The Plight of Southern Resident Killer Whales:

Wicked Problems and Land & Water Governance Challenges

Review Paper

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Executive Summary

Southern Resident Killer Whales are a culturally important whale community in the Northeast Pacific. After over twenty years listed as endangered, it still struggles to recover. Many external and intrinsic factors inhibit its recovery. Anthropogenic threats such as declining prey abundance, increased disturbance, and contamination have cumulative impacts on the population.

The recovery of Southern Resident Killer Whales has been artificially inflated due to artificial barriers. Artificial boundaries inhibit the recovery of Southern Resident Killer Whales through fragmented management and barriers to information sharing. Furthermore, the Salish Sea is plagued by many competing interests that put pressure on the transboundary habitat of the population. The traditional feeding grounds of whales have been disrupted by human activities such as fishing, shipping, and pollution. In addition, the construction of dams and other infrastructure has altered the flow of rivers and streams, affecting the availability of salmon, a primary food source for whales.

All these activities are managed through various levels of government on both sides of the border. In order to ensure the recovery of Southern Resident Killer Whales, the artificial boundaries must be recognized and mitigated. An integrated management approach that considers the Salish Sea and related watersheds as a whole ecosystem is necessary.

Table of Contents

.... **0**

EXECUTIVE SUMMARY **1**

TABLE OF CONTENTS **1**

ACKNOWLEDGMENTS **3**

LIST OF TABLES AND FIGURES **3**

ABBREVIATIONS AND ACRONYMS **4**

INTRODUCTION **5**

PURPOSE 7

METHODS 8

THE CONTEXT OF SOUTHERN RESIDENT KILLER WHALE RECOVERY **8**

BACKGROUND 8

KILLER WHALES IN THE NORTHEAST PACIFIC 9

Current Population Trends *10*

WHY AREN'T SRKWS RECOVERING? 11

Meeting energy demands is becoming increasingly difficult. *12*

Survival Is Challenging When You're Among the Most Polluted Cetaceans *14*

It is Hard to Forage and Communicate Over the Anthropogenic Din *17*

Cumulative Effects *20*

THE INTRICATE NETWORK OF BOUNDARIES AFFECTING SRKW CONSERVATION EFFORTS **23**

A SHARED LEGAL OBLIGATION TO PROTECT AND AID RECOVERY. 25

WHAT HAPPENS UPSTREAM AND ON LAND MATTERS. 27

DECENTRALIZED AND FRAGMENTED WATER GOVERNANCE IN CANADA 29

At the Federal Level *30*

At the Provincial Level *30*

At the Local Level *31*

Artificial Barriers in Environmental Science and Management 32
Estuaries and Coastal Areas Management 34
The Fate of SRKWs Rests on Restoring Chinook Habitat 39
Habitat degradation and loss of connectivity 41
Water Contamination Resulting from Land-Based Activity 45
Competing Interests and Cumulative Effects 52
SRKW RECOVERY CALLS FOR MARINE ECOSYSTEM-BASED MANAGEMENT 60
CONCLUSIONS 64

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List of Tables and Figures

Figure 1. A framework for environmental risk assessment and management 8
Figure 2. Population trends from 1979 to 2018 for both Resident Killer Whale populations. 11
Figure 3. Conceptual diagram of the three functional groupings of potential risk from contaminants to killer whales. 15

FIGURE 4. CONCEPTUAL DIAGRAM OF THE MAIN PATHWAYS OF CONTAMINATION (POPS) FROM MATERNAL TRANSFER AND PREY CONSUMPTION. 17

FIGURE 5. MEAN MODEL SIMULATIONS OF POPULATION SIZE FOR SINGLE-THREAT SCENARIOS (B, C, D, AND E) AND THE CUMULATIVE EFFECTS AND HISTORICAL SCENARIOS OF THESE THREATS (F). 22

FIGURE 6. REFERENCE MAP FOR THE SALISH SEA BIOREGION 24

FIGURE 7. MARINE ACTIVITIES FALL WITHIN MULTIPLE JURISDICTIONS IN CANADA. 30

FIGURE 8. THE CONCEPTUAL RELATIONSHIP BETWEEN ECOSYSTEMS AND ESTUARINE ENVIRONMENTS. 35

FIGURE 9. FEDERAL MANAGEMENT MEASURES SUPPORT SOUTHERN RESIDENT KILLER WHALE RECOVERY IN 2018. 39

FIGURE 10. NATURAL AND HUMAN-INDUCED PRESSURES ON SALMON HABITATS AND WHERE RELATED RESPONSIBILITIES FALL. 41

FIGURE 11. 42

FIGURE 12. MAP SHOWING THE ESTIMATED HISTORICAL FLOODPLAIN, CURRENTLY ACCESSIBLE FLOODPLAIN FISH HABITAT, AND CURRENT DIKING INFRASTRUCTURE IN THE LOWER MAINLAND OF BRITISH COLUMBIA. 44

FIGURE 13. ESTIMATES OF CONTAMINANT RELEASE FROM POINT SOURCES TO WATER AND LAND, INCLUDING FORECASTS OF CONTAMINANTS TRANSPORTED VIA SURFACE WATER RUNOFF TO WATERS IN THE FRASER RIVER BASIN THAT AFFECT RKWS AND THEIR PREY. 47

FIGURE 14. LAND COVER IN THE SALISH SEA BIOREGION FROM 2015 DATA. 49

FIGURE 15. 50

FIGURE 16. 51

FIGURE 17. A COMMENT SHOWCASING FINGER-POINTING AND SENTIMENTS REGARDING ACTIONS IN SHARED WATERS. 53

FIGURE 18. CUMULATIVE IMPACTS ON THE SALISH SEA. 54

FIGURE 19. CONCEPTUAL DIAGRAM OF THE SOCIAL-ECOLOGICAL SYSTEM RELATING TO SRKW DECLINE AND RECOVERY. 60

Abbreviations and Acronyms

CEC: Contaminants of Emerging Concern

COSEWIC: Committee on the Status of Endangered Wildlife in Canada

ECCC: Environment and Climate Change Canada

ESA: Endangered Species Act

dB: Decibels

DFO: Ocean and Fisheries Canada

MFLNRO: Ministry of Forests, Lands and Natural Resource Operations

NMFS: National Marine Fisheries Service

PBDEs: Polybrominated Diphenyl ethers

POPs: Persistent organic pollutants

PCBs: Polychlorinated biphenyls

PVA: Population Viability Analysis

RKWs: Resident Killer Whales

SARA: Species at Risk Act

SRKWs: Southern Resident Killer Whales

NRKWs: Northern Resident Killer Whales

WWTP: Wastewater treatment plant.

Introduction

The Southern Resident Killer Whales (SRKWs, *Orcinus orca*) are an endangered icon of British Columbia's marine ecosystem and hold great cultural significance for coastal First Nations and coastal communities neighbouring the Salish Sea (Transport Canada, 2021). However, the status of the population and the current threats it faces could lead to extinction if more is not done for its recovery. SRKWs have been listed in the Species at Risk Act (SARA) since 2003 (Government of Canada, 2021) and the US Endangered Species Act (ESA) since 2005 (Federal Register, 2005).

The population of SRKWs peaked at 98 individuals in the mid-1990s but has mostly declined since 2006, oscillating between the low and mid-70s (Center for Whale Research, 2022). This population decline occurred even after almost two decades of protection under SARA and ESA, raising questions about the adequacy of the current recovery efforts. In their 2017 study, Lacy et al. found that there would be no population growth if restoration efforts and environmental conditions remained constant. An increase in anthropogenic disturbances could lead to population decline. Further decline could be dramatic for this community, as a small population can lead to high levels of inbreeding, and SRKWs already exhibit inbreeding depression, which affects their population dynamics (Ford et al., 2018; Kardos et al., 2023).

In 2018, the Government of Canada launched a program to invest $1.5 billion in an Oceans Protection Plan and $61.5 million specifically for measures to strengthen the protection of SRKWs (Government of Canada, 2022b). The recovery of SRKWs is a very complex issue that is hindered by a network of interconnected wicked problems, such as those related to land use (e.g., competing land-use interests) (van den Ende et al., 2023), agricultural nutrient loading in freshwaters (Wiering et al., 2023), non-point source water pollution (Patterson et al., 2013), water resource management (Lach et al., 2005), fisheries and coastal governance (Jentoft & Chuenpagdee, 2009), ocean health (de Salas et al., 2022) and climate change (Levin et al., 2012). Wicked problems are complex, dynamic societal problems with multiple levels, actors, and sectors, where different players may have different perspectives on the issue and often have competing goals. (Rittel & Webber, 1973; Bianchi et al., 2021). Environmental governance issues' environmental, economic and social dimensions are intertwined, often involving competing interests and varying degrees of economic and political influence on policy and decision-making (Jentoft & Chuenpagdee, 2009).

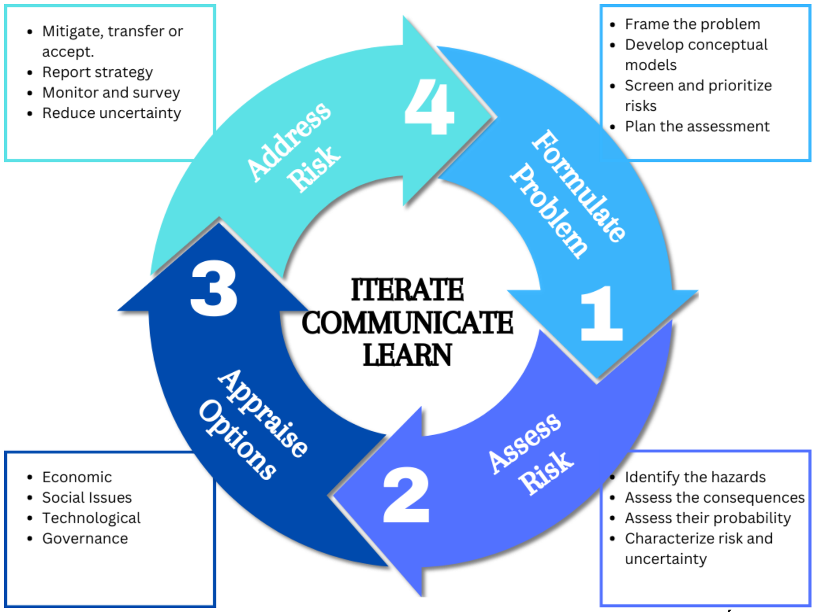
Political and administrative boundaries in international law and domestic jurisdiction can create bureaucratic hurdles and lead to ecosystem fragmentation (Jones et al., 2021). Ecosystems' complex and interconnected nature call for a more holistic approach to ecosystem management. To ensure the survival and recovery of the SRKW and Chinook salmon, land-based activities in the Fraser watershed must be examined and incorporated as part of broader, more integrated coastal ecosystem management.

Purpose

This report aims to review and assess the inherent governance conflicts among government agencies in addressing the wicked problem of conserving species at risk. To achieve this, this report examines the various threats that SRKWs face owing to the connection between their marine habitat, the associated freshwater and terrestrial ecosystems, and the multiple jurisdictions that manage them.

This review focuses mainly on the first three steps of the environmental risk assessment and management framework, as outlined in Figure 1.

Figure 1. A framework for environmental risk assessment and management



Note. Adapted from "Guidelines for Environmental Risk Assessment and Management." by Á. Gormley, S. Pollard, & S. Rocks. 2011. Used under an Open Government Licence.

Methods

This review consists of a systematic literature review of published materials from all relevant governmental and non-governmental organizations (NGOs) and academic sources.

The Context of Southern Resident Killer Whale Recovery

Background

Killer whales, or orcas, are the largest dolphin and can measure up to almost 10 meters (NOAA Fisheries, 2023a). They are considered the ocean's top predators and can be found in oceans around the world. Their lifespan is around 30-90 years, with females having more extended lifespans (NOAA Fisheries, 2023a). Killer whales are separated into many ecotypes that substantially vary in their behaviour, genetics and social structures (Marine Mammal Commission, n.d.). While the killer whale is a prey generalist, different ecotypes have different foraging specializations, some of which are carnivores, whereas others are piscivores (Ford & Ellis, 2006). Killer whales have complex social structures and have a high level of cooperation. They are part of a very exclusive group of species in which females have post-reproductive years and go through menopause (NOAA Fisheries, 2023a). They have a long gestation period, typically around 15 to 18 months, whereas calves typically nurse for about a year (NOAA Fisheries, 2023a).

Killer whales in the Northeast Pacific

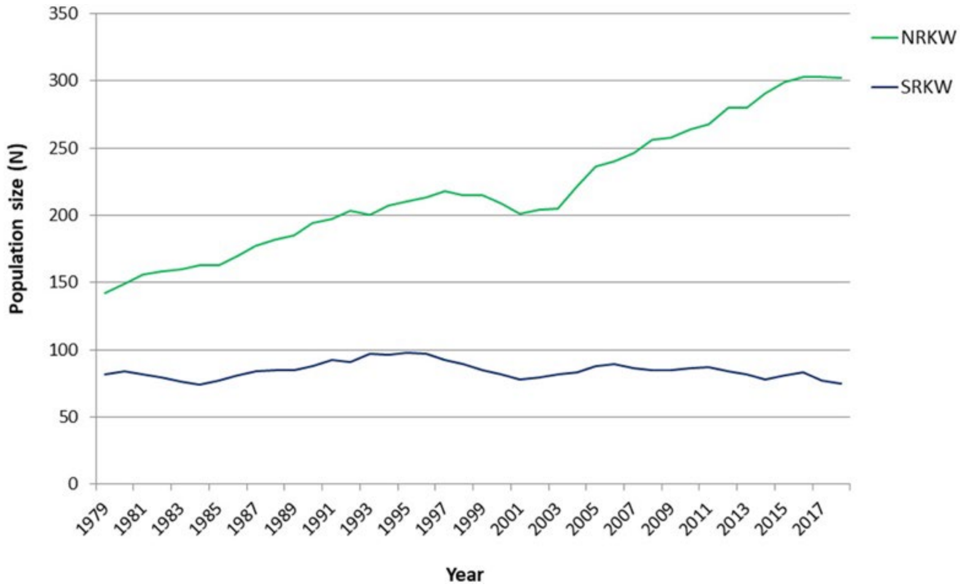
The Northeast Pacific coast of North America is home to three ecologically distinct types of killer whales: residents, transients (Bigg's), and offshores (Bigg, 1982; Ford et al., 1998; Fisheries and Oceans Canada, 2019). Although the geographic distributions of these ecotypes overlap, they appear to be genetically diverse, with differences in appearance, behaviour, social structure, feeding techniques, and communication (Marine Mammal Commission, n.d.). Three distinct populations comprise the fish-eating Resident ecotype: Alaska Residents (US), Northern Residents (US-CA), and Southern Residents (CA-US) (Marine Mammal Commission, n.d; Fisheries and Oceans Canada, 2019). As suggested by their names, the northern residents' habitat ranges from southeast Alaska to central Vancouver Island, which overlaps with the southern residents' habitat in the north, extending south to Washington State. These communities are composed of whales that share the same range and associate with one another. Bigg et al. (1990) explained that these communities are divided into pods and smaller groups that frequently travel together within the community. Subpods are smaller groups within the pod that sometimes split off temporarily from the pod, and intrapod groups are individuals who always travel close to each other. Individuals live in stable matrilineal groups, led by the eldest female (Bigg et al., 1990; Parsons et al., 2009). The SRKWs are comprised of three pods, J, L and K.

Current Population Trends

While the two resident populations of the Canadian water overlap and share a preference for the same prey (Ford et al., 1998), they have been experiencing vastly different population trends. Following years of live capture that resulted in the death and displacement of several individuals in marine parks, both populations began to be counted in the early-mid 70s. By interacting with orcas in captivity, the public's perception of killer whales shifted, and people began to speak out against their captivity, ending the live capture of orcas (Bigg & Wolman, 1975; Cullis-Suzuki, 2020).

When the first population census began in 1974, the Southern and Northern Resident populations comprised approximately 71 and 120 individuals, respectively (Resident Killer Whale Recovery Team, 2007). From 1974 to the mid-1990s, the two resident populations experienced similar long-term population growth, with the southern population peaking at 98 (Ellis, 2011). After the mid-1990s, the population trends began to differ. The Southern Resident population has mainly fluctuated downward, while the Northern Resident population has maintained a constant average growth (Center for Whale Research, 2022; DFO, 2023). Figure 2 shows the differences in population growth.

Figure 2. Population trends from 1979 to 2018 for both Resident Killer Whale populations.



Note. From "A cumulative effects model for population trajectories of resident killer whales in the Northeast Pacific" by Murray, C. C., Hannah, L. C., Doniol-Valcroze, T., Wright, B. M., Stredulinsky, E. H., Nelson, J. C., Locke, A., & Lacy, R. C. 2021. Biological Conservation, 257, 109124. https://doi.org/10.1016/j.biocon.2021.109124. (Used under CC BY-NC-ND 4.0) Data sources are DFO Cetacean Research Program and the Center for Whale Research.

The latest census (2022) on the North Resident population is estimated to be 341, while the Southern Resident population is 73 (Center for Whale Research, 2022; DFO, 2023). In June 2023, the Center for Whale Research confirmed that two new calves had joined the L pod of SRKWs, potentially bringing the total number to 75 (Center for Whale Research, 2023).

As a result, this report focuses primarily on the recovery of SRKWs, since they are struggling to recover even after two decades of protection under the Species at Risk Act, thus raising questions about the adequacy of current recovery efforts and the feasibility of their recovery.

Why Aren't SRKWs Recovering?

SRKWs face a wide range of threats in their transboundary habitat resulting from the actions of Canada and the USA. The three main threats identified by both countries are reduced prey availability, disturbance, and environmental contaminants (DFO, 2018a; NOAA Fisheries, 2023b).

Meeting energy demands is becoming increasingly difficult.

Resident killer whales specialize in foraging for salmonids and have a strong penchant for the largest Pacific salmon, chinook salmon (Ford & Ellis, 2006; DFO, 2019b).

Hunting mobile prey requires higher muscle performance to chase and hunt hard to catch prey successfully. The energy requirement for this muscle performance may require more energy to meet the daily demands of their activities and metabolic rate (Spitz et al., 2012). Foraging specialists, such as resident killer whales, may target energy-dense foods because of their energetically demanding lifestyles (Spitz et al., 2010; Spitz et al., 2012). When the expense of pursuing prey exceeds the potential gain, the trade-off may not be worthwhile. Therefore, species with high cost of living are vulnerable to shifts in the quantity and quality of prey available to them (Spitz et al., 2012).

While the fondness for this salmonid species may have been due to their historical abundance and energy value per fish (Ford & Ellis, 2006), SRKWs do not receive the same energetic return on investment they have historically grown to expect. Chinook salmon are not as abundant as they used to be, and twenty-two populations of Chinook salmon are listed in Canada's *Species at Risk* Public Registry as endangered, threatened, or at risk (Government of Canada, 2023).

Not only are Chinook salmon populations declining, but every catch no longer provides the same nutritional value as it did historically, taking a toll on SRKWs (Couture et al., 2022). Their average length at age is decreasing, which has also been found to affect the number of eggs laid per fish by approximately 16% (Oke et al., 2020). Apart from becoming smaller, resulting in lower energy intake per fish, not all salmon stocks are equal in their caloric content. Different Chinook Salmon stocks have varying contents of lipids, which implies that the whales are not getting the same gain for their energy expenditure when targeting other stocks (Lerner & Hunt, 2023). Unfortunately for SRWKs, the salmon stocks they rely on for their high-lipid diet are among the most vulnerable, meaning killer whales must spend more time foraging to catch more fish to meet their cost of living (Lerner & Hunt, 2023). This could prompt whales to switch to lower-reward prey or reduce their activity levels to catch something more worthwhile. For example, older, larger fish provide the highest energy gain and could be a priority target for killer whales (Ohlberger et al., 2019). However, not all resident killer whales likely have equal access to older salmon (Ford & Ellis, 2006; Hanson et al., 2021). While both Resident populations have overlapping ranges, NRKWs' northern range may provide priority access to some of the oldest Pacific salmon returning from Southeast Alaska and the north coast of British Columbia to spawn in west coastal rivers (NOAA, 2020). Even though SRKWs are abundant in the coastal and estuarine waters of the Salish Sea when older Chinook salmon migrate back to rivers to spawn (Transport Canada, 2022; Thornton et al., 2022), the oldest, more energy-rich fish may be preyed on before they make their way to the critical foraging area of SRKWs (Hanson et al., 2021).

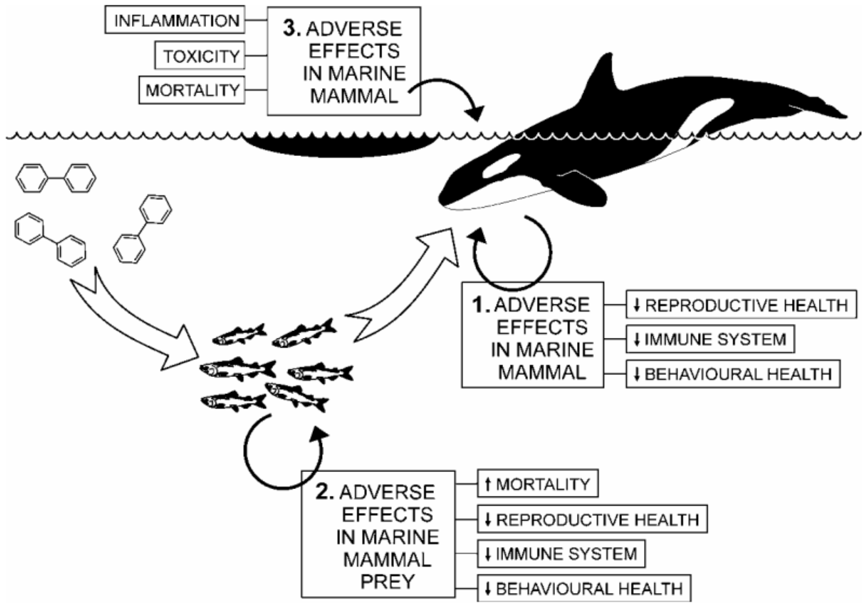
When a population faces greater difficulty in satisfying its energy needs, it can significantly affect the population dynamics (Wasser et al., 2017). Evidence suggests that SRKWs face periods of nutritional stress (Couture et al., 2022). Their low reproductive success has been linked to the stress they experience in times of low prey quantity, and the chance of reproductive success can change by 50 percent between years of low and high salmon abundance (Ward, 2009; Wasser et al., 2017). Differences in net energy acquisition between different populations could partly explain why these populations experienced different population trends.

Survival Is Challenging When You're Among the Most Polluted Cetaceans

Chemical pollutants are widespread in killer whales and may have grave consequences for survival (Desforges et al., 2018). Killer whales in British Columbia's coastal waters have been determined to be among the most contaminated cetaceans in the world, putting them in danger of toxic effects (Ross et al., 2000). There are three ways contamination can represent a risk to killer whale survival, as presented by Garrett and Ross (2010):

1. Accumulation of pollutants in SRKWs from prey consumption.
2. Contaminants in prey habitats lead to reduced prey quality and quantity for SRKWs.
3. Indirect effects on SRKWs due to the contaminants on the ocean surface

Figure 3. Conceptual diagram of the three functional groupings of potential risk from contaminants to killer whales.



Note. From "Recovering Resident Killer Whales: A Guide to Contaminant Sources, Mitigation, and Regulations in British Columbia" by C. Garrett & P.S. Ross. 2010. Can. Tech. Rep. Fish. Aquat. Sci., 2894, xiii + 224 p

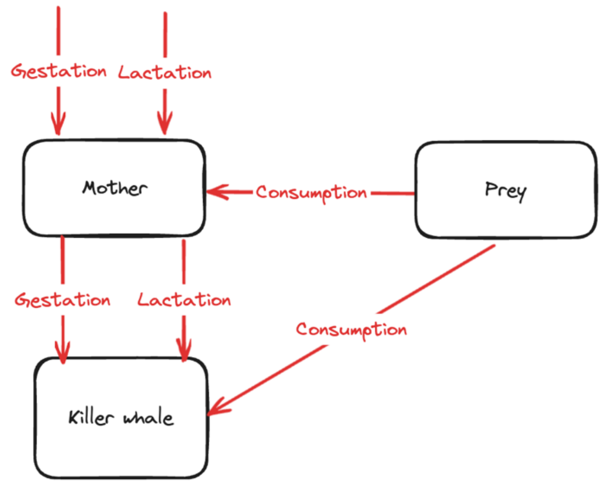
Persistent Organic Pollutants (POPs) are a broad category of persistent chemicals that bioaccumulate and are toxic (Garrett & Ross, 2010). POPs are both hydrophobic (water repellent) and lipophilic (fat-loving) (Jones & de Voogt, 1999). POPs bind strongly to solids such as organic matter in aquatic ecosystems (Jones & de Voogt, 1999). Owing to their hydrophobic properties, POPs tend to accumulate in sediments and soils where there is an abundance of organic matter that is consumed by organisms living in the sediment and eventually bio-magnifies in higher tropic species such as marine mammals (Gray, 2002; Burd et al., 2022).

Three classes of POPs, polychlorinated biphenyls (PCBs), organochlorine pesticide DDT, and polybrominated diphenyl ethers (PBDEs), are of primary concern for SRKWs and have been found in high numbers in their bodies, prey, and the environment (Mongillo et al., 2016). PCBs and DDT are legacy POPs contaminants that have been widely banned but still linger in the environment, whereas PBDEs are contaminants of current concern and use (DFO, 2018a). These chemicals can cause various problems, impairing health, reproduction, and development (Mongillo et al., 2016; DFO, 2018a).

Long-lived marine mammals with higher trophic status are particularly susceptible to the effects of these contaminants because they accumulate in aquatic systems at successive trophic levels (Drouillard, 2008). For example, PCBs can accumulate in killer whale bodies, adversely affecting their health and reproductive success (Jones & de Voogt, 1999; Noël et al., 2009). High concentrations of PCBs have been detected in killer whale tissue. It has been suggested that PCB exposure may contribute to low recruitment and long-term population decline (Desforges et al., 2018). The J pod of SRKWs has been found to have the highest predicted PBDE and PCB concentrations due to their higher residence time in areas close to industrial centres, such as the Fraser Estuary (Mongillo et al., 2012).

A recent study analyzing samples from deceased SRKWs and Biggs' killer whales found that the maternal transfer rates of many chemicals were exceptionally high in killer whales (Lee et al., 2023). For example, despite the widespread ban on PCBs, they remain a significant threat to killer whale populations because of the heavy toxicological burden placed on newborns through the maternal transfer of PCB to calves, especially from first-time mothers (Schnitzler et al., 2019). This can lead to increased calf mortality.

Figure 4. Conceptual diagram of the main pathways of contamination (POPs) from maternal transfer and prey consumption.



Notably, the combination of environmental pollutants to which SKRWs are exposed may also interact as additive, synergistic, or antagonistic (Mongillo et al., 2016). With synergistic interactions, the sum of the effects of these chemicals may be much greater than the estimated value.

These contaminants can harm killer whales by decreasing their fitness, survival, and reproductive success (Lacy et al., 2017).

It's Hard to Forage and Communicate Over the Anthropogenic Din

The importance of acoustic information for Killer Whales

Killer whales have evolved highly sophisticated hearing systems to help them navigate their environment where visibility is often poor (Au et al., 2000). The speed of sound in seawater, which varies based on oceanographic variables, travels much faster in water than in air, allowing the propagation of acoustic energy over great distances (DOSITS, n.d.). The sound environment of the ocean allows whales to make sense of their habitats and communicate with each other (Au et al., 2000; Hildebrand, 2005).

Owing to their acoustic sensitivity, killer whales can use echolocation, which uses sound to gather information about nearby objects. This is achieved by emitting high-frequency clicks and brief sound pulses and then waiting for the echoes to return from the target (Ford, 1989; Au et al., 2004). This makes echolocation an excellent tool for finding prey such as salmon, where the echo that bounces off the fish's swim bladder provides the whale with a range of information, including the ability to identify the type of prey (Foote, 1980; Au et al., 2010). Although killer whales have broad hearing sensitivity (~0.6-114kHz), they have the best sensitivity at high frequencies (~34kHz) (Branstetter et al., 2017).

Anthropogenic Noise is a sensory pollutant on Killer Whales

Noise pollution is pervasive on land and in oceans. Underwater noise pollution can be heard over greater distances because of the increased propagation speed, which makes it difficult to escape. For example, low-frequency noises (<500 Hz) can be heard over distances greater than 100 km (Nolet, 2017). Consequently, it can be important in increasing the overall ambient noise levels. For sound signals to be detected, they must stand out from ambient background noise. Masking occurs when background noise prevents an animal from hearing relevant sounds with similar frequencies (Hildebrand, 2005). Unfortunately, the noise from ships overlaps with the hearing frequency of killer whales. A study of the noise level in Haro Strait in the critical habitat of SRKW showed that the combined increase in several types of ships resulted in an increase of 19 dB re 1 Pa above the mean background level, including increases at both low (100–1,000 Hz) and high frequencies (10,000–40,000 Hz) (Veirs et al., 2016). Thus, not only can noise from ships mask killer whale communications and echolocation, but they also overlap with their most sensitive frequencies.

Because of masking, the species must be louder for their signals to be heard. The Lombard effect (Kunc et al., 2022) has been observed in killer whales, where they have been observed to increase the volume of their calls by one decibel for every decibel of ambient noise (Holt et al., 2009). They have been shown to lengthen the time of their calls (Foote et al., 2004). Killer whales frequently change their behaviour in response to anthropogenic disturbances, which may affect their energy expenditure and intake (Noren et al., 2016). Not only are they less likely to catch prey in the presence of vessel disturbance, but they are also less likely to engage in foraging when noise levels increase (Lusseau et al., 2009; Williams et al., 2021; Holt et al., 2021). As a result, estimates have shown that killer whales may consume 18% fewer calories because disturbances reduce their foraging opportunities (Williams et al., 2006). When coupled with declining prey availability and quality, these energy costs can have long-term population effects (Williams et al., 2006). If a great deal of background noise masks echolocation, it becomes harder for the whale to catch its prey, and expending its energy on foraging might not be worthwhile.

Vessels in their environment can also result in direct physical threats. Impact collisions can result in fatal strikes, and if a whale survives the impact, it may result in serious injury (Visser, 1999; Raverty et al., 2020). For a small population, a fatal vessel strip can have a significant impact (Murray et al., 2021).

Cumulative Effects

As defined by Environment and Climate Change Canada (ECCC), the term cumulative effects *"generally refers to the combined effects from past, present, and reasonably foreseeable future activities and natural processes"* (Canada, 2022). They occur when the effects of many stressors overlap and the system cannot recover (DFO, 2019c). Individually, the activities and their impact may be negligible, but collectively, they are significant and have emerging consequences (DFO, 2019c).

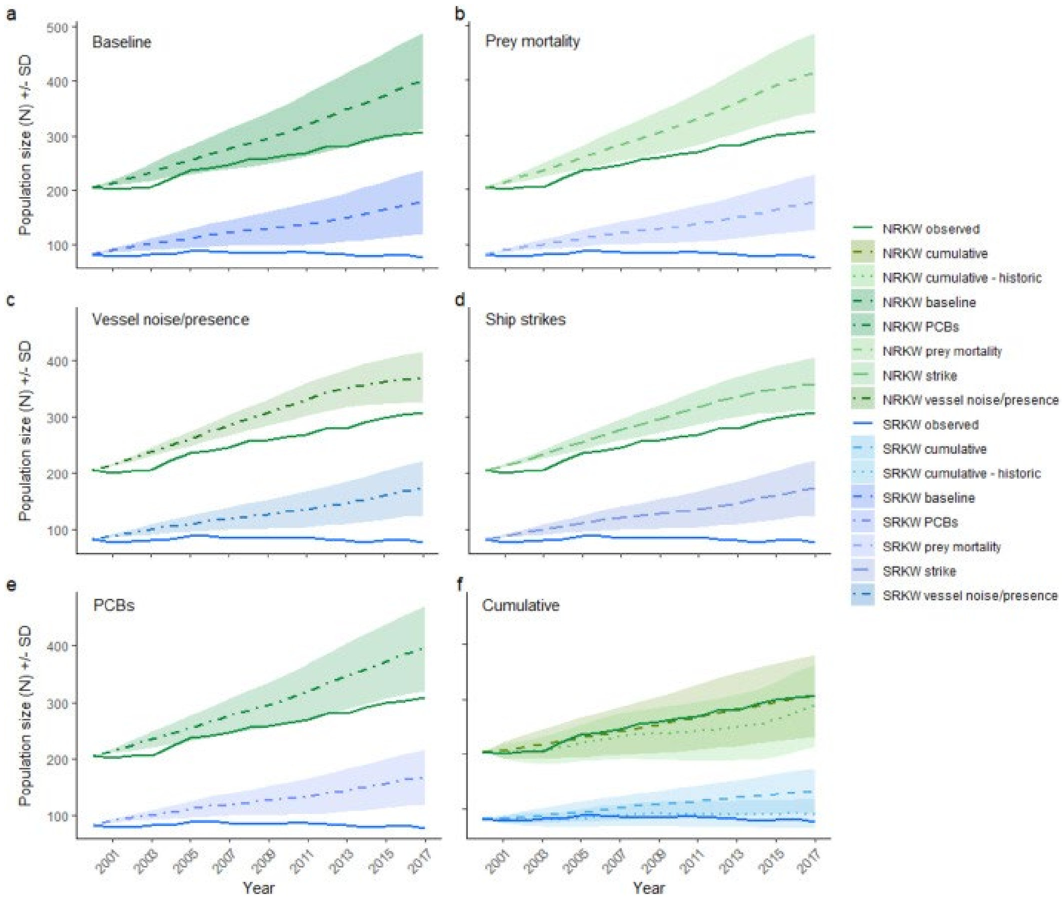
The cumulative effects of several stressors on a species or ecosystem must consider the interaction effect of multiple intrinsic and extrinsic factors (Benscoter et al., 2013; Palmer & Yan, 2013). Various factors can make species, subspecies, or communities more vulnerable than others (Sih et al., 2004; Benscoter et al., 2013). For instance, the dwindling SRKW population, which has been reduced primarily because of human activities (such as captivity), is more vulnerable to extinction owing to inbreeding depression, a significant issue in isolated populations (Ford et al., 2018; Kardos et al., 2023).

Most importantly, these factors can act synergistically, and the combined impact may be much higher than the sum of their parts (Sih et al., 2004). The cumulative effect of the three main threats faced by SRKWs plays an important role in population dynamics. For example, since their preferred prey is decreasing in size and SRKWs may have less access to older, more energy-dense Chinook salmon, they must consume an increasing number of salmon to meet their energy demands. As a result, they may ingest more PCBs (Cullon et al., 2009). Additionally, food scarcity resulting from reduced prey intake due to disturbance or prey availability can potentially result in a toxic response as they draw on their lipid reserves in their blubber, resulting in the mobilization of POPs into the circulation (Mongillo et al., 2016; Lundin et al., 2016). Pregnant or new killer whale mothers can have adverse effects on the calf, as these mobilized contaminants can be transferred to the calf through gestation or lactation (Aguilar & Borrell, 1994; Mongillo et al., 2012).

Modelling the risk to a population over time can be performed using risk management tools such as Population Viability Analysis (PVA). As shown in Figure 5, a 2021 PVA that analyzed the threats faced by resident populations discovered that no single threat could duplicate the patterns observed in either population (Murray, 2016). When the threats were combined, the population trend closely resembled that observed.

This further emphasizes the need to understand how the different components of SRKWs' habitat inhibit their recovery and the various actors tasked with ensuring their survival.

Figure 5. Mean model simulations of population size for single-threat scenarios (b, c, d, and e) and the cumulative effects and historical scenarios of these threats (f).



Note. From "A cumulative effects model for population trajectories of resident killer whales in the Northeast Pacific" by Murray, C. C., Hannah, L. C., Doniol-Valcroze, T., Wright, B. M., Stredulinsky, E. H., Nelson, J. C., Locke, A., & Lacy, R. C. 2021. Biological Con. (Used under CC BY-NC-ND 4.0)

The Intricate Network of Boundaries Affecting SRKW Conservation Efforts

Killer whales are often considered to be indicator species. The decline in SRKWs may reflect the degradation of their transboundary habitat, the Salish Sea (Environment and Climate Change Canada & EPA, 2021). SRKW's core habitat falls under various official responsibilities and management structures that differ between the two countries (Jones et al., 2021). The recovery of SRKWs is complicated because it relies on an ecosystem that transcends artificial (human-defined) boundary lines, which are at odds with the ecosystem's natural boundaries. For example, artificial boundaries can define the scope of an authority's territory by separating the area within its jurisdiction from those that do not (Haider-Markel, 2013). This type of divide can lead to fragmented ecosystem management.

For example, before 2010, the Strait of Juan de Fuca, the Strait of Georgia, and Puget Sound were regarded as distinct bodies of water (Tucker & Rose-Redwood, 2015). Designating this area as the Salish Sea officially recognized it as a single geographic entity. The Salish Sea Bioregion includes the entire region from which water drains into the Salish Sea, regardless of geographical borders (Salish Sea Bioregional Sanctuary, n.d.).

Figure 6. Reference Map for the Salish Sea Bioregion

Note. From Aquila Flower, 2020, used under CC BY-NC-ND 4.0.

While this name change recognizes the Salish Sea as an ecosystem that must be viewed as a whole, conservation initiatives by the US and Canada remain fragmented (Jefferies et al., 2021). Managing multiple activities and their impact within each country is complex. For example, when it comes to public health and environmental protection, the Canadian Federal Government alone is responsible for more than twenty-five different statutes, including the Oceans Act, Species at Risk Act, Canada Water Act, Canada Wildlife Act, Canadian Environmental Assessment Act, Fisheries Act, and Indian Act (Government of Canada, 2022a).

Since artificial boundaries do not reflect natural boundaries, policies and decisions at the local, provincial, and national levels can spill over neighbouring communities, provinces, and countries (Haider-Markel, 2013). However, these decisions are often made without consideration or collaboration with neighbouring jurisdictions. Consequently, this approach often fails to assess the actual cumulative effect of a decision.

Managing marine ecosystems, such as the Salish Sea, is challenging because these ecosystems *"are complex, science is incomplete, stakes are high, and conflict is inevitable"* (Wondolleck & Yaffee, 2017, p. 2).

A Shared legal obligation to protect and aid recovery.

The Species at Risk Act (SARA) is an essential piece of Canadian federal legislation for conservation. The purpose of the Act is *"to prevent wildlife species from being extirpated or becoming extinct, to provide for the recovery of wildlife species that are extirpated, endangered, or threatened as a result of human activity, and to manage species of special concern to prevent them from becoming endangered or threatened"* (Species at Risk Act (S.C. 2002, c. 29),). SARA is a federal statute that applies to all federal lands and waters, making it important for coastal and marine areas (Hewson et al., 2023). Through SARA, migratory birds, aquatic species, migratory birds, and species on federal lands are automatically protected

(Nixon et al., 2012). Under this law, it is illegal to kill, harm, harass, capture a protected species, or destroy its habitat (Species at Risk Act (S.C. 2002, c. 29),).

After a species has been classified as *Endangered* or *Threatened*, and the Minister has identified its critical habitat, the legal protection of this habitat must be established by implementing a regulation or order (Hewson et al., 2023). Subsection (33) of SARA states that: *"No person shall damage or destroy the residence of one or more individuals of a wildlife species that is listed as an endangered species or a threatened species, or that is listed as an extirpated species if a recovery strategy has recommended the reintroduction of the species into the wild in Canada."* (Species at Risk Act (S.C. 2002, c. 29),)

However, this federal statute only applies automatically to species on land under federal jurisdiction (Nixon et al., 2012). In response, the Canada-BC Agreement on Species at Risk 2005 established an administrative framework that requires collaborative knowledge sharing between provincial and federal government agencies while they remain responsible for recovering the species that fall within their jurisdiction (Government of British Columbia,). The Province can also designate a species as endangered or threatened under the British Columbia Wildlife Act (Government of British Columbia,).

These legislations are essential for providing a legal obligation to different levels of government to protect certain species and their habitats, which have often been degraded due to anthropogenic activities. In the US, the *Endangered Species Act (ESA)* works similarly and has the same purpose. For example, SRKWs are listed under the federal ESA, as well as Washington State's ESA, and have been petitioned for Oregon State's ESA (Wiles, 2004; Oregon Department of Fish and Wildlife, 2023). At the federal level, the National Oceanic and Atmospheric Administration and the US Fish and Wildlife Service are responsible for the implementation of the ESA, each having primary responsibility for marine and anadromous species, and terrestrial and freshwater species, respectively (EPA, 2022). However, there are sometimes differences between the two laws and definitions of certain elements. For example, while acoustic degradation is part of the definition of critical habitat for SRKW, the US ESA critical habitat for SRKW omits this factor (Williams et al., 2013; Williams et al., 2014). Variations in interpretation and definition can result in discrepancies in management efforts. Furthermore, ESA and SARA often differ in their recovery goals for certain species, with varying ambitions and quantitative goals (Pawluk et al., 2019). Although similar rules and regulations have been enacted on both sides of the border to mitigate the threats SRKWs face, some differences exist.

What Happens Upstream and on Land Matters.

There are serious concerns regarding the environmental effects of human development near the land-sea interface of coastal watersheds (Mallin et al., 2000). How upstream rivers and their adjacent lands in the watershed are managed can significantly impact estuaries and the marine environment (Mallin et al., 2000). Therefore, it is crucial to integrate freshwater and coastal resource management to protect water-related resources, species, and habitats. This entails holistically considering activities within the watershed and avoiding fragmented management, without sufficient collaboration among competing interests.

The British Columbia Auditor General's 2015 report on governmental management of cumulative effects notes that individual agencies can make decisions without considering the effects on other sectors

(Auditor General of British Columbia, 2015). Additionally, the Law does not explicitly mandate ministers or agencies to manage cumulative effects when approving the utilization of natural resources.

Land-based activities and projects are often approved in aquatic systems without considering their impact on connected aquatic ecosystems. The issues with this fragmented management of resources if beautifully illustrated in the report with the following descriptive example:

> *"Imagine, for example, a watershed with a stream that provides spawning habitat for salmon and drinking water for a nearby community. A logging company builds a road in the watershed, and the construction causes sediment to enter the stream. A year or two on, the oad enables a rancher to have his cattle access range land. The cattle trample the stream banks, and their waste enters the stream. Later, water is diverted from the stream to supply a new mine and irrigate nearby crops.*
>
> *Each of these activities – forestry, ranching, mining and agriculture – are individually regulated and managed to limit and mitigate their environmental impacts. However, residual impacts (effects expected to remain even after mitigation) can combine and have a greater effect than any one individual activity could.*
>
> *For the stream just described, the cumulative effects of the water diversions combined with the sediments and contaminants entering the stream could make the water unsafe for human consumption, and usuitable for supporting salmon. Human health, a commercial fishery and wildlife that rely on salmon, would ow all be at risk."*

- Auditor General of British Columbia (2015)

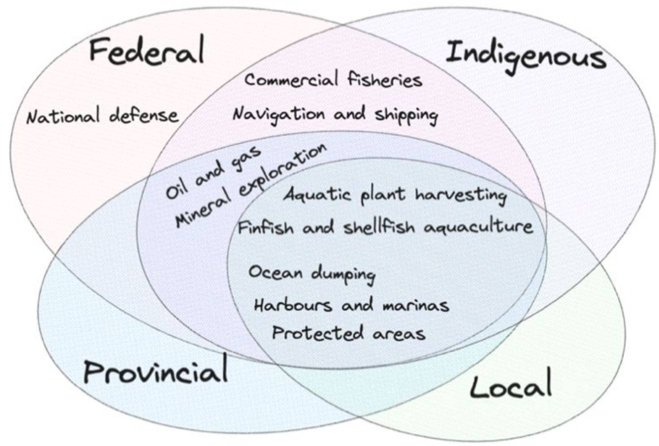
According to Carlson & Baylis (2022), the Crown Legal System permits and normalizes activities that damage salmon habitats because these activities are justified as ill-defined trade-offs between harm to salmon and other socio-economic values. Despite the interconnected nature of salmon ecosystems, the crown legal framework is disjointed, with different laws and jurisdictions governing the same impact but from various activities (Carlson & Baylis, 2022). Many regulatory tools fail to provide legal support for restoring salmon habitat (Carlson & Baylis, 2022).

Decentralized and Fragmented Water Governance in Canada

It is vital to understand the complexity of its governance to investigate the current management of resources and habitats relevant to killer whale recovery.

In Canada, responsibility for water management is shared between federal, provincial, and municipal governments and indigenous authorities (ECCC, 2016). Canada's constitutional framework allows overlapping jurisdictions (Hewson et al., 2023). There are more than 30 government agencies responsible for water quality, waste management, land use, water use and habitat protection in addition to their sub-departments (e.g. local governments) (Langer, 2019). In many instances, such as for freshwater management, regulatory authority over specific matters is shared between federal, provincial, and local governments and indigenous peoples.

Figure 7. Marine activities fall within multiple jurisdictions in Canada.



Note. Based on information from Table 2 of "Protecting the Coast and Ocean: A Guide to Marine Conservation Law in British Columbia" by S. Hewson, L. Nowlan, G. Lloyd-Smith, D. Carlson, & M. Bissonnette. 2023. UBC Press.

At the Federal Level

Federal responsibilities that have jurisdiction over matters related to water resources, such as fisheries, shipping and navigation, freshwater on federal lands, pollution prevention, and international relations, such as boundary waters (ECCC, 2016; ECCC, 2020). These responsibilities fall in the hands of various departments and agencies within the federal government.

At the Provincial Level

According to the Constitution Act (1867), the constitutional responsibility for inland water management and conservation primarily rests with the provinces, although federal obligations also provide some jurisdiction (ECCC, 2020). All waters within a province's borders, which are not on federal lands or First Nation reserves, fall under its jurisdiction. In British Columbia, water is managed under a complex set of laws and policies by both the Ministry of Environment and the Ministry of Health Services (ECCC, 2017).

Table 1.

Legislations	Policies & Strategies
Drinking Water Protection Act	Agricultural Policy Framework
Environmental Management Act	A Freshwater Strategy for BC
Water Act	Planning, Protection and Sustainability
Water Protection Act	Water Conservation Strategy for BC

Importantly, provinces have legislative authority to authorize water use developments, regulate pollution, and develop thermal and hydroelectric power, all of which can affect marine and freshwater species. (ECCC, 2017). The Province can delegate some elements of water management to local governments. For example, it includes water supply and wastewater management (Government of British Columbia, n.d.).

At the Local Level

The Province can delegate water and environmental management elements to local governments, such as water supply and wastewater management (Government of British Columbia, n.d.). Local government control over land use and zoning plays a significant role in conservation, particularly concerning riverine health and connectivity.

While this decentralized approach to environmental governance enables local governments to make decisions that represent the needs and challenges at the community level, it leads to a high degree of fragmentation of governance (Nowlan, 2010; Bakker & Cook, 2011).

"The lines between Crown, provincial, federal, and local government jurisdiction are not always clear, nor are Indigenous rights, title, and law consistently honoured and upheld. This complexity can lead

to challenge, conflict, delay, and inaction when it comes to protecting ocean areas." (Hewson et al., 2023) p. 13

Consequently, this can result in ambiguous roles and responsibilities regarding some regions of water and environmental governance (Ebbwater Consulting Inc, 2021). Without proper funding and provincial or federal policy guidance, this can result in inaction or disparities between approaches (Ebbwater Consulting Inc, 2021).

The MLA for Saanich North and the Islands, Adam Olsenm captures this sentiment in the following excerpt from a recent blog post (Olsen, 2023):

> *"One of the first big issues I confronted as a councillor in the District of Central Saanich in 2008 was the multi-jurisdictional swamp that governs the waters around our communities. The province owns the land below the water and grants limited power to municipalities to make "land" use decisions. The federal government controls the surface and water column. First Nations have unrealized inherent rights and jurisdiction. It's a total mess that often results in finger-pointing and administrative gridlock. The result of the dysfunctional relationships is evident.*

Artificial Barriers in Environmental Science and Management

Freshwater and marine environments are often managed and researched separately (Salomon et al., 2011). There are often significant differences in management approaches for freshwater and marine fisheries (Cooke et al., 2014). For researchers, this is partly due to the different histories and epistemologies that underpin these disciplines. In contrast, different institutional mandates and conflicting objectives can lead to a false dichotomy between fresh and marine resource management

(Salomon et al., 2011). For example, although marine and commercial fisheries are the federal government's responsibility, freshwater recreational fisheries are the responsibility of provinces (Hewson et al., 2023).

As explained by Cooke et al. (2014) in *Where the Waters Meet: Sharing Ideas and Experiences between Inland and Marine Realms to Promote Sustainable Fisheries Management*, *"In the fisheries world, the scientific community may be called 'guilty' of promoting an artificial boundary between the marine and freshwater (herein called inland) realms. The divide between marine and inland fisheries may simply stem from the way such resources are managed by different institutions and governance systems. Moreover, marine and inland fisheries sciences have emerged from different scientific traditions"* (p. 1594).

The transmission and spread of information across geographical, legal, cultural, and institutional boundaries are central to the diffusion of innovations (He & Berry, 2022; Maclean et al., 2022). Sometimes, artificial borders can hamper knowledge sharing between scientists and decision-makers, and effective conservation requires knowledge sharing across borders (Cvitanovic et al., 2016).

For example, knowledge sharing in fragmented local governments is hindered by two obstacles to the dissemination of knowledge from research partnerships (Mullin, 2021):

1) Findings may not be generalizable across all settings
2) Lack of access to the findings by local governments who could benefit from it.

Consequently, owing to their interconnectedness, marine and freshwater fishery agencies must work together to enhance fishery governance through a more integrated approach to water resource management (Cooke et al., 2014). This is also the case for land and water management.

Estuaries and Coastal Areas Management

Coastal and estuarine ecosystems are highly productive and account for approximately one-third of the global value of ecosystem services (Costanza et al., 1998; Barbier et al., 2011).

As with the governance of aquatic ecosystems, managing coastal areas in British Columbia depends on various laws, regulations, policies, and programs administered by different governmental bodies and departments (Government of British Columbia, 2022). Furthermore, under various indigenous, national and international laws, Indigenous peoples have rights to govern their traditional territories and coastal waters (Hewson et al., 2023).

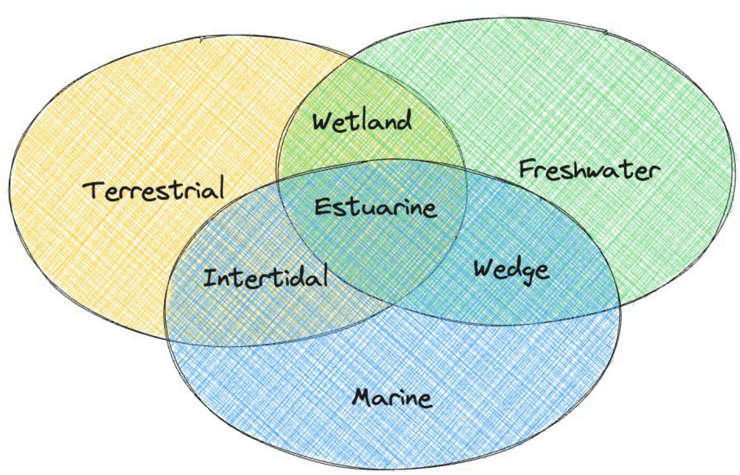
In contrast to the United States, which has the Coastal Zone Management Act (CZMA) (16 USC 1451 et seq.) (BOEM, n.d.), Canada does not have a similar Federal statute governing coastal zones. The CZMA provides a formal framework for addressing the challenges of urbanization of coastal areas and competing residential, recreational, commercial, and industrial uses by mandating the implementation of coastal plans by states and encouraging collaboration in the design and implementation of such plans (BOEM, n.d; NOAA, 2023).

British Columbia's coastal areas are one of the few maritime jurisdictions in North America without a comprehensive coastal strategy ecosystem (Government of British Columbia, 2022; Hewson et al., 2023).

As a result, British Columbia's coastal areas have often suffered from the challenges of managing these complex, multi-stakeholder ecosystems without legally binding cooperative actions (Government of British Columbia, 2022; Hewson et al., 2023).

Freshwater and riverine sediments mix with marine saltwater and tidal sediments, and the influence of both environments creates a unique ecotone that is biologically productive (Coast Information Team, 2004). As mentioned earlier, these unique conditions and related keystone processes make estuaries some of the most productive ecosystems in the world and important actors in nutrient loading in coastal systems (Costanza et al., 1993; Schaefer, 2004; Wołowicz et al., 2007; Watson et al., 2018; Jones et al., 2020). These systems are naturally rare, accounting for only 2.3% of the rugged coastline of British Columbia (Flynn et al., 2006). Nonetheless, their contribution to biodiversity is very large relative to their size, making them keystone ecosystems (Costanza et al., 1993; Pojar, 2003). The Fraser Estuary is globally recognized for its biodiversity (Flynn et al., 2006). The size of the river's freshwater outflows makes the entire southern Strait of Georgia technically an estuary (Flynn et al., 2006).

Figure 8. The conceptual relationship between ecosystems and estuarine environments.



Source: Adapted from (MacKenzie & Moran, 2004)

Since estuaries are characterized by a blend of terrestrial and aquatic elements, they frequently encounter administrative challenges due to the division of responsibilities between various levels of government (Bennett, 2020). Furthermore, some estuaries, such as the Fraser River Estuary, extend over boundary lines. Estuaries are frequently mismanaged and require collaboration at many levels because no agency or level of government can fully safeguard them (WWF, 2013). As a result, estuaries risk falling into the cracks of unclear and overlapping jurisdiction.

As David C. Mosher wrote in the Fraser River Delta, British Columbia: Issues of an Urban Estuary, *"Management of the Fraser River estuary is not simply a scientific problem; it involves the legal community as well, especially with respect to resolving issues involving competing interests,"* (2003, p. xiv).

Currently, the Provincial Government has designated most of the area surrounding the Fraser River Delta as a Wildlife Management Area (WMA) because of its importance to wildlife (Government of British Columbia, n.d.). This area is vital for migrating salmon species that spend weeks acclimating to saltwater (Chalifour et al., 2021). Hundreds of thousands of migrating and wintering waterfowl, shorebirds, and raptors use the area yearly. The entire delta is an essential part of the Pacific Flyway, serving as a resting place for migratory birds and a wintering area for the most significant number of waterfowls in Canada (Government of British Columbia, n.d.).

Coastal, marine, and estuarine environments are complex ecosystems that require collaboration among governments through governance agreements and joint planning (Hewson et al., 2023). The province is creating a province-wide coastal marine strategy concentrating on activities and uses under the province's responsibility (Government of British Columbia, 2022). However, as discussed, this strategy must form a joint plan or collaboration with the federal government because overlapping jurisdictions may impede the province's ability to implement specific measures. In the USA, as in Canada, Federal law limits the ability of states to enforce environmental regulations in transboundary waters and connected estuarine and marine environments (Jones et al., 2021).

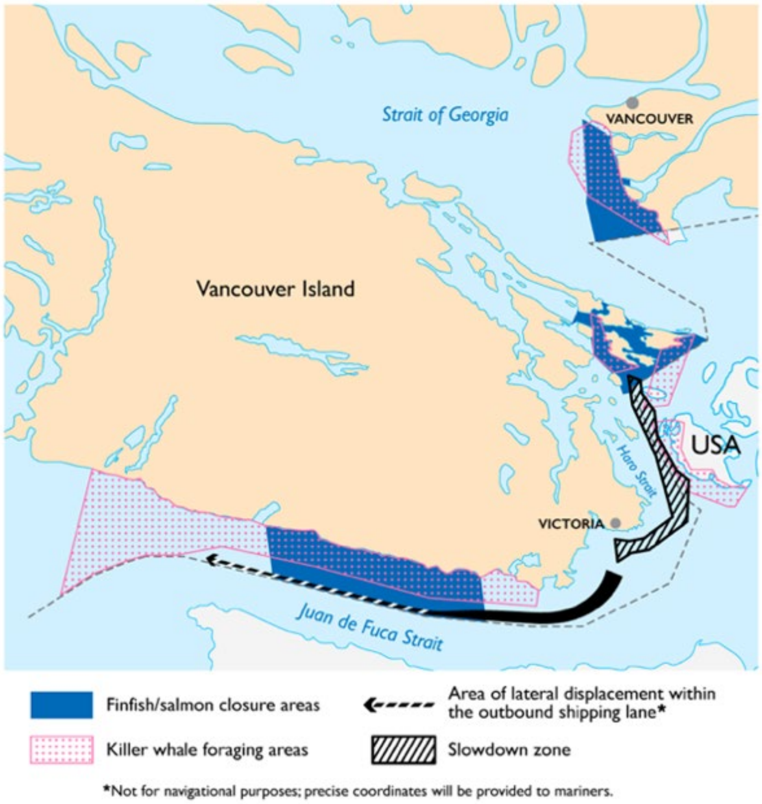
For example, when multiple states and provinces tried to collaborate to advance the conservation of the transboundary waters of the Gulf of Maine three decades ago, they were met with a lack of support and even discouragement from federal governments on both sides of the border, as Wondolleck and Yaffee detailed in their 2017 book (Wondolleck & Yaffee, 2017, p. 1). However, this collaboration between the governments of Maine, Massachusetts, New Brunswick, New Hampshire, and Nova Scotia resulted in the creation of the *Gulf of Maine Council on the Marine Environment (*GOMC)*,* an intergovernmental organization that aims to maintain and enhance the health of the gulf, including its marine, estuarine, and watershed environments (GOMC, n.d; MacDonald et al., 2007). Although the Federal Government initially provided little support for the initiative, it has since become an essential source of support (MacDonald et al., 2007).

For example, even if the provincial government establishes protected areas (WMAs or MPAs), these areas would not be off-limit to federally regulated marine activities. However, through collaboration, the Province can work with the Federal Government to request no fisheries or vessel zones.

As explained by Williams et al. (2019) concerning mitigating anthropogenic underwater noise pollution in MPAs: *"The biggest barrier to creating quieter MPAs, in our opinion, is the issue of jurisdiction. The MPA management plan must take into account noise-generating activities both inside and outside the boundaries, which would require multi-stakeholder and agency collaboration and international cooperation."* (Williams et al., 2019) p. 465

Figure 10 shows the Federal Government's 2019 measures for the recovery of SRKWs, including most of the areas of the Fraser River estuary, which fall under two provincial WMAs (Sturgeon Bank WMA and Roberts Bank WMA) in its fishery closures for recreational finfishing and commercial salmon fishing (Transport Canada, 2022; Government of British Columbia, n.d.).

Figure 9. Federal management measures support Southern Resident killer whale recovery in 2018.



Source: Government of Canada (2022)

The Fate of SRKWs Rests on Restoring Chinook Habitat

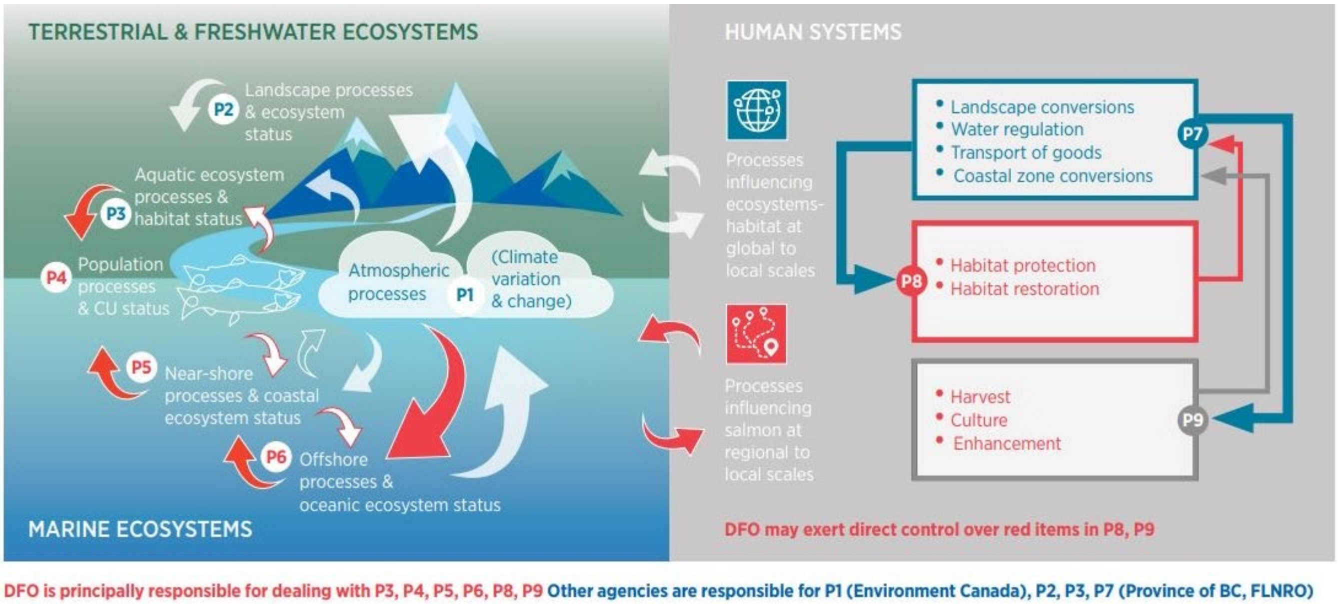
The federal government manages Pacific salmon populations under the *Wild Salmon Policy* (DFO, 2005). The overarching goal of this policy is to ensure that future generations of Canadians can continue to enjoy abundant and diverse salmon populations by restoring and conserving these populations and their habitats (DFO, 2005). As a result, the decline and recovery of wild Pacific Salmon have mainly been investigated through their federally managed marine environment and less so in their equally important inland habitats (Finn et al., 2021).

Under the Fish and Fish Habitat Protection provisions of the Fisheries Act, the death of fish, harmful alterations, and the disruption or destruction of fish habitats must be avoided (Fisheries and Oceans Canada, 2022). Additionally, SARA offers protection by protecting critical habitats. While protecting and restoring fish habitats is a federal responsibility, close intergovernmental collaboration with the British Columbia government is required for land and water use policies that may impact critical habitats. Almost the entire province (94 %) is provincial public land, including foreshores, riverbeds, streams, lakes, and the limited coastal waters of Crown Land fall under the jurisdiction of British Columbia (Government of British Columbia, n.d; DFO, 2018b). Therefore, provincial land, water, and resource development decisions directly affect wild salmon populations and their habitats (DFO, 2018b).

Protecting and restoring vital salmonid habitats through new and updated provincial legislation and increased investment are two of the main recommendations made by the Wild Salmon Advisory Council (WSAC) to increase the number of wild salmon in British Columbia (Wild Salmon Advisory Council, 2021). The provincial and federal governments have responded by allocating $30.5 million to twenty-two separate projects under the British Columbia Salmon Restoration and Innovation Fund (BCSRIF) (DFO, 2022).

Figure 10 shows the various natural and anthropogenic pressures that affect salmon habitats at multiple levels of government.

Figure 10. Natural and human-induced pressures on salmon habitats and where related responsibilities fall.



Note. Source (DFO, 2018b)

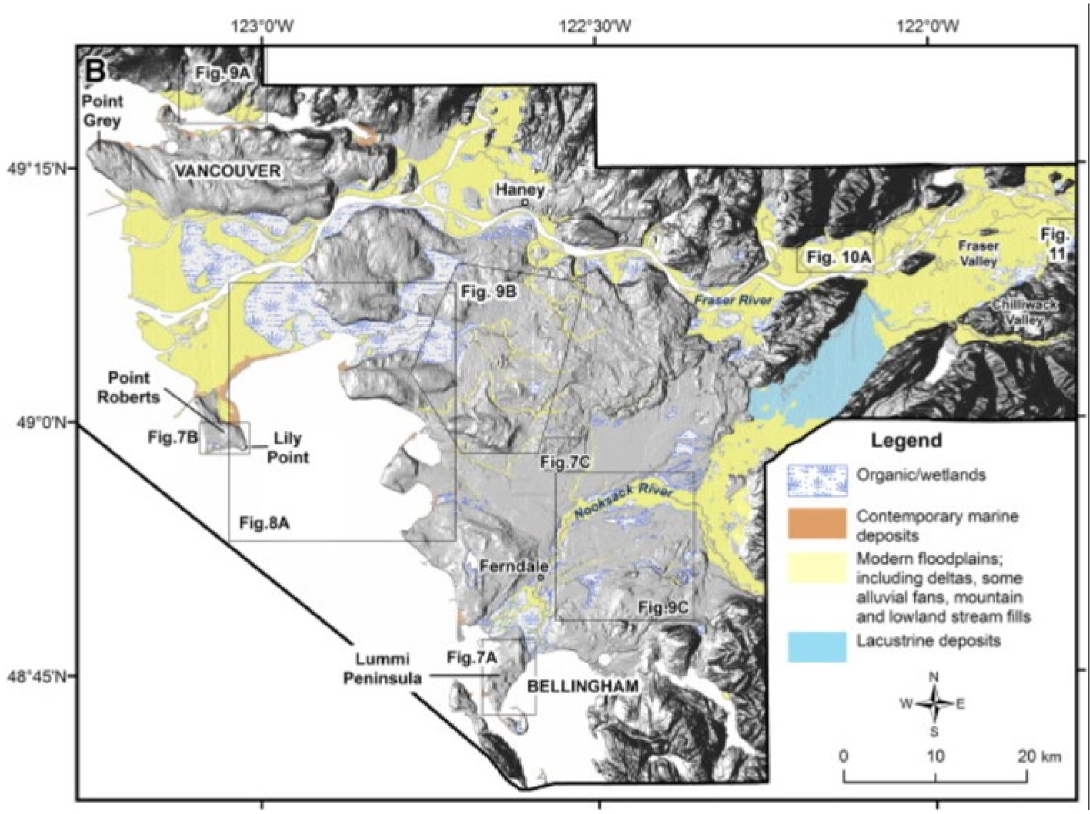
Habitat degradation and loss of connectivity

Estuaries and floodplains are critical habitats for many fish species and serve as nurseries for both inland and coastal species (Beck et al., 2001; Hall et al., 2023). Natural rivers and their riparian corridors are among the most dynamic biophysical habitats (Naiman et al., 1993).

While impressive, the human need to engineer and control their environment has allowed for urbanization in floodplains and has severely impacted other species' habitats (Evenden, 2004). Significant portions of floodplains have been altered to accommodate urban and agricultural development and needs; therefore, they do not function as they did historically (NMFS, 2011). Dikes and floodgates, which serve as instream barriers to protect anthropogenic land development from flooding, are significant factors in the cumulative degradation of native fish habitats by reducing oxygen levels and creating dead zones (Gordon et al., 2015; Scott et al., 2016). For example, over 160,000 acres of economically valuable land are shielded by more than 200 km of regulated dikes in British Columbia (Government of British Columbia, n.d.). Figure 11 shows the extent of the lower mainland of BC on modern floodplains.

Figure 11.

Map showing modern floodplains and deltas.

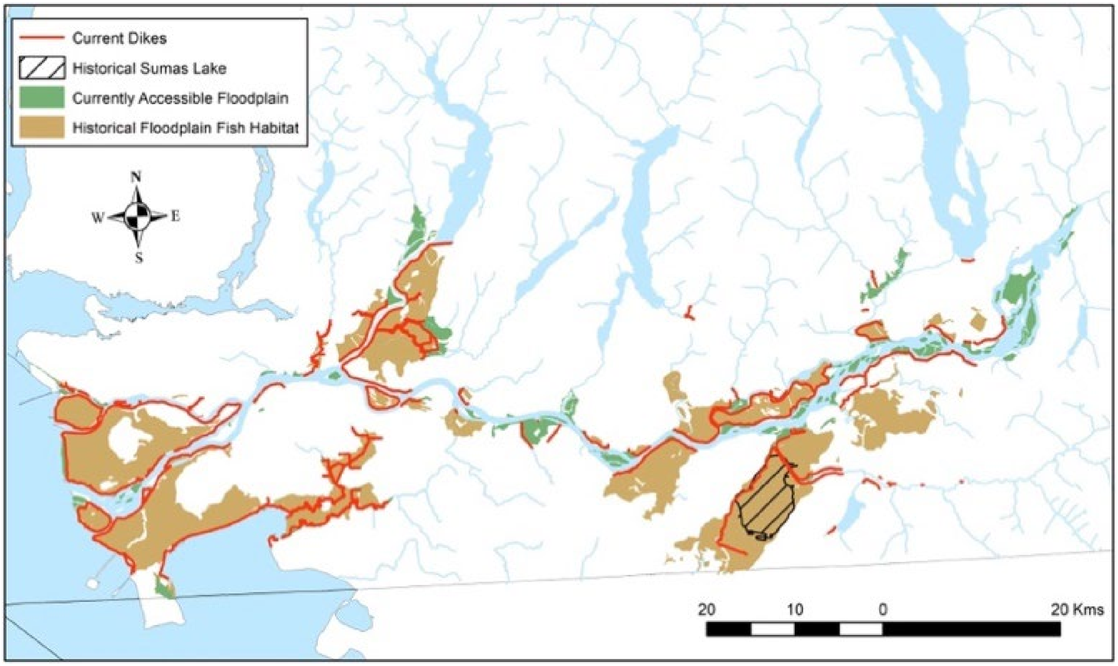


Note. From "The paraglacial geomorphology of the Fraser Lowland, southwest British Columbia and northwest Washington" by D. Kovanen & O. Slaymaker. 2015. Geomorphology, 232, 78-93. Copyright 2014 by Elsevier BV, with permission from Elsevier (publisher) (Kovanen & Slaymaker, 2015)

As a result, human activity is fragmenting habitats, leading to a decline in biodiversity despite the importance of maintaining habitat connectivity for protecting ecosystems (Dynesius & Nilsson, 1994; Tockner & Stanford, 2002; Haddad et al., 2015).

While the Fraser River is the most important salmon-producing river in Canada (Northcote & Atagi, 1997), most naturally occurring stream routes in the Lower Fraser are obstructed by barriers (Finn et al., 2021). Anthropogenic barriers leading to freshwater habitat degradation and disruption of habitat connectivity pose severe threats to aquatic ecosystems, particularly diadromous and anadromous species, such as Pacific salmon (Arthington et al., 2016). Of the 659 km^2 of historical floodplains in the Lower Fraser River, 102 km^2 were still accessible in 2020 (Finn et al., 2021). This can significantly affect the success of spawning in river tributaries, with only 15% of historical figures remaining (Finn et al., 2021). Figure 12 shows the extent of the diking system blocking the historical floodplains.

Figure 12. Map showing the estimated historical floodplain, currently accessible floodplain fish habitat, and current diking infrastructure in the lower mainland of British Columbia.



Note. From "Quantifying lost and inaccessible habitat for Pacific salmon in Canada's Lower Fraser River," by Finn, R. J. R., Chalifour, L., Gergel, S. E., Hinch, S. G., Scott, D. C., & Martin, T. G. 2021. Ecosphere, 12(7). CC BY 3.0

Identifying the Key Players in Salmon Habitat Loss and Restoration

Through the Floodplain Management Guidelines of 2004, the provincial government delegated the responsibility of local governments for floodplain designation, planning, and management (Ministry of Water Land and Air Protection, 2004). Through their role as the principal authority in land use planning, local governments have significant responsibilities and power for flood management. The *Local Government Act* and the *Municipal Act* allow local governments to carry diking and drainage within their jurisdictions (Ministry of Environment Lands and Parks, 1999; MFLNRO, 2019). Barriers to good Flood Risk governance were identified in a 2021 report, such as unclear roles and responsibilities, competing mandates and relationships, a lack of an approach that respects the land, and a lack of transparent best practices aligned with guiding policy statements or mandates at the Provincial or Federal level (Ebbwater Consulting Inc, 2021).

The various jurisdictions involved in the fragmentation of streams and salmon habitats, with those aimed at protecting them, have led to the complex management of existing and proposed stream barriers. The Federal Government's duty to protect the Pacific salmon habitat under *SARA* and the *Fisheries Act* makes it part of its responsibility to ensure that the Pacific salmon habitat is not destroyed by flood infrastructure (Partridge & Curran, 2017).

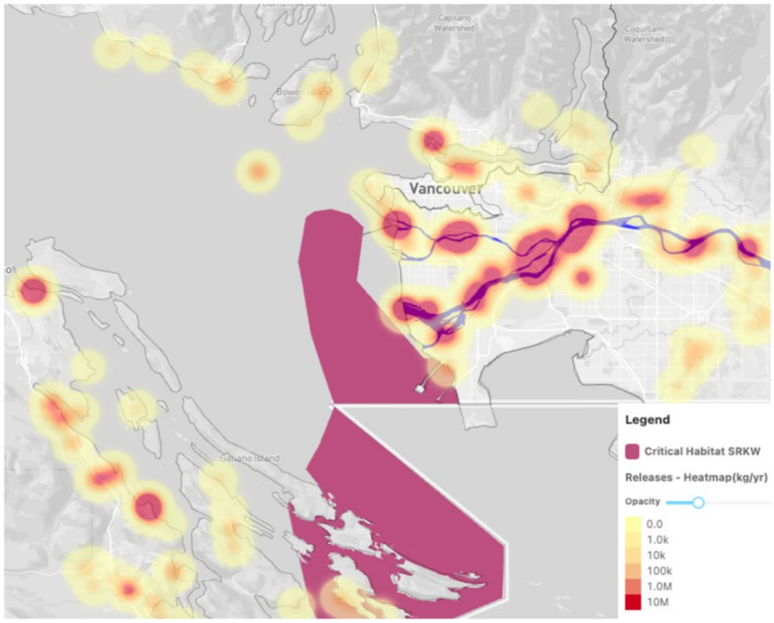
Water Contamination Resulting from Land-Based Activity

Habitat fragmentation is not the only negative impact of land-based activities and estuarine and coastal health management. The enactment of increasingly stringent water standards on both sides of the border has resulted in a significant decrease in water pollution over the last few decades (e.g., Canada Water Act (CWA), Wastewater Systems Effluent Regulations (WSER), Fisheries Act, Canadian Environmental Protection Act (CEPA) and Clean Water Act (USA)). CEPA (1999) includes the Precautionary principle among its several guiding principles, as follows: *"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"* (ECCC, 2019). The act's guiding principles also call for the "virtual elimination" of persistent, bioaccumulative, and toxic substances or reducing such releases to levels where they can no longer be reliably measured (ECCC, 2019).

However, legacy and contaminants of emerging concern (CEC) continue to degrade the quality of waterways and pose a threat to species (Mongillo et al., 2016; DFO, 2018a; Lee et al., 2023). Pollutants, such as POPS, are often concentrated in urbanized estuaries and coastal waters, particularly in marine sediments (Burd et al., 2022). While discussing and listing all the contaminants found in SRKWs' environment is beyond this review's scope, some contamination sources will be addressed.

Large quantities of anthropogenic pollutants from both point and non-point sources make their way to land and sea (Wells & Côté, 1988). Rivers are the primary entry point for vast pollution from land-based industries and municipalities entering marine ecosystems (Wells & Côté, 1988). Figure 13 depicts estimates of contaminant release from point sources to water and land, including forecasts of contaminants transported by surface water runoff to the Fraser River Basin waters. Most of the pollutants entering the critical habitat of the SRKW (indicated in pink) originate from the Fraser River or adjacent land.

Figure 13. Estimates of contaminant release from point sources to water and land, including forecasts of contaminants transported via surface water runoff to waters in the Fraser River Basin that affect RKWs and their prey.



Note: From the Pollutants Affecting Whales and their Prey Inventory Tool (PAWPIT) by ECCC. https://pawpit-oipabp.ca/map

These pollutants originate from many sources, including wastewater treatment plant effluent, urban and agricultural runoff, and landfill leachate (Wells & Côté, 1988).

Every level of government in Canada, from municipal to provincial to federal, contributes to chemical risk mitigation (Government of Canada, 2022a). For example, wastewater treatment plants, which can be an important source of contaminants, are managed by municipalities or regional governments under *Municipal Wastewater Regulation. However,* authorization is required under the Environmental Management Act*,* depending on the discharge rate (Government of British Columbia, n.d.). Recent measurements of PBDE concentrations in parts of the Salish Sea have revealed that wastewater treatment plants contribute nearly half of the direct PBDE input, with atmospheric deposition and the Fraser River constituting the rest (Sun et al., 2023). Lee et al. (2023) also found that chemical 4NP, commonly found in toilet paper, likely entering the ocean via wastewater from sewage treatment plants and industrial effluents, is prevalent in the tissues of some SRKWs.

Although point source pollution has been increasingly regulated, urban non-point source pollution has become increasingly challenging (Arnold & Gibbons, 1996). Urban stormwater runoff is one of the most significant land-based pressures on the estuarine ecosystem of the Salish Sea (Sobocinski, 2021). Rapid urbanization in the Salish Sea region over the past few decades has resulted in the replacement of natural pervious ground covers with impervious surfaces, such as streets, driveways, sidewalks, and roofs (Mallin et al., 2000; Sobocinski, 2021; Satistic Canada, 2022). The term 'impervious surface' refers to any surface that does not allow water to permeate into the ground (Arnold & Gibbons, 1996).

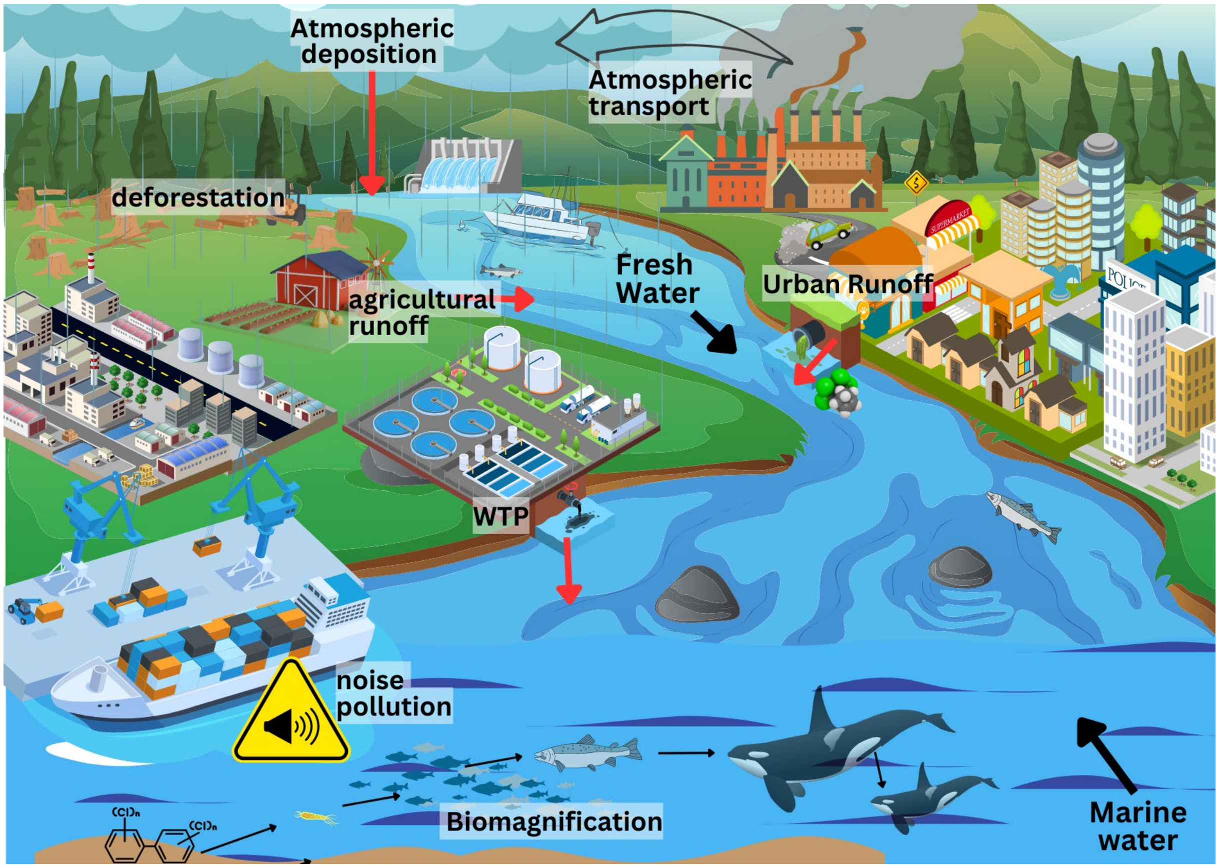
Figure 14. Land cover in the Salish Sea bioregion from 2015 data.

Note. Map by Aquila Flower, 2021. CC BY-NC-SA 4.0 License. Data from the CEC and Salish Sea Atlas.

Rainwater that does not soak into the ground on impervious surfaces and, as a result, carries a wide range of contamination, such as metals, organic pollutants, and pathogens, into nearby waterways (Müller et al., 2020; Sobocinski, 2021). As a result, many chemicals whose effects on streams have not been assessed can enter waterways via stormwater runoff. Streams are affected at >10% impervious cover and are degraded at >30% impervious cover (Schueler, 1995). Figure 15 shows the different pollution pathways in estuarine environments.

Figure 15.

Annotated diagram showing the biomagnification of contaminants by species and land and air-based anthropogenic pollutant sources that discharge into estuarine waters.

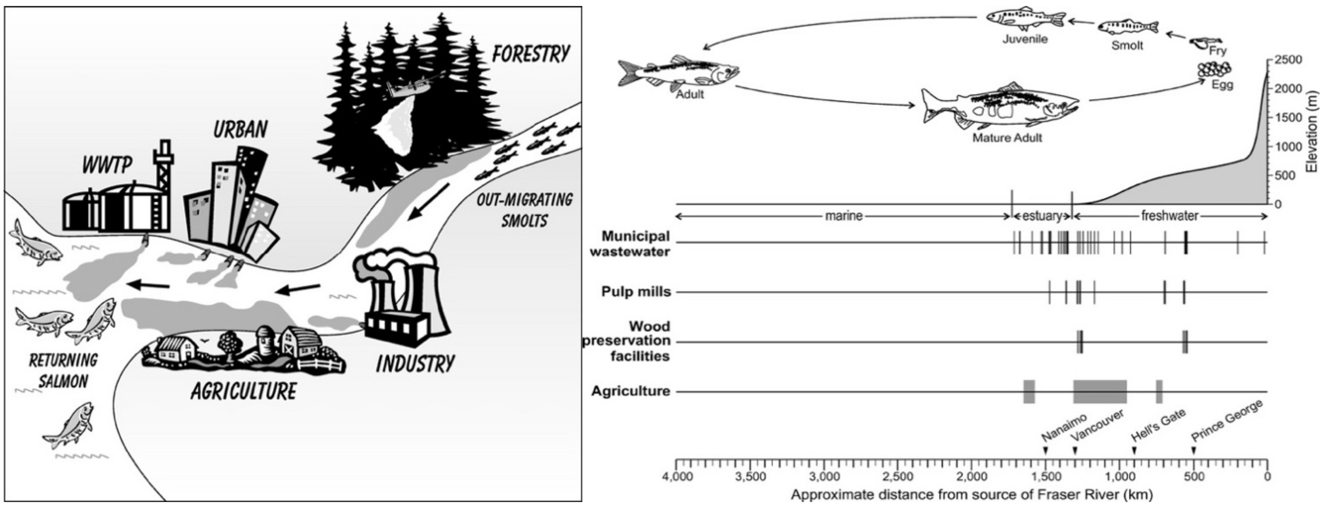


One of the most important means of contamination for RKWs is eating contaminated prey (Garrett & Ross, 2010). Furthermore, contamination can affect SRKWs by reducing prey quantity and quality.

Salmon can collect POPs from various sources along their migratory routes, including freshwater, estuarine, and coastal habitats. Contaminated estuarine habitats have been shown to impact sea-migrating juvenile Chinook species that migrate to these polluted estuaries by reducing their overall survival rate by 45% compared with Chinook habitats that migrate through uncontaminated estuaries

(Meador, 2014). This is also true for the time spent at sea, where it has been estimated that this period is significant for pollutant accumulation in salmon (Cullon et al., 2009).

Figure 16. The life histories of migrating salmon make them vulnerable to contaminant exposure from various sources (left) and point source pollution in the Fraser River sockeye salmon (right).



Note. From "The trouble with salmon: relating pollutant exposure to toxic effect in species with transformational life histories and lengthy migrations" by Ross, P. S., Kennedy, C. J., Shelley, L. K., Tierney, K. B., Patterson, D. A., Fairchild, W. L., & Macdonald, R. W., 2013, Canadian Journal of Fisheries and Aquatic Sciences, 70(8), 1252-1264. Copyright © 2013 by Canadian Science Publishing with permission.

According to the Salish Sea Marine Survival Project Synthesis Committee, mounting evidence suggests that contaminant loads impede the recovery of many Salish Sea Chinook stocks (Pearsall et al., 2021). While Section 36 (3) of the *Fisheries Act* stipulates that "*no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water*," deposits can still be permitted under different regulations (e.g., *Wastewater Systems Effluent Regulations* ()) (Fisheries Act (R.S.C., 1985, c. F-14),).

Source controls and pollution prevention are essential for reducing pollutants in urban stormwater and their potential consequences in receiving water bodies (Müller et al., 2020). However, managing salmon toxicity levels and exposure sources can be complicated by their life histories and extensive migration (Ross et al., 2013). Throughout their life, salmon migrate to different ecosystems, contributing to the transfer of nutrients and contaminants.

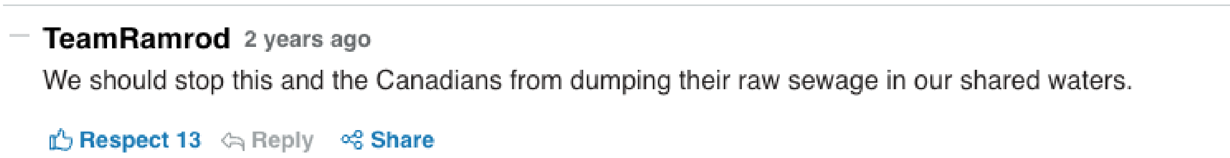
However, Lee et al. (2023) recently identified many novel POPs, some of which are not yet regulated in Canada (Lee et al., 2023). This raises concerns regarding the need for more monitoring and information regarding novel and contaminant levels. As explained earlier, most contaminants present in SRKW bodies originate from their prey species. If Chinook salmon contains high levels of pollutants, they will be transferred to SRKWs, where they can biomagnify. Therefore, land-based, freshwater and marine activities can significantly impact killer whales' recovery and health in how their pollution is managed and regulated.

Competing Interests, and Cumulative Effects

The Salish Sea is a 'commons' as described in Hardin's 1968 well-known allegory of *The Tragedy of the Commons* (Hardin, 1968). As shown by the history of fishing in the Salish Sea (e.g., the Pacific Salmon Treaty) (Emery, 1997), transboundary waters and species are at risk of overexploitation in the absence of clear rules regarding consultation and collaboration on such matters (Munro, 1990). While both countries and their various actors stand to gain individually from using the commons for economic growth, everyone bears the burden of the ensuing degradation. For instance, the history of finger-pointing between the

United States and Canada regarding the Salish Sea (Wondolleck et al., 2017) demonstrates how the actions of a neighbouring nation can be perceived on the other side of the border.

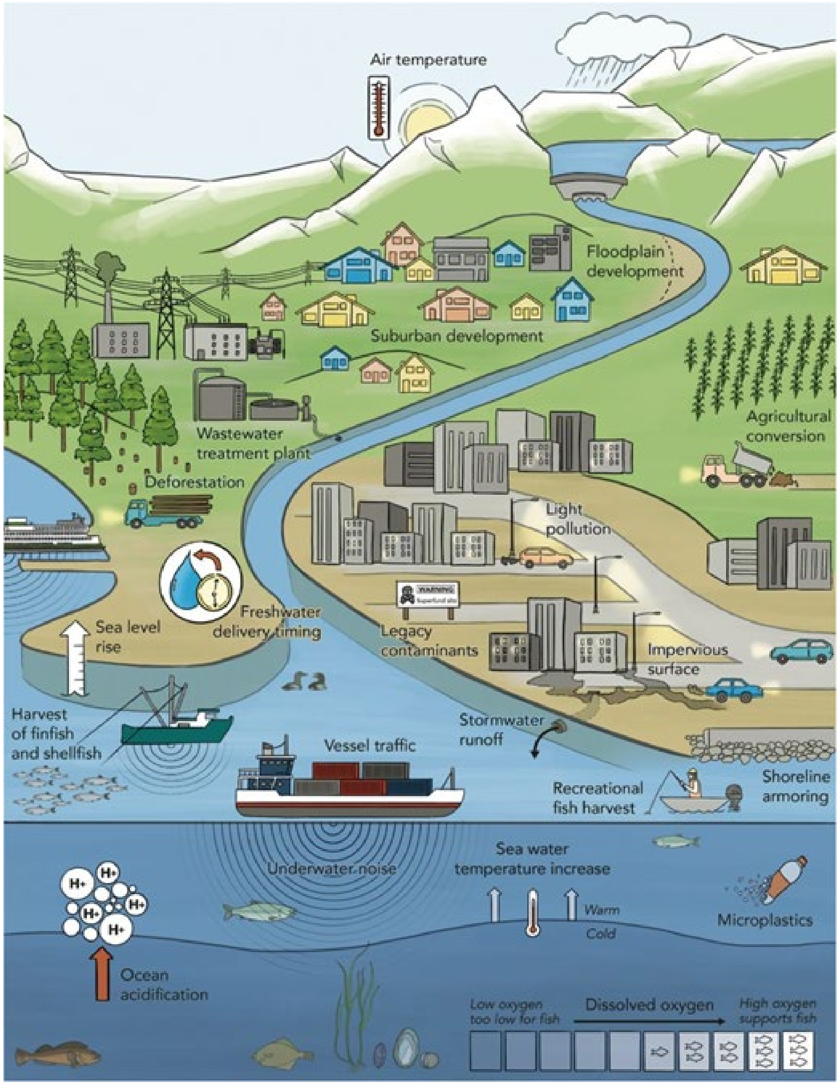
Figure 17. A comment showcasing finger-pointing and sentiments regarding actions in shared waters.



Note. Comment left on the article "Why would we allow cruise-ship waste of any kind in the Salish Sea?" by Seattle Times, 2021. https://www.seattletimes.com/opinion/why-would-we-allow-cruise-ship-waste-of-any-kind-in-salish-sea/#comments

Anthropogenic decisions leading to cumulative effects result from a web of laws and policies favouring the extraction and development of natural resources (Carlson & Baylis, 2022). However, the sum of these decisions can have disastrous consequences over time, and this cumulative impact has historically been poorly managed (Auditor General of British Columbia, 2015).

Figure 18. Cumulative impacts on the Salish Sea.



Note. From "Urban seas as hotspots of stress in the Anthropocene ocean: The Salish Sea example." by K. L. Sobocinski, C. D.Harvell, N. J. K. Baloy, G. Broadhurst, M. N. Dethier, A. Flower & J. R. Delaney. 2022. Elementa: Science of the Anthropocene, 10(1). Used under CC BY.

Tensions often arise between government agencies with contradictory responsibilities and competing interests, such as those between economic development and environmental protection. Estuarine ecosystems' high variability and unpredictability can make it challenging to create effective management strategies that often address competing ecological and economic goals (Costanza et al., 1993).

The Office of the Auditor General of Canada (OAG) recently presented the results of a performance audit on the Federal Government's management of Species at Risk. The audit concluded that ECCC, DFO, and Parks Canada failed to ensure that activities for Species at Risk recovery were on track towards the federal target, as stipulated by their legislated mandates (Office of the Auditor General of Canada (OAG), 2022b). They also found that DFO's management approach led to prolonged listing delays and failures to list species with commercial value for Aquatic Species at Risk (Office of the Auditor General of Canada (OAG), 2022a).

Projects proposed, such as the Roberts Bank Terminal 2 project by the Vancouver Fraser Port Authority, can also cause significant tensions between economic development and conservation. The project involves building a new three-berth marine container terminal, widening the causeway, and expanding the tug basin (The Review Panel for the Roberts Bank Terminal 2 Project, 2020). While various cities, the province and the country would benefit from the economic development propelled by this project, a federal government review panel on the project's potential environmental impacts concluded that it would result in numerous adverse cumulative residual effects that cannot be mitigated and could potentially lead to the extinction of species listed under SARA (The Review Panel for the Roberts Bank Terminal 2 Project, 2020). Specifically, the project would have severe adverse and cumulative effects on the SRKW by destroying a portion of their legally protected critical habitat and influencing the lower Fraser Chinook Salmon by disrupting their migration (The Review Panel for the Roberts Bank Terminal 2

Project, 2020). This would reduce the SRKW's access to prey and their ability to hunt by making the environment noisier. The cultural traditions of the Tsawwassen First Nation and the Tsleil-Waututh Nation were also found to be at risk of significant adverse effects.

Despite this, the Federal Government gave the project the green light (Impact Assessment Agency of Canada, 2023). This project does not respect SARA's mandated protection of endangered species and their habitats, and moving forward with the project overrides the federal government's obligation toward endangered species under SARA.

In response to the decision, Charlotte Dawe, a Conservation and Policy Campaigner for the Wilderness Committee, stated: *"The panel determination should have signified the end for this harmful and short-sighted project by the Port of Vancouver. Instead, we are seeing what could be a death sentence for southern resident killer whales. The Fraser Estuary is an ecological jewel being sacrificed for corporate profits"* (Wilderness Committee, 2023).

Furthermore, the environmental impact assessment should have considered the cumulative impacts of previous, ongoing, and upcoming projects in the Fraser Estuary. It barely acknowledged this project's cumulative impact with the Trans Mountain Pipeline Expansion Project. While the project also requires the province's approval, this decision has yet to be announced by the BC Government.

However, there has been some pushback from some municipalities. The Delta council voted against the project unanimously, and Mayor George Harvie expressed his disapproval by saying, *"Our federal scientists have come out and said the adverse effects will be immediate, continuous and cannot be* *mitigated…We need to support our federal scientists; they are the ones that I listen to"* (Global News, 2022).

Tensions between economic growth and environmental protection can also occur across borders. While Canada's decision to allow the expansion of the port within its waters falls within its sovereignty, the cumulative impacts of this project will transcend borders and impact the transboundary species and resources of Washington State.

Forty-one environmental groups wrote to Washington Governor Jay Inslee to express the inadequacy of the project's environmental review in addressing the potential impacts on the state’s natural, cultural, and economic resources and Tribal Treaty Rights, as well as public and private property (Friends of the San Juans, 2020). The letter further stated, "*Washington State has made significant investments in the protection and recovery of Southern Resident Orcas, their critical habitat, and their food web. RBT2 will put at risk the progress made to date on the Task Force's recommendations and the protection and recovery of the Southern Resident orcas"* (Friends of the San Juans, 2020).

The government of Washington's opposition to projects that would impact shared water in the Salish Sea is not new. In 2018, Governor Inslee described the Trans-Mountain Pipeline Expansion Project as "unneighborly*"* on our shared heritage (Inslee, 2018)*. The* same year, Governor Inslee rejected Vancouver Energy's proposal to build a massive oil shipping terminal in the state, which would have transported more than 131 million barrels of oil annually down the Columbia River (Earthjustice, 2018). Although the project would have given the region an economic boost, the environmental impact was considered too great (Tesoro Savage Vancouver Energy Distribution Terminal Facility, 2015; Earthjustice, 2018).

While Canada stands to gain economically for both projects discussed, the cost to the environment is shared by the two nations, including the indigenous communities on both sides of the border. Good neighbourliness has legal norms (Norman & Bakker, 2015). The common law maxim *sic utere tuo ut alienum non laedas* means that *"one State's sovereign right to use its territory is circumscribed by an obligation not to cause injury to, or within, another State's territory"* (Oxford University Press, 2022).

These cases raise fundamental questions about a country's neighbourly duty when authorizing projects without engaging in bilateral cooperation and consultation. The consequences of such decisions significantly impact shared resources and endangered transboundary species that have been the subject of significant conservation investments on both sides of the border.

> *"[The governments] don't always think on both sides of the border. They don't always consider the tribal and First Nations implications of things they're doing. We're all linked together. If we don't put that in the forefront, we're all going to suffer."*
>
> *- Joseph Gaydos, science director at SeaDoc Society* (CBC, 2020)

As a result, decisions need to be made in relation to the entire ecosystem and not just the additional damage they cause. For instance, if a project will increase underwater noise levels and cause further disturbance, the assessment must consider the cumulative effects of this and other threats (such as the reduction in prey abundance) and other projects currently underway or proposed in other jurisdictions. Project evaluations involving transboundary resources should follow geographical rather than political borders. Furthermore, considering the substantial value of ecosystem services from estuaries and marine environments (Barbier et al., 2011; Costanza et al., 1998), the value of the loss of such ecosystem services must always be a part of decisions. As the SeaDoc Society wrote, "*If healthy ecosystems foster economic prosperity, unhealthy ones represent lost opportunities and income. Whether we depend upon the ocean for our living or for our quality of life, we all benefit from a healthy Salish Sea"* (SeaDoc Society, n.d.).

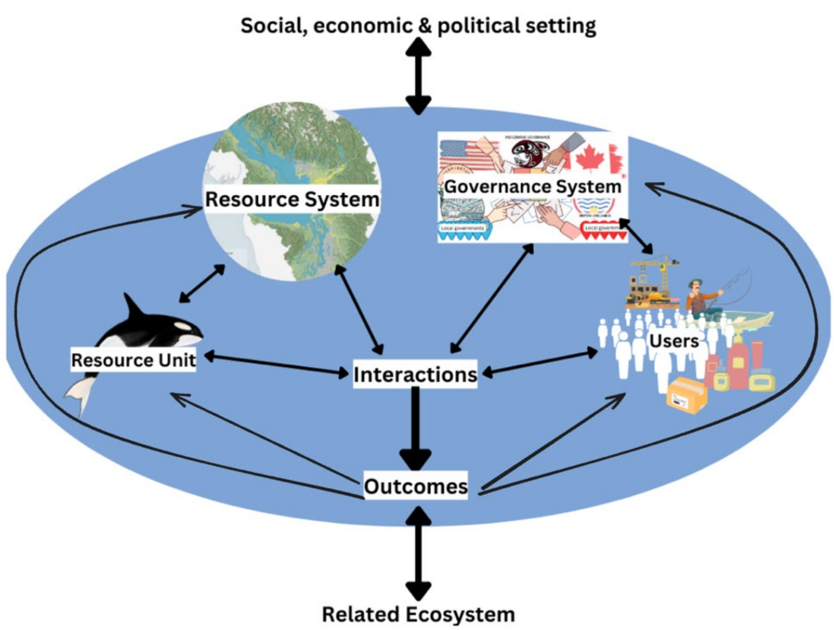
Moreover, the cumulative impacts of the growing population in the Northeast Pacific, paired with current ways of living, may be pushing the Salish Sea beyond its carrying capacity, as evidenced by the decline in several keystone species in the Northeast Pacific. This is important for the survival of SRKWs, because human activity may have reduced the carrying capacity of their habitat (how many whales it can support). It has been conjectured that the carrying capacity of the Salish Sea for RKWs has declined due to the deterioration of SRK habitat quality brought in part by the rising international trade from both Canada and the United States (Taylor, 2022; Taylor & Mayer, 2023). Asymmetrical impacts of vessel disturbance in the SRKW habitat and prey competition from NRKWs have put this community on a path to extinction (Taylor, 2022).

Compromises must be made, and regulations must be implemented to ensure the recovery of SRKWs and many other endangered, threatened, or at-risk species of the Northeast Pacific. As Hardin wrote in *Extensions of "The Tragedy of the Commons"* (Hardin, 1998): *"The more the population exceeds the carrying capacity of the environment, the more freedoms must be given up."* Reducing personal freedom may be inevitable given the growing Salish Sea Bioregion population and the consequent more significant cumulative impact of individuals' lifestyle choices. The cumulative effects of various decisions grow with population size. This means, for instance, that more people will be boating in the Salish Sea, that the demand for salmon will increase, that more pollutants will enter the water due to the increase in impervious surfaces and that more chemicals will be used. As a result, the individual liberty of each nation within a shared ecosystem to approve harmful projects on the commons must also diminish as we approach the Salish Sea's carrying capacity.

SRKW Recovery Calls for Marine Ecosystem-Based Management

As discussed in this review, it is clear that artificial boundaries are a barrier to managing SRKWs, their habitat, or the resources associated with them. Ultimately, issues relating to the recovery of SRKWs and the conservation of their habitat raise important questions about their complexity.

Figure 19. Conceptual diagram of the social-ecological system relating to SRKW decline and recovery.



Note. Adapted from Ostrom (2009) and (Parrott et al., 2012)

The threats outlined in this review result from variables falling within the control of governance systems (e.g. organizations involved in administration), resource systems (e.g. the Salish Sea) and users (e.g. growing population). , but also depend on the resource unit (e.g. population size and low recruitment) and are subject to interactions between these systems (Ostrom, 2009).

A substantial body of work conducted over the past few decades has determined the primary causes of the decline in SRKWs (DFO, 2018a; DFO, 2019a; NOAA Fisheries, 2023b; Lacy et al., 2017). Hence, current governance systems artificially inflate the complexity of SRKWs' recovery through artificial boundaries.

Putting economic growth above ensuring the health of the ecosystems on which many species depend has been proven to have disastrous effects time and time. Nonetheless, the federal government still approves projects such as Robert Banks Terminal 2. It seems dubious that we can stop the Sixth Mass Extinction or even slow it down without a radical shift in our way of thinking (Cowie et al., 2022). As stated by fisheries biologist Otto E. Langer, *"Despite the 50 year struggle to better protect the living resources and habitats of the globally important Fraser River Estuary, society and its governance bodies lack the will to do its job. This attitude of neglect cushioned by the belief that we can have continuous growth and better protect what we have with anemic conservation action is a myth. This thinking must change."*

Indigenous peoples have been stewards of the land and its occupants for thousands of years. As a result, one needs to look at what was introduced in the SRKW environment that caused their decline. As illustrated in Adam Olsen's recent post (Olsen, 2023), *"The W̱SÁNEĆ territory once bubbled with wild Pacific salmon and herring, and the beaches were alive with shellfish. In about 100 years, federal government policy empowered industrial resource harvesting practices that reduced stocks to near extinction. Provincial government policy enabled industrial logging practices that destroyed the creeks and streams in the interior of the province. Local governments have zoned industrial, commercial, agricultural, and residential development, choking the rivers and shorelines. The cumulative impact of all the decisions has had devastating consequences for the biodiversity of the Salish Sea."*

- Adam Olsen, MLA for Saanich North and the Islands

As a result, to patch up the fragmentation caused by our governance systems, scientific traditions, and cultural values, we need to manage the Salish Sea and its species using an ecosystem-based management approach. Management in this context must take an ecological perspective, emphasizing the importance of building relationships with people across various political, scientific, and cultural boundaries to share knowledge and pool resources (Ostrom et al., 1999). As written in 'Political Governance of Wicked Problems,' *"For large emerging issues with high levels of uncertainty, ongoing engagement with diverse stakeholders is valuable for articulating different perspectives, sharing information, and seeking closer agreement on goals, strategies and cooperative action"* (Head, 2022). Although the designation of the Salish Sea as a distinct ecosystem was a significant first step, management of the geographical area remains largely disjointed.

Transboundary initiatives exist for the protection of transboundary waters in North America. As previously discussed, the GOMC is an example of such an initiative. On the West Coast, Puget Sound Georgia Basin (PSGB) International Task Force was formed to manage the shared environment of the Salish Sea using an integrated approach (Puget Sound/Georgia Basin International Task Force, 2000). In 2000, the United States and Canada signed a non-binding agreement called the Joint Statement of Cooperation (SoC) on the Salish Sea. This SoC lays the groundwork for federal agency collaboration in the transboundary management of the Salish Sea (ECCC, 2022). While the PSGB and GOMC are two examples of transboundary initiatives for the conservation of a shared resource, they had different outcomes, mainly because the GOMC approach was able to bridge transboundary lines while the PSGB Task Force struggled (Wondolleck et al., 2017). The GOMC is still going strong, and the PSGB Task Force has since been disbanded. Wondolleck et al. (2017) explained, *"In the PSGB Task Force, multiple organizational layers had been established to encourage communication about transboundary issues. However, the existence of multiple, overlapping transboundary structures, including the ECC, task forces, and Statement of Cooperation Working Group, while all well intended, may have been "too much of a good thing." They appear to have created confusion about roles and responsibilities and seemed duplicative to participating staff. Since these transboundary organizations typically involve the same individuals, they placed a significant burden on agency staff that had to attend multiple meetings."*

Hence, the complex and overlapping structure of the PSGB Task Force may not have had the same benefits in fostering information sharing and facilitation management through a coordinated approach similar to that of the GOMC. Asymmetrical governance frameworks can arise, making it difficult to achieve practical cooperation. This demonstrates the need to establish a transboundary entity not plagued by inflated bilateral and vertical complexity and competing interests to preserve or restore the Salish Sea's health and, by extension, its capacity to support SRKWs.

Conclusions

Over the past decades, SRKWs have experienced a significant threat to their survival. This has been due to several negative impacts affecting them both spatially and temporarily. Canada and the USA have made substantial horizontal and vertical investments in the recovery of SRKW. However, existing governance systems continue to play an important role in the decline of SRKWs and the species on which they depend. Even though restrictions are tightening and human contact with marine mammals is heavily regulated, SRKWs still struggle to recover. This is because, despite stricter regulations, the growing population in the Salish Sea is increasing the impact and cumulative effect of each governance decision on the watershed.

While estuarine ecosystems are complex to manage, the SRKW's transboundary multijurisdictional context artificially inflates the complexity of their recovery. To reduce this complexity, some artificial boundaries, such as those in science and competing interests must be mitigated through multilevel and bilateral cooperation and knowledge-sharing. As Albert Einstein famously said: *"we cannot solve our problems with the same level of thinking that created them."*

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