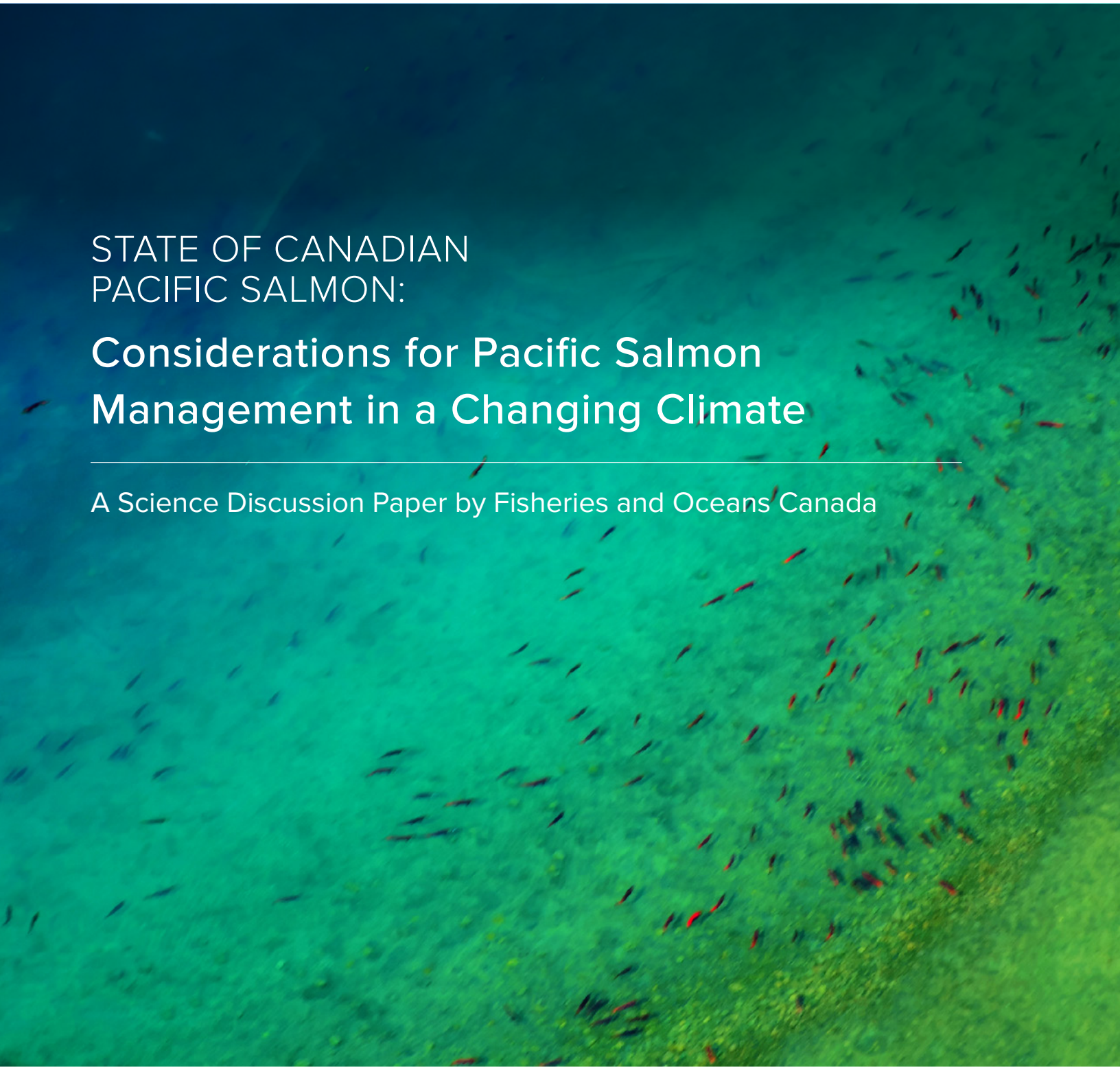

STATE OF CANADIAN PACIFIC SALMON:

Considerations for Pacific Salmon Management in a Changing Climate

A Science Discussion Paper by Fisheries and Oceans Canada

Canada

We humbly and respectfully acknowledge that this paper was written on the unceded traditional territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), and səlilwətaɬ (Tsleil-Waututh) Nations. We recognize that these Nations have been stewards of the land and water since time immemorial, and we honour their deep understanding of the interconnectedness between people and natural systems.

Recommended citation: MacDonald, B. and Grant, S.C.H. (2023). *State of Canadian Pacific salmon: considerations for Pacific salmon management in a changing climate.* Department of Fisheries and Oceans Canada Report 23-2305. 27 p.

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Cat. No. Fs144-70/2023E-PDF ISBN 978-0-660-68922-7

Preamble

This discussion paper was requested during the early stages of the Pacific Salmon Strategy Initiative (PSSI) to provide strategic direction with respect to climate change and Pacific salmon. The PSSI was announced in June 2021 as a strategic, long-term response to the negative effects of climate change, habitat loss, and fishing pressures on salmon [1]. It is a $647-million initiative with the goal of "stemming the severe and ongoing decline of key Pacific salmon populations on Canada's West Coast and restoring them to a sustainable level for future generations of Canadians" [2]. The PSSI aims to protect and rebuild stocks where possible through habitat, harvest, and hatchery actions, as well as increased integration and collaboration [3].

The intent of this work is to provide further scope on the topic of climate change and salmon, through identifying issues and lessons from the literature and engagement with Fisheries and Oceans Canada (DFO) staff. This paper is a high-level document written for an audience with an informed interest in Pacific salmon.

A Fraser Chinook takes a leap at Rearguard Falls in the upper Fraser River, B.C. Photo by Shane Kalyn, 4 Element Photos.

Executive Summary

When will the state of Pacific salmon return to normal? In recent years, Canada's Pacific Region has experienced extreme environmental conditions, and many populations of salmon have declined. Fluctuations in environmental conditions and in salmon abundances are not a new phenomenon. Periods of poor salmon production have occurred in the past, as have better periods, varying around an average or "normal" state. Canada's Pacific salmon management systems were built on such historical observations, assuming that future conditions would reflect those experienced in the past. However, climate change is forcing environmental conditions outside of their historical range, which is impacting salmon habitats, survival, and distribution.

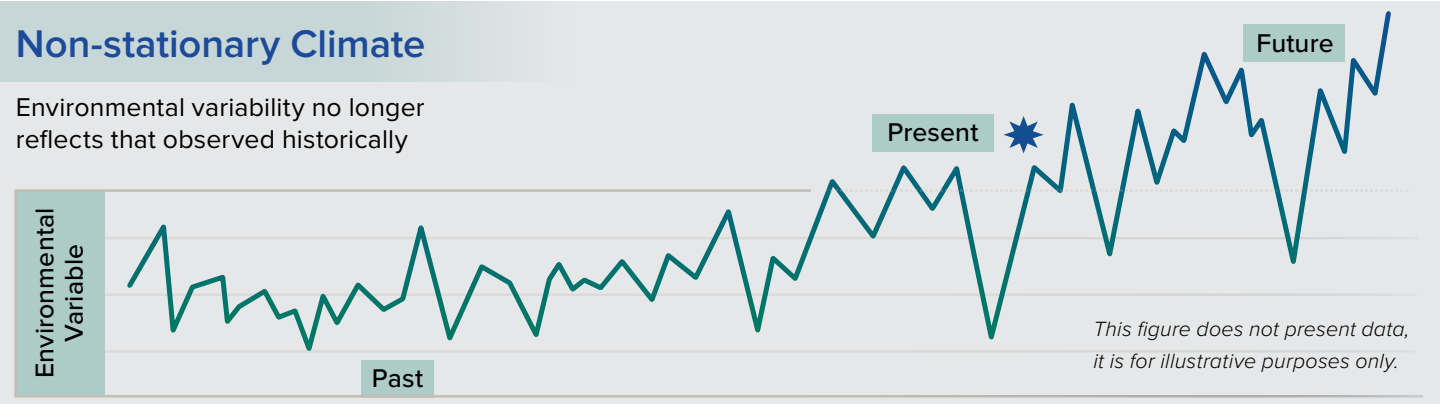
"Normal" no longer exists in a changing climate. As the planet's climate continues to change, some salmon populations will fare better than others, affecting their overall distribution on the landscape and in marine areas. The salmon populations of tomorrow will not look like those of today, and we will be unable to prevent all losses and other changes due to climate effects.

There is an urgency to act. This paper shows how climate change is creating challenges for Pacific salmon management, and how this is impacting the well-intentioned and costly work being performed across the region. In keeping with the scientific evidence and national leadership provided in Canada's National Adaptation Strategy, we propose a new strategic direction aimed at supporting and aligning Pacific salmon management with our reality of change:

Climate change adaptation is foundational to DFO policies, programs, and activities related to Pacific salmon.

Adaptation means using information on current and future changes in climate not only to avoid or reduce negative impacts, but also to exploit potential benefits. We define meaningful adaptation as forward-looking and proactive. Incorporating climate adaptation into new and ongoing planning and decision-making processes has been associated with successful implementation of adaptation, and supports commitments made by the Government of Canada to build resilience into its operations.

We provide a way forward with a list of activities and tools that can enable us to more thoroughly address climate change in salmon management. These include developing our capacity to adapt, creating a team to lead and support adaptation, improving collaboration, and initiating adaptation assessment and planning processes that are supported by climate change projections, vulnerability assessments and scenario planning.



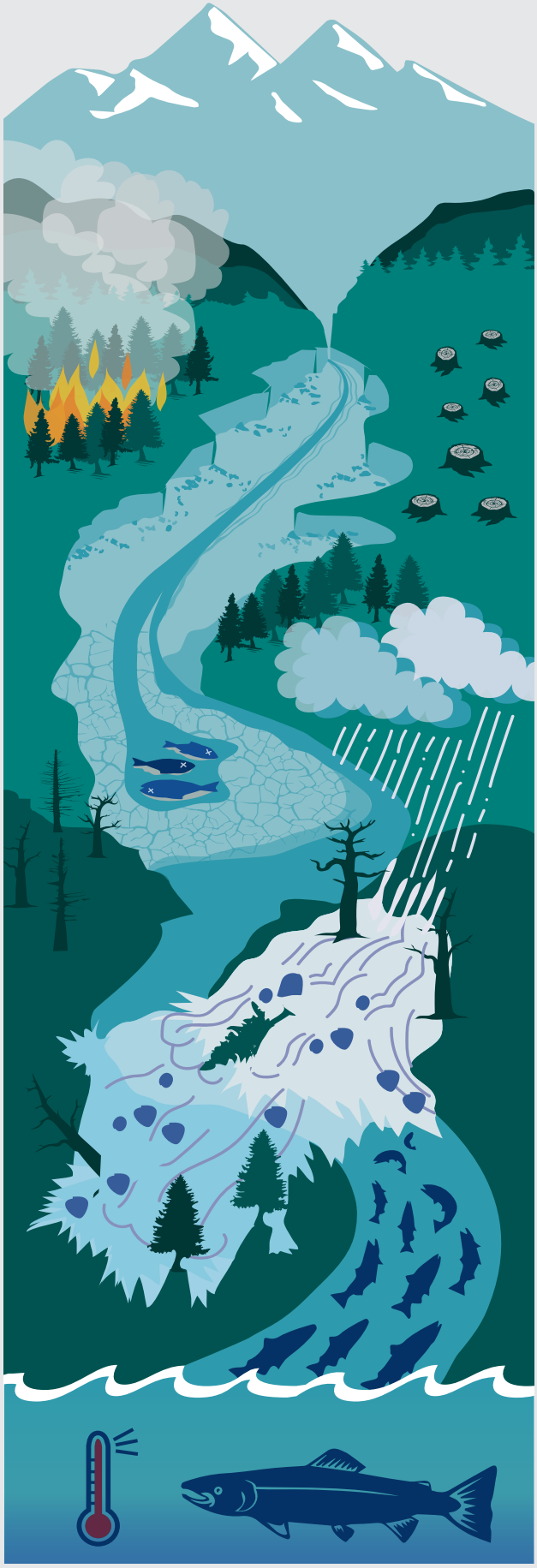
A Salmon's Journey on a Warming Planet

Pacific salmon are some of the world's greatest migrators. They begin their first migration after hatching, making their way to the water's surface for a small gulp of air to fill their swim bladders[4]. It is a short but critical swim that begins an incredible journey. They'll go on to travel hundreds of kilometres through freshwater and ocean habitats, eventually returning to their natal streams and rivers to spawn.

Climate change is now affecting Pacific salmon at all points in their life cycle. Salmon are increasingly less likely to make it past their first life stage as eggs. Ever more frequent floods and high river flows either scour spawning beds or bury the eggs in sediment [5–11]. In contrast, during dry periods, dewatering of riverbeds can strand, suffocate and kill salmon eggs and juveniles [12].

The timing of salmon life events like hatching and juvenile migration to streams, lakes, and the ocean is being altered by changes in water temperatures and river flows. This can create mismatches between the timing of migration and the availability of food if salmon arrive too early or late to align with food production [8]. Once in the ocean, food sources such as zooplankton are of lower quality more often now [13–20], yet salmon in warmer waters require more, and higher quality, food to sustain their growth [21].

When they return to their natal rivers to spawn, salmon are encountering rising water temperatures that stress their bodies, increase their susceptibility to disease, affect their reproductive viability and the condition of their offspring, and at times exceed the lethal limit [22–27]. Salmon are also encountering more barriers to migration, such as landslides or low water levels due to drought, which cut off access to their spawning grounds [27,28]. Such catastrophic events will happen with greater frequency and severity in the years to come [29–31].



Introduction

The Government of Canada recognizes that climate change is having irreversible effects on the environment and on people [29].

In response, Canada has identified the need to adapt to climate change, and released a *National Adaptation Strategy* and accompanying *Action Plan* in mid-2023 [32,33].

Like many other natural resource agencies, DFO developed its approach to managing fisheries resources, specifically salmon, their habitats, and the socio-economic systems that rely on them, under the historically prevailing assumption of **environmental stationarity — the idea that environmental conditions fluctuate within a known range** [35–37]. Under this premise, natural resource management agencies have used past conditions as baselines or benchmarks for habitats and populations [38,39]. To date, most management responses to human and environmental stressors have aimed to restore or conserve ecosystems as we have known them [36,39,40]. However, this goal does not align with the reality of climate change [39,41,42].

"In the context of record-breaking wildfires across the country, record hurricanes like Fiona and record floods in British Columbia, this Strategy is needed now, more than ever, to establish a shared vision of our future."

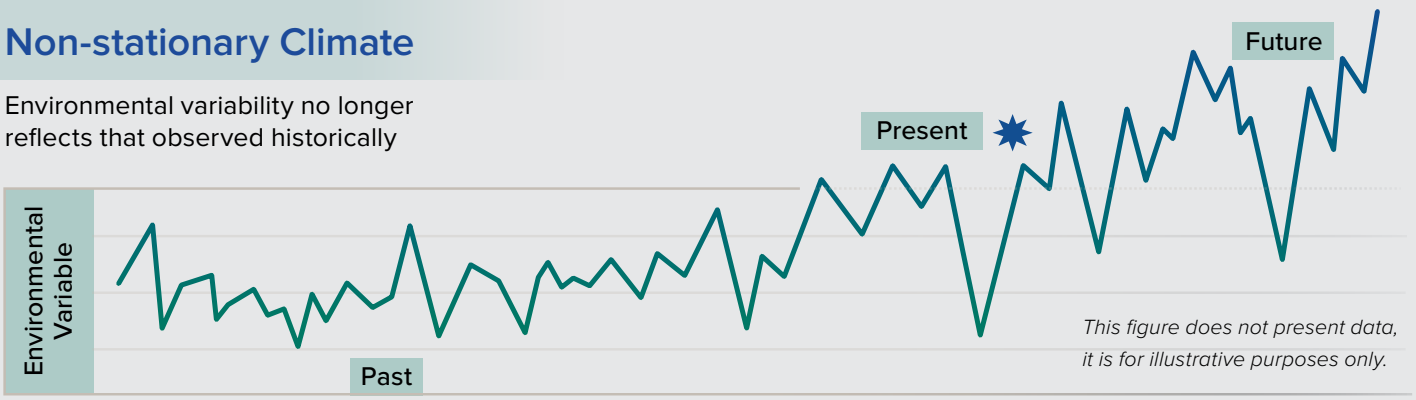
— The Honourable Steven Guilbeault, Minister of Environment and Climate Change, June 27, 2023 [34].

National Adaptation Strategy Vision: "All of us living in Canada, our communities, and the natural environment are resilient in the face of a changing climate. Our collective adaptation actions enhance our well-being and safety, promote justice, equity, and reconciliation with Indigenous Peoples, and secure a thriving natural environment and economy for future generations [32]."

Climate change is consistently forcing environmental conditions outside the bounds of our past experience [36,39]. In our new reality, Pacific salmon ecosystems are responding to

Non-stationary Climate

Environmental variability no longer reflects that observed historically



both the effects of the changing climate, and the compounding effects of climate change on other stressors, such as water extraction and deforestation [8]. In response to intensifying stressors, rapidly changing environments are increasingly unlikely to return to "normal" [36,39].

As climate change pushes environments further from what we have known, we will not be able to control all outcomes. Some Pacific salmon populations will fare better than others, affecting their overall distribution on the landscape and in marine areas. Salmon migrations and habitat use in the future will not look like they do today. Ultimately the distribution of Pacific salmon is expected to shift northward [43–48].

We can address current and future change by transforming salmon management. This goes beyond strategies that focus solely on enhancing the resilience of natural systems in the hope that they will rebound to their prior state [49]. A new natural resource management paradigm is emerging that focuses on preparing for and managing change through forward-looking adaptation [39,49–51]. This means using information on future climate change to take action now to avoid or minimize expected negative impacts, and to prepare for potential opportunities.

This discussion paper is step one in a process intended **to foster climate change adaptation** within Pacific salmon management. Here we

- *define what we consider to be meaningful climate adaptation;*
- *show how systems of salmon management that developed under assumptions of stationarity are challenged by climate change, and how additional risks may be created in the absence of meaningful adaptation;*
- *propose a new strategic direction that recognizes the importance of embedding adaptation throughout our salmon management operations; and*
- *present activities and tools that provide a way forward.*

Braided glacier-fed channels flow into Berg Lake in the upper Fraser watershed in British Columbia. In Canada, glaciers have rapidly receded over the past decade [29]. This will lead to declines in glacial meltwater supply, and increases in temperatures in the rivers and streams they have historically fed [10]. Photo by Shane Kalyn, 4 Element Photos.

What is Meaningful Climate Adaptation?

Meaningful climate adaptation is an ongoing process that aims to reduce the vulnerability of social, ecological, and economic systems to climate change impacts [52].

In this case, these systems include salmon, their ecosystems, and the people and institutions that rely on and manage them.

To do this, climate adaptation must be forward-looking and proactive.

Forward-looking adaptation is informed by plausible climate change trajectories. Indigenous, scientific, and other knowledge systems work together to determine what futures are possible [53,54], and to facilitate behavioral, technological, and institutional changes to prepare for those futures [55,56]. The approach is strategic and deliberate [49,57], but does not imply that we can control all outcomes, even with effective adaptation [58]. For example, local species extinctions or displacements have occurred and will continue to occur, affecting a variety of species in different regions of the world, as a result of climate change [59,60].

Climate change adaptation falls on a continuum from **incremental to transformational** [59]. Incremental adaptation maintains the essence and integrity of a system or process at a given scale, whereas transformational adaptation changes the fundamental attributes of the system, creating new states and interactions [61,62]. Incremental actions are limited by social, economic, and governmental structures [59], and may be insufficient to avoid risks as climate change impacts escalate [62–64]. Transformational adaptation can overcome such limits, and can expand the range of solutions available for the future [59].

Proactive and transformative approaches to addressing change are less likely to lead to **maladaptation** [64]. This occurs when actions fail to appropriately address the root causes of climate change vulnerability [57]. Through maladaptation, poorly planned actions can actually increase vulnerability to climate change, and reduce the number of future solutions available [56,57]. For example, vulnerability would likely increase if subsidies were used to support, or "lock-in", unsustainable fishing practices where catches have declined as a result of climate change [65]. Often maladaptation is the result of planning that focuses on individual economic sectors and climate risks in isolation, as well as on short-term gains [59].

Meaningful adaptation planning for future change is critical for infrastructure investment and policy development [56]. Proactive actions can also remove barriers and allow systems to respond more quickly after changes occur [56].

The salmon-bearing Eagle River winds its way along the edge of town in Sicamous B.C. Pacific salmon exist within systems of interacting social and ecological components and processes. Photo by Shane Kalyn, 4 Element Photos.

The Perils of Managing for the Past

The goal of Canada's Wild Salmon Policy is "*to restore and maintain healthy and diverse salmon populations and their habitats for the benefit and enjoyment of the people of Canada in perpetuity*" [66].

While this goal is highly desirable, we recognize that restoring and maintaining salmon populations and habitats **as we have known them** relies on environmental stationarity, yet we are experiencing a non-stationary world.

In this section we show how Pacific salmon management systems that were developed under assumptions of stationarity are being challenged by climate change, and how this is undermining the well-intentioned and costly work we perform and support.

Current Management Approaches

Prioritizing Populations for Conservation and Recovery

Investment in Pacific salmon recovery is largely directed at populations that are most at risk of extirpation [67]. This is in keeping with requirements of the *Species at Risk Act* and the *Fisheries Act*, both of which mandate recovery planning for at-risk populations. Since many salmon populations are declining, particularly in Southern BC [8], there is pressure to extend recovery efforts to a growing number of populations.

When resources are limited, prioritizing the most at-risk populations for investment has opportunity costs [68]. For example, more viable populations may be bypassed, or moved down the priority list. Often such trade-offs go unrecognized [69]. With endangered species, focusing only on those species most at risk is unlikely to minimize the total number of extinctions over the long term [70]. On the other hand, investing in species that are not currently in a critical state or that have greater viability may improve their resiliency and prevent these species from becoming at risk in the future [68].

Climate change will increasingly call upon us to make difficult decisions when assigning limited resources to competing project proposals [71]. Given that climate change is likely to affect species and populations differently, it is important that decision-makers consider future context when defining and evaluating their management goals [69]. This process makes trade-offs explicit, improving transparency and accountability in decision-making [72].

Management Levers

We use three primary levers to manage Pacific salmon populations and their habitats:

1. ***Habitat Restoration and Regulation;***
2. ***Hatchery Enhancement; and***
3. ***Harvest Management.***

Habitat Regulation and Restoration

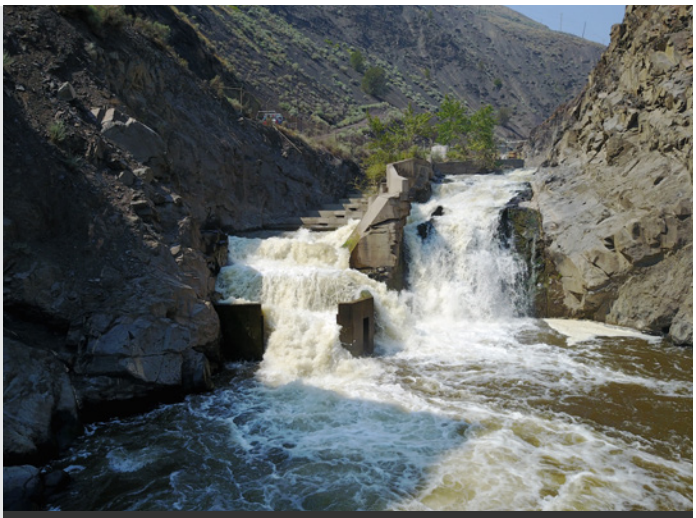
Habitat regulation aims to conserve and protect salmon habitats from potential degradation and losses. Restoration is performed to conserve and improve salmon production where degradation has occurred, or where habitats can be improved [73]. Restoration plans have most often been developed without considering the impacts of climate change on the habitats being restored [74]. Instead, *natural* or historical states may be used to diagnose and guide restoration efforts where current conditions limit salmon production [73–75]. Ecosystem characteristics, such as river flows, have been

assumed to remain within the range of historical variability [76]. However, such traits are deviating from what we have observed historically, and this is expected to escalate [29,30,77,78].

In many areas of B.C., changing river flows are hampering the success of restoration projects. More variable flow timing and more severe flows have impaired or reduced the functionality of costly infrastructure (see box: **Bonaparte Fishway**), and damaged restored habitat. Salmon habitat restoration activities that focus on in-stream rehabilitation are particularly susceptible to failure as river flows change [74].

Recurring High Flows Damage and Hamper Restoration of the Bonaparte Fishway

Contributed by Chantal Nessman and Sarah Ostoforoff, DFO Resource Restoration Unit



The damaged Bonaparte River fishway in 2018. Photo credit: DFO Staff.

The Bonaparte fishway near Cache Creek, B.C. was built in 1988, opening up more than 70 km of spawning and rearing habitat for Chinook, coho and steelhead salmon. Gravel accumulation and damage were identified at this site in 2017 (Lee McCabe, DFO, Aug 2, 2022, pers. comm.), and repair work was initiated [79]. Subsequently, heavy rain events in spring and summer 2018 led to unprecedented high water levels, heavy debris, and sediment flows in the Bonaparte River that significantly worsened damage to the fishway infrastructure [79], causing a catastrophic failure (Lee McCabe, DFO, Aug 2, 2022, pers. comm.). In fall and winter 2018, opportunities to perform repairs at the site were limited by much higher than average river flows during the typical low-flow period [80]. It is suspected that the massive 2017 Elephant Hill wildfire, which spanned a large portion of the Bonaparte watershed, has altered the movement of water through this landscape [81]. Significant construction efforts carried out under adverse environmental conditions through 2018-2019 successfully remediated the fishway and re-established fish passage. However, ongoing monitoring and further upgrades are required to ensure future operation of the fishway under changing conditions. Meanwhile, the damage and challenges created by recent river flows in the Bonaparte River have impacted multiple return years of salmonids that use this river system.

Impacts:

Cost | Changing salmon production | Uncertainty

> "There's nothing to soak up the water. We're seeing unprecedented flows of about 500 per cent of the typical low-flow volume. It either makes work impossible, because it doesn't allow people to get in to do the work, or what we do is washed away."
>
> — Lee McCabe, DFO project engineer told the Ashcroft-Cache Creek Journal on August 30, 2019 [79]

Where restoration efforts previously succeeded in offsetting impacts of landscape change, climate change can now render efforts insufficient [82,83]. In some situations, climate change will intensify changes in landscapes and ecological processes and undermine restoration efforts. Existing projects are already being hindered by high summer water temperatures and changing water availability (see box: **Mamquam Channels**).

Juvenile Coho Concerns in the Mamquam Channels

Contributed by Chantal Nessman and Murray Manson, DFO Resource Restoration Unit

The Mamquam groundwater channels in Squamish, B.C. annually produce 15,000-20,000 coho smolts. This likely represents the bulk of salmon produced by the Mamquam system. The first channels were constructed in 1985; they were later expanded and deepened to address concerns over low flows in the late 1980s and early 1990s. These channels continue to be affected by low flows in summer months, which are exacerbated by increasingly frequent extreme weather conditions, and possibly by competing water extraction. The speed and severity of channel drying was particularly pronounced in summer 2021, leaving small, hot, oxygen-deprived pools of water in which juvenile salmon became trapped and perished [84].

Dry segment of the Mamquam spawning channels in August 2021. Photo credit: Jennifer Thuncher/The Squamish Chief.

Impacts:

Changing salmon production

Uncertainty

> "It is just a fish killer at this time of year. There's so much habitat that literally has no water in it".
>
> — Clint Goyette (Valley Fishing Guides/Squamish-Lillooet Sportfish Advisory Committee) told The Squamish Chief, August 23, 2021, referring to the spawning channel adjacent to the Squamish Valley Golf Course [84]

Habitat regulation and restoration are important tools that provide options to support salmon populations under changing conditions. Prioritizing healthy and viable salmon habitats for conservation and protection is a key step towards reducing overall losses due to climate change. Further, restoration practices can be adapted, and new tools and techniques developed, to prepare more effectively for future changes. Flexibility and experimentation will be key to learning and to adapting practices under uncertainty.

Hatchery Enhancement

Hatcheries are established to supplement harvest opportunities, assess populations, rebuild populations, and increasingly, support conservation. Hatcheries rely on cool water for egg incubation and juvenile rearing. They also rely on adult salmon that swim into the hatchery, or are collected from nearby rivers, for breeding (called *broodstock*). Climate change is interfering with access to these inputs at some hatcheries (see box: **Quinsam Hatchery**).

Variable Flows at Quinsam Hatchery Challenge Broodstock Collection

Contributed by Paige Ackerman and Carolyn Churchland, DFO Salmonid Enhancement Program

Declining water levels during adult migration have prevented larger returning fish from swimming into Vancouver Island's Quinsam River Hatchery in recent years. "Swim-ins" no longer represent the population, so hatchery staff have begun collecting broodstock in the lower river using a floating fence, accessed through private property. This situation is precarious, not only because broodstock collection now relies on the cooperation of a local landowner, but because the river has coincidently become more unpredictable. Intense high flow events are more frequently preventing successful use of the fence, creating uncertainty in broodstock collection. River instability from high volume events has impacted broodstock collection at multiple other sites in B.C., including the Conuma Hatchery near Tahsis, and Shovelnose Creek near Squamish.

A high water event at the Quinsam Hatchery in January 2017 shows the type of flow and debris that can impact broodstock collection. Photo credit: Lorne Frisson, DFO.

Impacts:

Changing salmon production

Uncertainty

"Conservation implications aside there is a fundamental question that has been largely overlooked until recently[85]: will these hatcheries be able to function in the future as they have in the past?"

— K. C. Hanson and D. P. Peterson, 2014, in *Modeling the potential impacts of climate change on Pacific salmon culture programs: an example at Winthrop National Fish Hatchery*, page 434.[86]

As water flows and temperatures continue to change, hatcheries will likely experience additional challenges [85]. Extreme events could create bottlenecks that impact hatchery operations [86]. These climate impacts have prompted the U.S. Fish and Wildlife Service to begin conducting climate change vulnerability assessments for their hatcheries [87–90]. Further, if environments become unsuitable for salmon populations including the juvenile salmon released by hatcheries, supplementation may no longer achieve its objectives [85,86,88].

Harvest Management

Harvest management has historically relied on predictable salmon abundances, behaviours, and population processes to determine sustainable catch levels. However, in many fisheries, salmon behaviors and processes like population growth rates are shifting and becoming more variable

Increasing Tension in the Fraser Pink Fishery

Contributed by Lester Jantz, DFO Resource Management, Pacific Salmon Commission Fraser River Panel Co-chair

Mature pink salmon that have returned to spawn. Photo credit: Shane Kalyn, 4 Element Photos.

Over the past 20 years, coinciding with warming ocean trends, Fraser Pink abundances and adult return migration behaviours have changed, and become more variable [91,95]. This has increased the uncertainty of in-season Fraser Pink abundance estimates, because the historical data and the assumptions used to tune the in-season estimation models are no longer representative. Further, in recent years, the bulk of Pink returns have migrated through only one test fishing area instead of being more evenly distributed across multiple test fisheries. This shift in migration behaviour limits the catch information that can be collected from the test fisheries in-season, exacerbating the existing uncertainty.

The high degree of uncertainty in the in-season Fraser Pink return estimation process has delayed fisheries management decision-making in recent years. This has occurred at a time of increased fishing interest in Fraser Pinks and lower Fraser Pink returns, a situation that reinforces the need for precise and timely in-season estimates of returns. The disconnect between the need for reliable information for decision-making, and the ability of salmon biologists to provide estimates with the desired level of precision has created tension, frustration, and disappointment in the management process. Ultimately, delays have caused missed fishing opportunities at a time when opportunities were already limited.

Impacts:

Conflict

Changing salmon production

Uncertainty

> "The effect of climate change may be experienced as a slow 'squeeze', exacerbating existing problems, rather than a push generating new action."
>
> — A. McIlgorm and colleagues., 2010, in *How will climate change alter fishery governance? Insights from seven international case studies*, page 176.[94]

as environmental conditions change [91]. This creates increased uncertainty in the tools developed to inform harvest management (see box: **Fraser Pink**), which can lead to overfishing, or alternatively, missed opportunities for fishing activities targeting abundant populations [92,93].

As local fish abundances and behaviours change due to climate effects, fishers may want to respond by altering their target species, gear, fishing locations, or timing [92,96]. However, their ability to do so can be constrained by the existing regulations or economic considerations [97,98]. If management responses lag, mismatches or gaps can be created between changing ecological realities and policies or regulations that rigidly define target species, gear types, fishing locations, and practices [92,98,99]. Such mismatches can limit opportunities for fishers [97], and create conflict and distrust with the management system [100].

Pacific salmon fisheries could face increasing pressures as shifts in the distribution of salmon affect potential catch, which may no longer align with international agreements [101]. Cooperative management can break down when incentives to cooperate are disrupted by unmet fisheries expectations, creating conflict over catch allocations [102], and risk of overexploitation [98,103].

Coho salmon. Photo by Paul Vecsei.

Flexibility and adaptability in fishery management systems are important in order to deal with the uncertainties inherent in future conditions and in salmon and human responses to change [41,104,105]. This means structuring systems so they are able to quickly identify and respond when management changes are needed, or when opportunities arise [57,100,104,106].

Increasing Risk and Uncertainty

Managing Pacific salmon populations and habitats according to goals and assumptions developed under relatively stationary environmental conditions could mean missing opportunities to reduce the impacts of climate change on salmon and on the people who rely on them. Further, if management systems became increasingly complex in order to maintain the status quo, we would risk deepening our vulnerability to climate change [57,58]. As climate change continues to alter salmon habitats, management issues would be exacerbated, and coping would likely become unsustainable, leading to maladaptation [57,64].

Likewise, if we fail to adequately prepare for change, we could miss out on opportunities to make the most of future conditions. Changing environmental conditions are expected to benefit some Pacific salmon populations and create opportunities for expansion into new habitats [46,106,107]. Identifying and supporting these populations and habitats, and properly managing emerging opportunities, will be key to maximizing the potential benefits of change.

Managing for the Future

The severity of future climate change impacts on salmon and on the social and economic systems that rely on salmon will depend on how well we anticipate and prepare for those impacts [104].

Knowing that climate change is going to intensify in coming years, there is a clear need to reduce vulnerabilities, identify opportunities, and improve our ability to respond to change.

Though DFO does not have a comprehensive, long-term strategy for climate adaptation [109], climate change considerations are being incorporated into some of DFO's work with respect to Pacific salmon. We can ensure that adaptation is considered systematically throughout salmon management systems by embedding climate change adaptation within our everyday operations. Incorporating climate adaptation into new and ongoing planning and decision-making processes, **referred to as *mainstreaming***, has been associated with successful implementation of adaptation [110–112]. We therefore propose a new strategic direction to support and align Pacific salmon management with our reality of change:

Climate change adaptation is foundational to policies, programs, and activities related to Pacific salmon.

Broad mainstreaming of adaptation is viewed as critical in Canada's National Adaptation Strategy (NAS)[32]. The Government of Canada Adaptation Action Plan cites a responsibility to

Alevins swarming the camera. Photo by Paul Vecsei.

incorporate climate adaptation into everyday federal activities, including policies and programs, to support implementation of the NAS and enable adaptation throughout government operations [33]. Further, the Government of Canada has committed to mainstreaming adaptation and reducing climate risks to federal assets, services, and operations throughout relevant departments and agencies under the Greening Government Strategy and the Federal Sustainable Development Strategy 2022-2026 [33,113].

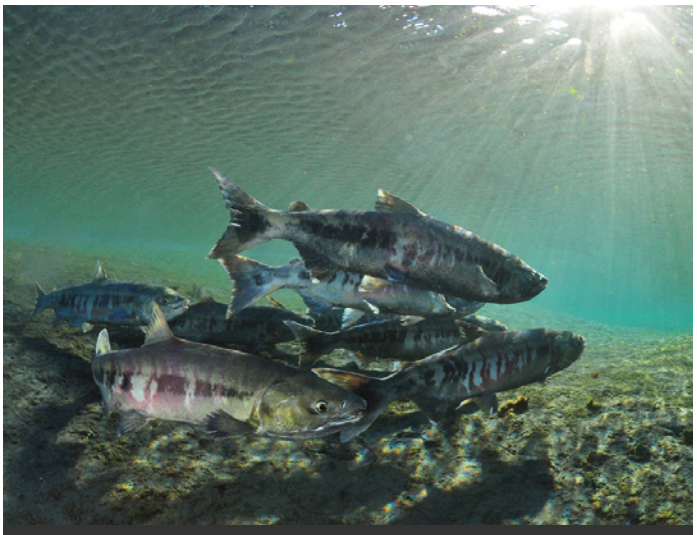
> "Everyone in Canada needs to consider climate change impacts in everyday decisions. For governments and businesses, this is called mainstreaming. As climate impacts become more severe and frequent, and the costs mount, incorporating adaptation considerations in health, social, environmental, infrastructure and economic decisions-making is critical to ensure that our collective efforts keep pace."
>
> — Canada's National Adaptation Strategy, 2023 [32].

Where to Begin

In recognition that adaptation is a social process [114,115], we highlight actions that can create enabling conditions for adaptation. These include:

- *improving awareness and access to relevant climate change information;*
- *building organizational capacity to address adaptation needs;*
- *enabling leadership and coordinated support for adaptation work;*
- *creating opportunities to develop shared understanding of climate change risks and opportunities; and*
- *initiating flexible, iterative risk assessment and adaptation planning processes that embrace shared learning.*

These activities aim to facilitate effective adaptation while addressing some common organizational factors that can act as barriers. Such barriers can include, but are not limited to, a lack of coordination, and constraints created by existing work routines, norms, and practices [114,116]. We follow this by identifying specific tools that can support adaptation assessments and planning.



Chum salmon that have returned to spawn in the Kluane River, Yukon. Photo by Paul Vecsei.

Developing Our Capacity to Adapt

Building adaptive capacity is an important first — and ongoing — step in climate change adaptation [114]. This refers to the capacity to adapt to change, which can be limited by a lack of awareness and understanding of the threats posed by climate change, or by a tendency to downplay those threats and focus on addressing immediate needs [49,117,118]. Effective communication of climate risks and adaptation opportunities is key to improving individual and organizational capacity for adaptation planning and implementation [58,114].

Developing adaptive capacity helps to expand the group of people who are involved in adaptation work, and reduces barriers to implementation [114,119]. The following suggestions, adapted from Shirk *et al.* (2021), are a starting point for building adaptive capacity throughout salmon management systems:

- *Provide climate change risk and adaptation education and training.*
- *Improve access to relevant climate information and adaptation resources.*
- *Incorporate adaptation duties into job descriptions, work plans, and organizational structures.*
- *Create new positions to directly support research on climate impacts as well as carry out adaptation assessment, planning, and implementation. New positions can also offset the work loads of experts, providing them with more time to engage in research and adaptation assessments.*

Creating a Team to Lead and Support Adaptation Activities

Adaptation planning and implementation can be more successful when this work is led and supported by a dedicated team. The creation of a specialized team for climate change

adaptation helps define responsibilities, facilitate coordination, and support efforts to institutionalize adaptation [112,116,120]. A climate adaptation team ideally consists of members representing all sectors and programs affected by climate impacts and responsible for managing change. Having such a team assists with coordination and ensures that a range of knowledge and opinions are represented [120]. Team members also act as conduits into each sector, improving awareness of climate impacts, recognition of the need to adapt, and communication of progress [120].

The U.S. National Marine Fisheries Service (NOAA Fisheries) has benefitted from establishing regional climate teams, each of which has developed a regional action plan outlining goals and activities in support of the NOAA Fisheries Climate Science Strategy [121]. This regional framework has increased coordination, collaboration, and implementation of activities to work towards strategy goals [121].

A climate adaptation team for DFO Pacific salmon could lead and support adaptation activities by developing and disseminating educational materials on climate risks and adaptation, identifying organizational needs, developing work plans, reviewing organizational structures, and leading climate risk assessments and adaptation planning processes.

Improving Collaboration

Broad participation by a range of collaborators and integration of research and management are important components of adaptation processes [114]. Collaboration provides valuable learning opportunities that have been shown to improve organizational capacity when it comes to addressing climate change impacts [122]. In the context of Pacific salmon, adaptation will rely on improved coordination across a wide range of actors within and outside of DFO.

Engagement with other federal agencies and other levels of government will be necessary, particularly with respect to industries that influence freshwater salmon habitats, such as forestry and agriculture. Engaging Indigenous communities and groups is crucial to ensure the success of this work, and is in keeping with Canada's commitment to reconciliation with Indigenous peoples. Centering Indigenous and local knowledge in planning and decision-making is necessary to understand and address the root causes of climate vulnerability [57,123]. Further, developing a shared understanding and common goals is critical to adaptation success. Collaboration that brings different value systems and worldviews together to collectively identify and reconcile risks and opportunities for adaptation builds a pathway to transformation [114].

Chilko-Taseko junction: where the milky waters of the Taseko River join the clear blue Chilko River. Photo by Shane Kalyn, 4 Element Photos.

Initiating Adaptation Assessment and Planning

Adaptation planning is part of an **iterative** cycle that can stand alone or be integrated into existing processes [69]. Assessing climate-related risks is a key component of this planning [58,69]. Adaptation needs and options can be identified based on their potential to reduce climate risks while ensuring that they align with overall management objectives [124]. Such processes require flexible, adaptive planning, and frequent review of the objectives of management considering potential risks and adaptation options [32,69,114].

In this paper, we have begun to identify some of the current challenges and potential future risks facing Pacific salmon management under climate change. Initiating a more thorough, systematic assessment that revisits our past and present assumptions of stationarity throughout salmon management systems would expand our understanding of climate change risks and opportunities for adaptation. A similar assessment has recently been performed by the Washington Department of Fish and Wildlife to identify their risks and adaptation needs (see Box: **Washington Department of Fish and Wildlife**).

Progress in adaptation assessment and planning at the Washington Department of Fish and Wildlife

In 2017, the Washington Department of Fish and Wildlife (WDFW) adopted *Policy 5408: Addressing the Risks of Climate Change*, which provides direction on managing departmental operations and assets in such a way as to better understand, mitigate, and adapt to the impacts of climate change. WDFW established a Climate Action Team, which held workshops to assess the climate change risks faced by each of their agency programs (Habitat, Fish, Wildlife, and Capital & Asset Management) [125]. The WDFW assessment summarized program vulnerabilities according to four overarching concerns in relation to their mission, which is "to preserve, protect and perpetuate fish, wildlife and ecosystems while providing sustainable fish and wildlife recreational and commercial opportunities" [126]. These concerns include:

Cover of the 2021 report 'Preparing Washington Department of Fish and Wildlife for a changing climate: assessing risks and opportunities for action', by A. Shirk and colleagues[125]*. Photo by Climate Impacts Group; aerial support by LightHawk.*

1. risks to harvest and recreation;
2. risks to species conservation and recovery;
3. risks to providing effective technical assistance, permitting, research and planning; and
4. risks to WDFW lands and infrastructure [125].

To respond to these risks, WDFW recognizes a need for new policies, regulations, and management plans [123]. They also identify needs for new research, monitoring, tools and data management to track and assess changing conditions; increased staff capacity, training and coordination to manage risks; and greater outreach, communication, collaboration and partnerships to link to external partners and stakeholders [123]. WDFW is currently working on next steps.

Planning and Assessment Tools

Effective adaptation planning requires inputs to support the identification of risks and management responses, and to aid in decision-making [119]. Such information is also used to evaluate goals and to scope adaptation options [69]. The following tools can support adaptation assessment and planning:

Projecting future conditions

Projections of future ocean and freshwater conditions and the responses of ecosystems and socio-economic systems are required to inform forward-looking climate adaptation [121]. Projecting future conditions is a complex process that first requires downscaling global climate model projections to spatial and temporal resolutions that are relevant to Pacific salmon ecosystems [71]. The next step is to develop models or processes that link projected changes in climate variables to salmon ecosystems [71].

Climate change vulnerability assessments

Identifying and understanding vulnerability is crucial for designing effective adaptation strategies [69]. Climate change vulnerability assessments (CCVAs) are used to examine and rank climate change vulnerability according to three components: exposure, sensitivity, and adaptive capacity [71]. Outputs can inform priority-setting for adaptation investment through identifying key vulnerabilities and the most impactful actions [69]. CCVAs also enable adaptation planners to refine their goals in light of future outlooks [69].

The Government of Canada recognizes the need for CCVAs in the context of Canadian fisheries management. DFO's 2021 mandate letter emphasizes that there is an urgent requirement to "expand climate vulnerability work to better inform marine conservation planning and management." CCVAs for Pacific salmon integrate expert knowledge on salmon species, their ecosystems, and climate change projections to predict the relative level of threat each Pacific salmon population faces [7,127]. CCVAs for Canadian Pacific salmon populations could begin with a regional scan to identify priorities for further assessment. More detailed CCVAs could then be completed where priorities are identified.

Scenario Planning

Though climate projections and CCVAs can improve our understanding of the future, there will still be uncertainty about what the future will look like. Scenario planning can enable decision-makers to overcome potential "management paralysis" [69] in the face of such great uncertainty [71]. Scenario planning is a structured process of incorporating uncertainties into decision-making and planning by evaluating management strategies or adaptation plans across a range of plausible future scenarios [69,128,129]. Rather than depending on current scientific ability to accurately predict the future, participants can design and evaluate management strategies to identify those that are most robust to the range of futures identified [69,105]. Additionally, scenario planning can help managers design monitoring programs for key uncertainties in order to better assess changes [69,71].

Defining plausible, not probable, future scenarios is a core component of these processes, which encourage participants to think about unexpected and unprecedented events [129]. Plausible future scenarios are narratives about potential futures that can incorporate ecological, social, political, and economic uncertainties [69,129]. The narrative approach allows participants to be creative and envision a range of potential futures that combine uncertainties in quantitative information with descriptive information [69,129]. Broad participation is beneficial because it expands the information included in scenarios and allows for integration across sectors [129].

Future Work

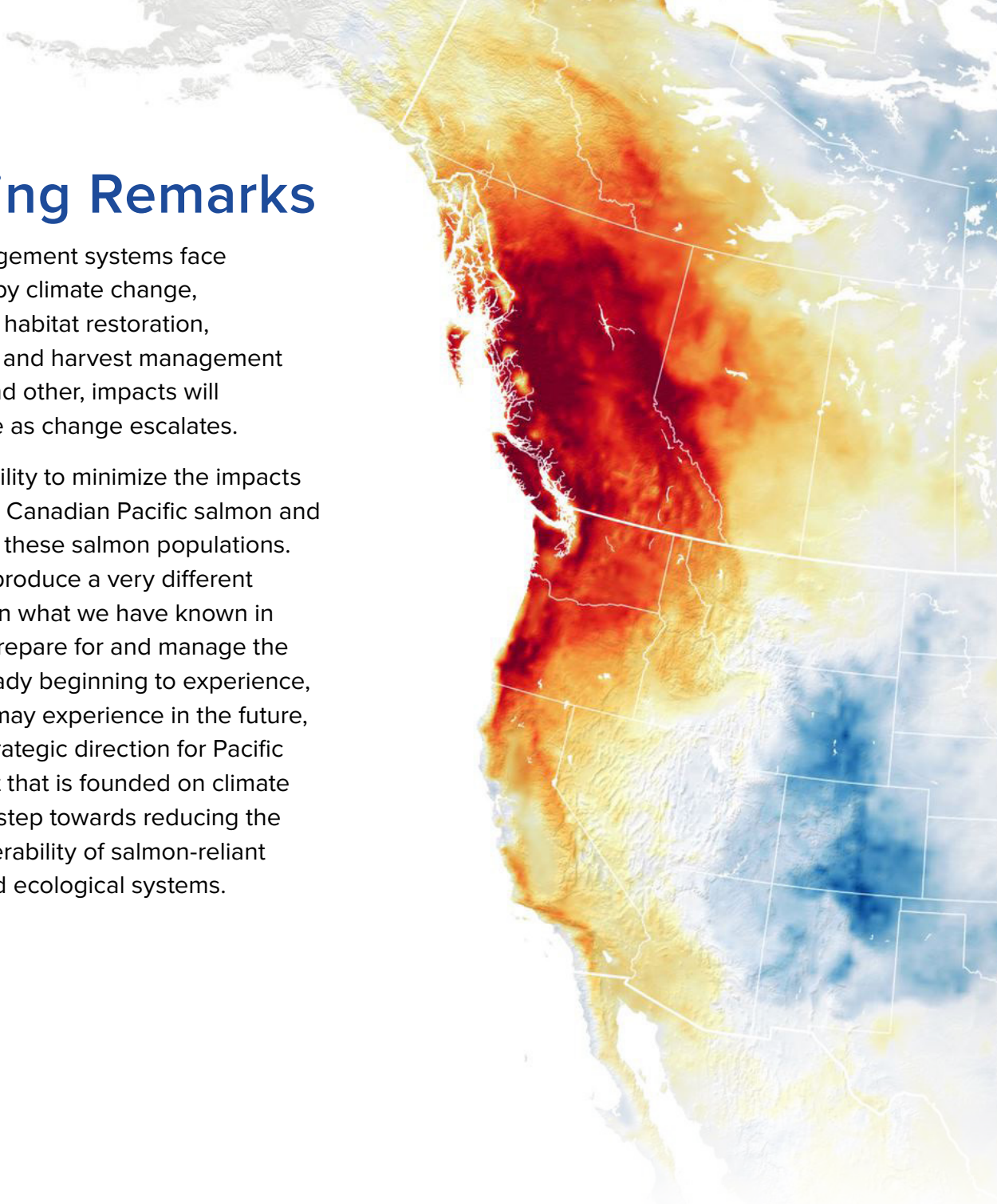
Adaptation may be aided by formal development of a strategic plan for climate adaptation in Pacific salmon management. This would build on the actions described here, and could be undertaken through a series of interdisciplinary workshops that engage Pacific salmon experts along with experts from other relevant fields. Adaptation plans can establish adaptation principles and objectives, identify commitments, specify information and resource needs, and flag potential roadblocks, such as policies, legislation, jurisdictional boundaries, and treaties, that perpetuate assumptions of stationarity [58].

An airtanker drops fire retardant to prevent wildfire spread. Photo by NowMedia.

Concluding Remarks

Pacific salmon management systems face challenges wrought by climate change, including impacts on habitat restoration, hatchery operations, and harvest management processes. These, and other, impacts will become more severe as change escalates.

We have a responsibility to minimize the impacts of climate change on Canadian Pacific salmon and all those who rely on these salmon populations. Climate change will produce a very different future for salmon than what we have known in the recent past. To prepare for and manage the changes we are already beginning to experience, as well as those we may experience in the future, we have provided strategic direction for Pacific salmon management that is founded on climate adaptation. This is a step towards reducing the climate change vulnerability of salmon-reliant social, economic, and ecological systems.



This image shows air temperature anomalies at 2m above the ground on June 27, 2021 compared to the 2014-2020 average for that day. Dark red areas depict exceptional heat, where air temperatures climbed more than 15°C higher than the average for that day.

Photo credit: NASA Earth Observatory image by Joshua Stevens, using GEOS-5 data from the Global Modeling and Assimilation Office at NASA GSFC. earthobservatory.nasa.gov/images/148506/exceptional-heat-hits-pacific-northwest

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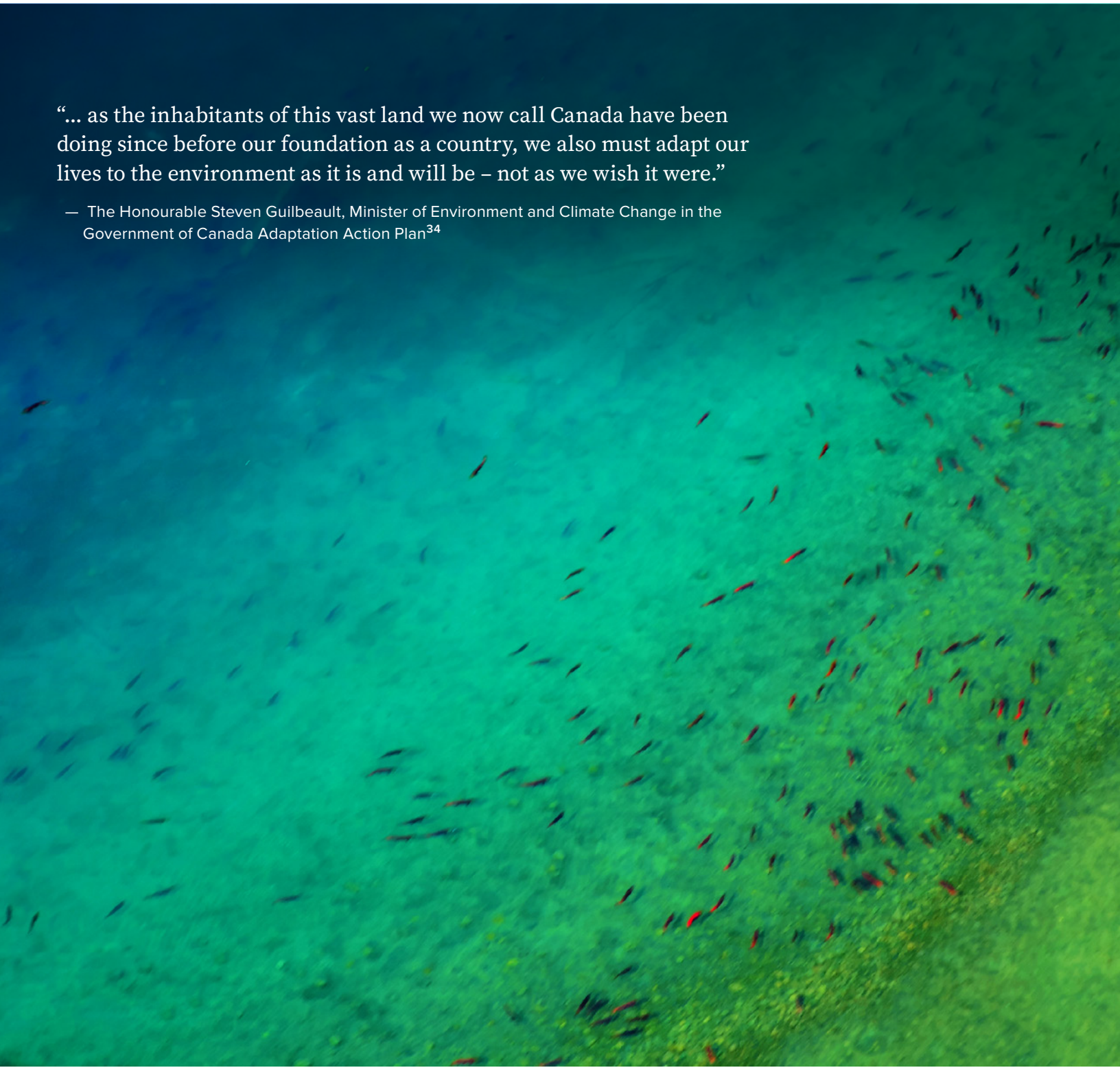

"... as the inhabitants of this vast land we now call Canada have been doing since before our foundation as a country, we also must adapt our lives to the environment as it is and will be – not as we wish it were."

— The Honourable Steven Guilbeault, Minister of Environment and Climate Change in the Government of Canada Adaptation Action Plan[34]

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