https://doi.org/10.47886/9781934874707.ch5

Chapter 5

Status and Management of Freshwater Fisheries Resources in Western Canada (Alberta and British Columbia)

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Abstract.—Alberta and British Columbia (western Canada) are tremendously varied in their topography, habitats, threats, and fisheries. Complex patterns of deglaciation across the region, coupled with contemporary stocking programs in specific areas, result in different fisheries in different areas. There are Indigenous fisheries in all areas of western Canada and a variety of recreational fisheries that varies across habitats and species distributions. Although there is a rich history of freshwater commercial fisheries in Alberta, there are currently no freshwater commercial fisheries in all of western Canada (aside from those focused on Pacific salmons during their upriver migrations). However, the region is also subject to a variety of threats, including water extraction and dams, cumulative effects of multiple natural resource extraction industries, invasive species, and climate change. Management has become increasingly restrictive and inventive in the face of human population expansion and increasing access as roads are built to service petrochemical and forestry sectors. Historic fisheries and habitat alteration have contributed to poor conservation status of numerous species, including Bull Trout *Salvelinus confluentus* and White Sturgeon *Acipenser transmontanus*, but contemporary management appears to be maintaining these species and even providing fishing opportunities in some cases. In this chapter, we document the various threats and opportunities across this diverse region to provide a complete understanding of the status and management of western Canada.

Introduction

Alberta and British Columbia (referred to collectively here as "western Canada") is a region of complexity and contrasts. To the east of the Continental Divide are Alberta and the Peace region of British Columbia (BC), which includes the east slopes of the Rocky Mountains and the Great Plains that consist of low-relief topography and high angling pressure on few lakes and streams (Post et al. 2002). To the west is most of BC, with high-relief topogra-

phy, and tens of thousands of streams and lakes; most fishing effort is focused on the relatively small and accessible portions in the interior plateau and in accessible valleys.

The Alberta and BC provincial governments are responsible for nonsalmon freshwater fisheries through delegated authority under the federal *Fisheries Act* (British Columbia Ministry of Environment 2007a). The BC government is also responsible for anadromous salmonines, including steelhead *Oncorhynchus mykiss* (anadromous Rainbow Trout), Coastal Cutthroat Trout *O. clarkii*, and Dolly Varden *Salvelinus malma*. Fisheries and Oceans Canada (DFO) often works directly with Indigenous nations to allocate and manage or co-manage First Nation, harvesting opportunities for both commercial and food, social, and ceremonial (FSC) purposes for freshwater and marine fish (Castaneda et al. 2020) in BC, while the Alberta government works with Indigenous nations to manage their FSC fisheries directly.

A variety of different habitats, regions, and species provide a rich diversity of recreational fishing opportunities across western Canada. Commercial freshwater fisheries are now nearly absent across the region due to low productivity, competition with other sectors, and, in BC, an absence of a regulatory framework: while DFO manages commercial fisheries for Pacific salmons *Oncorhynchus* spp. and other saltwater species, there is no parallel regulation structure to allow for commercial fishing in freshwater systems in BC. Indigenous fisheries for freshwater resources vary across First Nations, with some benefitting from seasonal abundance of migrating fish stocks while other have lost much of their fishing opportunities due to the legacy of historic overfishing or habitat loss from land use and industrial development (Baird et al. 2021). Importantly, fisheries still serve a major function for Alberta Indigenous nations, with many reserves situated adjacent to major fish-producing lakes.

This chapter focuses on freshwater fisheries in western Canada, with emphasis on the management, status, and threats to recreational, commercial, and First Nations fisheries, with brief discussion of species at risk in the region. Anadromous species that are under federal managerial jurisdiction (primarily Pacific salmons) will not be discussed here.

Zoogeography and Physical Environment

The contemporary distributions of many fish species in western Canada were primarily a consequence of glaciations during the Pleistocene, particularly by glacial retreat following the Wisconsin glaciations, ending approximately 10,000 years ago (reviewed in Nelson and Paetz 1992; McPhail 2007; Mandrak et al. 2023, this volume). During glaciation, fish populations either resided in the few inland glacial refuges (broadly, the Pacific, Great Plains, and Beringia refugia) or in coastal areas in the Pacific (for euryhaline, or salt-tolerant, species). Combined with the cool- to cold-water habitats found through most of the region, this contributed to the low species diversity and relatively simple aquatic community structure.

Glacial retreat was not a simple process due to variation in local and larger-scale climate variation, and complex topographical patterns (Clague 1981). While ice retreated rapidly in coastal areas, retreat in areas farther inland was protracted; many areas experienced minor re-advances. The re-expansion of ice tongues often caused the damming of rivers, which produced glacial lakes and often connected adjacent rivers that would otherwise be isolated, allowing fish dispersal (Nelson and Paetz 1992; McPhail 2007). Importantly, the realignment of watersheds due to glacial scouring and the temporary connection of watersheds during glacial re-advancement resulted in several species crossing the Continental Divide (McPhail 2007). Retreating glaciers also caused isostatic rebound, where land previously depressed under the

weight of glaciers rebounds, which resulted in many small water bodies gradually losing their connection to the ocean. This process cut off several populations of coastal species from their anadromous ancestors, resulting in divergence of genetically isolated populations; the amount of divergence ranging from the formation of species pairs in some Threespine Stickleback *Gasterosteus aculeatus* populations (McPhail 1994) to parallel evolution of multiple kokanee populations (nonmigratory lake foraging residents derived from anadromous Sockeye Salmon *O. nerka*; Foote et al. 1992; Taylor et al. 1996; Wood and Foote 1996).

Across western Canada, there are six ecoregions, based on climate, community composition, and watershed boundaries that broadly define species distributions: the Yukon, Columbia, upper Mackenzie, Pacific, Saskatchewan-Nelson and Missouri watersheds (Post et al. 2015). These ecoregions align with the freshwater biogeographic zones used by the independent advisory panel that evaluates species status in Canada: the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2018). Watersheds west of the Continental Divide (Pacific, Columbia, and Yukon) typically have lower fish diversity than those to the east, a function of glacial refugia (Smith et al. 2010; Post et al. 2015). Each of these watersheds flows west to the Pacific; their climate, productivity, and fished species composition progressively change as they move across and through different mountain ranges. These differences often drive regional management priorities and challenges. Watersheds to the east of the Continental Divide (upper Mackenzie, Saskatchewan, and Missouri River basins) flow from the Rockies and across the prairies and taiga areas of Alberta and northeast BC. These watersheds all transition to slow streams, lakes, and wetlands (Post et al. 2015). Characterized by very cold winters and warm to hot summers, these watersheds generally have higher species diversity compared to those to the west of the divide, though productivity and biodiversity is often lower than elsewhere in North America, with large Alberta lakes often having fewer than ten fish species.

Another major explanation of contemporary fish distribution is species introductions (Crossman 1991), both authorized and unauthorized (i.e., illegal introductions, transfers and aquarium releases). The net result is a "homogenization" of fish fauna, particularly problematic in BC with its naturally low species diversity (Taylor 2004). Governments of the past stocked many previously barren lakes and rivers with "desirable" species, particularly Rainbow Trout, Brown Trout *Salmo trutta*, Brook Trout *Salvelinus fontinalis*, Northern Pike *Esox lucius*, and Smallmouth Bass *Micropterus dolomieu*. The introduction of these now-established feral populations can compete with native local populations for space and food resources (Weber and Fausch 2003; Hirner and Cox 2007), and may introgress with these populations (e.g., Rainbow Trout, Cutthroat Trout *O. clarkii*, and Bull Trout *S. confluentus*), which can result in maladapted hybrids (Krueger and May 1991; Rubidge and Taylor 2005; Bennett et al. 2010). Some feral populations, however, have become important features of the recreational fishing landscape. For example, bass fishing is popular in various areas across southern BC and Rainbow Trout and Brown Trout fisheries are enjoyed in southern Alberta (Cahill et al. 2018). Illegal transfers of these and other species, notably those in the sunfish Family (*Lepomis* spp., *Pomoxis nigromaculatus*, *Micropterus* spp.), and Yellow Perch *Perca flavescens* continue to influence species distribution (Sharma et al. 2009). While fish-directed stocking continues to be an important feature of both the Alberta and BC fisheries programs, both organizations direct their stocking activities to minimize impacts and interactions with native fish populations and other important ecosystem components (such as native amphibians). Strategies include minimizing population persistence and movement using sterile and

all-female stocks or stocking in isolated pothole lakes and encouraging harvest of hatchery origin fish. Stocking is now generally restricted to a subset of all previously stocked locations; stocking in new locations, or those without ongoing stocking, is rare and requires an impact assessment (British Columbia Ministry of Environment 2007b). Stocking of urban put-and-take fishery ponds with increasingly exotic species such as catfishes *Ictaluridae* spp. and tiger trout (*Salmo trutta* × *Salvelinus fontinalis*), however, is increasing popular in Alberta. Notably, several coastal rivers are still stocked with reproductive Coastal Cutthroat Trout and steelhead, though the number of fish stocked into streams each year has been declining due to both risks to native populations and low adult returns (Godin et al. 1994).

Interactions between Humans and Fishes

Threats to fishes and fisheries vary greatly across western Canada. Road densities are high everywhere except in mountain ranges, where access is more difficult and constrained (Proctor et al. 2019), yet access is continually expanding with continued resource extraction (forestry, oil and gas; Schindler 2001). Roads across the Alberta prairies are generally straight, whereas those in much of BC are constrained to valleys or mountain passes, leading to greater travel times. However, Alberta has significantly fewer lakes and angling opportunities yet a similar number of licensed anglers, suggesting higher fishing effort and fishing mortality on each lake and stream (Sullivan 2003). Most fishing effort originates from urban centers (Carruthers et al. 2019), leading to higher effort in these areas and lower effort in more distant locations (Post et al. 2008). While anglers are often proponents for fish conservation and sustainable use, the inherent difficulties in managing fishing effort and extraction with limited data and surveillance can lead to overfishing being the main threat to the health of fish populations, particularly in areas with high fishing effort (Post et al. 2002, 2008; Hunt et al. 2011; Post and Parkinson 2012; Cahill et al. 2018).

Stressors to fish populations in addition to fishing include climate change, habitat degradation, and water regulation (Holt et al. 2003; Sinnatamby et al. 2020), which often lead to complex, cumulative impacts that can be difficult to delineate and manage (Bradford and Irvine 2000; Prowse et al. 2006). Several studies have demonstrated that water temperatures are warming across the region due to a combination of climate change and altered land use (Nelitz et al. 2007), which can result in negative impacts on fish populations and distribution (Parkinson et al. 2016). In their evaluation of contemporary stresses on freshwater biodiversity, Chu et al. (2015) found that systems in western Canada are generally classified as a high conservation concern, given a combination of biodiversity constraints, anthropogenic stress, and climate factors, particularly in the north of the region.

Climate change can affect many aspects of fish productivity and behavior, which impacts food resources and habitat availability, spawning and migration timing, and egg incubation periods (Hansen et al. 2012). Within western Canada, mean air temperatures have increased approximately 1.9°C over the past 70 years (Zhang et al. 2019) and are expected to increase in some areas by as much as 4–5°C in the next 70 years (Wang et al. 2016). Changes in mean air temperature, precipitation, and glacial influence in watersheds have led to mean summer water temperature in the Fraser River increasing by 1°C from 1950 to 2000, and peak summer temperatures are predicted to increase by as much as 3°C by 2080 (Morrison et al. 2002). Similar changes across the region are expected to alter species distributions due to physiological limitations as well as changes in competitive asymmetries (Chu et al. 2005).

Water regulation and extraction is also a major, direct threat to fish populations and aquatic habitats. Water extraction is required for most forms of resource development, including irrigation, cooling machinery, extraction processes (e.g., hydrocarbon extraction from shale or sand), or power generation, both from large hydroelectric facilities and small run-of-the-river operations (Statistics Canada 2010). This is particularly acute in Pacific coastal streams, prairie rivers and the dry BC interior plateau, where the proportion of water extraction from any particular drainage can be large and/or migration corridors are blocked (Post et al. 2006; MacPherson et al. 2012; van Poorten et al. 2018).

Fisheries Management

Management of freshwater fishes and their habitat is a difficult task, with different agencies taking on different roles. Sometimes, responsibilities overlap between agencies, making management challenging. We provide an overview of agencies and mandates in Table 1. Below, we discuss the management of the different types of freshwater fisheries across western Canada.

Recreational Fisheries

Primary management authority for recreational freshwater fisheries is held by provincial governments and Parks Canada, which allows fishing and harvest in most of the National Parks in the region (including Jasper, Banff, Yoho, Waterton Lakes, and Kootenay parks, among others). Management of recreational fisheries in the two provinces is relatively similar, although the policies and tactics vary. Provincial regional managers work collaboratively to develop and implement provincial policies in specific areas (British Columbia Ministry of Environment 2007a; Alberta Environment and Sustainable Resource Development 2014). Fisheries management (focused on sport angling) and fish conservation (focused on species at risk) are undertaken by Alberta Environment and Parks, while in BC, these roles have been divided into separate ministries: the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (BC-FLNRORD) and the BC Ministry Environment and Climate Change Strategy (BC-ENV), respectively. Both provinces provide popular recreational fisheries, with 4.2 and 5.1 million days fished in freshwater in Alberta and BC, respectively (Fisheries and Oceans Canada 2019b). Additionally, both provinces have also split some aspects of the traditional fisheries monitoring and management role between government and not-for-profit partner organizations that are partly funded through license revenue.

As with many other mountainous jurisdictions in western North America, fishes (primarily trouts) were stocked into the many previously fishless lakes or lakes lacking desired sport fishes, starting in the late 1800s and early 1900s (Pister 2001). Over time, introgression with wild populations of Westslope Cutthroat Trout *Oncorhynchus lewisi*, Bull Trout, Athabasca Rainbow Trout, and others became apparent (Taylor et al. 2007; Yau and Taylor 2013), leading to a more focused attempt to largely cease stocking where introgression may occur. In BC, the stocking program provides stocked fisheries in over 1,200 lakes (>500 of these are stocked annually) with a variety of species (Brook Trout, Coastal Cutthroat and Westslope Cutthroat Trout, Rainbow Trout, and kokanee), strains and stocks (e.g., diploid, triploid, all-female, and combinations; Figure 1; British Columbia Ministry of Environment 2007a; Freshwater Fisheries Society of British Columbia 2020) and is believed to support over 50% of the recreational fishery that takes

Table 1. Alberta and British Columbia fish species that have been assesses for at risk status by the Committee on the Status of Endangered Species in Canada (COSEWIC). Species are listed by designatable units as determined appropriate by COSEWIC. Also listed are the most recent assessment date, recommended status, and current status under the *Species at Risk Act* (SARA). Listings include Endangered, Threatened, and Special Concern. Status is not applicable (NA) for Not at Risk, Data Deficient, and Extinct species. No Decision means that the Minister of Environment has received a recommendation from COSEWIC but has not made a listing decision. Information from Government of Canada 2021.

Scientific name	Common name	Provincial range	Most recent assessment	Recommended status	SARA status
Acipenser fulvescens	Lake Sturgeon (Saskatchewan–Nelson River populations)	AB, SK, MB, ON	April 2017	Endangered	Under Consideration
Acipenser medirostris	Green Sturgeon	BC	November 2013	Special Concern	Special Concern
Acipenser transmontanus	White Sturgeon (Kootenay River populations)	BC	November 2012	Endangered	Endangered
Acipenser transmontanus	White Sturgeon (Lower Fraser River population)	BC	November 2012	Threatened	Not Listed
Acipenser transmontanus	White Sturgeon (Nechako River population)	BC	November 2012	Not Active	Endangered
Acipenser transmontanus	White Sturgeon (Upper Fraser River population)	BC	November 2012	Endangered	Endangered
Acipenser transmontanus	White Sturgeon (Upper Columbia River population)	BC	November 2012	Endangered	Endangered
Gila alutacea	Chiselmouth	BC	May 2003	Not at Risk	NA
Pantosteus jordani	Plains Sucker (Saskatchewan–Nelson River populations)	AB, SK	November 2010	Not at Risk	NA

Table 1. Continued.

Scientific name	Common name	Provincial range	Most recent assessment	Recommended status	SARA status
Pantosteus jordani	Plains Sucker (Milk River populations)	AB SK	November 2010	Threatened	Threatened
Pantosteus jordani	Cordilleran Sucker (Pacific populations)	BC	November 2010	Special Concern	Special Concern
Catostomus sp. cf. *catostomus*	Salish Sucker	BC	November 2012	Threatened	Threatened
Coregonus zenithicus	Shortjaw Cisco	NT, AB, SK, MB, ON	May 2003	Threatened	Not Listed
Cottus aleuticus	Coastrange Sculpin (Cultus population)	BC	November 2019	Endangered	Threatened
Cottus confusus	Shorthead Sculpin	BC	November 2010	Special Concern	Special Concern
Cottus hubbsi	Columbia Sculpin	BC	November 2010	Special Concern	Special Concern
Cottus ricei	Spoonhead Sculpin	YT, NT, BC, AB, SK, MB, ON, QC	April 1989	Not at Risk	NA
Cottus sp.	Rocky Mountain Sculpin (Eastslope populations)	AB	November 2019	NA	Threatened
Cottus sp.	Rocky Mountain Sculpin (Missouri River populations)	AB	November 2019	Threatened	Not Listed
Cottus sp.	Rocky Mountain Sculpin (Saskatchewan–Nelson River populations)	AB	November 2019	Threatened	Not Listed
Cottus sp.	Rocky Mountain Sculpin (Westslope populations)	BC	April 2010	Special Concern	Special Concern
Couesius plumbeus	Lake Chub (Atlin Warm Springs populations)	BC	November 2018	Threatened	Under Consideration
Couesius plumbeus	Lake Chub (Liard Hot Springs populations)	BC	November 2018	Threatened	Under Consideration
Entosphenus macrostoma	Vancouver Lamprey	BC	November 2017	Threatened	Threatened

Table 1. Continued.

Scientific name	Common name	Provincial range	Most recent assessment	Recommended status	SARA status
Gasterosteus aculeatus	Unarmoured Threespine Stickleback	BC	November 2013	Special Concern	Special Concern
Gasterosteus aculeatus	Giant Threespine Stickleback	BC	November 2013	Special Concern	Special Concern
Gasterosteus aculeatus	Little Quarry Lake Benthic Threespine Stickleback	BC	November 2015	Threatened	Under Consideration
Gasterosteus aculeatus	Little Quarry Lake Limnetic Threespine Stickleback	BC	November 2015	Threatened	Under Consideration
Gasterosteus aculeatus	Paxton Lake Benthic Threespine Stickleback	BC	April 2010	Endangered	Endangered
Gasterosteus aculeatus	Paxton Lake Limnetic Threespine Stickleback	BC	April 2010	Endangered	Endangered
Gasterosteus aculeatus	Vananda Creek Benthic Threespine Stickleback	BC	April 2010	Endangered	Endangered
Gasterosteus aculeatus	Vananda Creek Limnetic Threespine Stickleback	BC	April 2010	Endangered	Endangered
Gasterosteus aculeatus	Hadley Lake Benthic Threespine Stickleback	BC	May 2000	Extinct	NA
Gasterosteus aculeatus	Hadley Lake Limnetic Threespine Stickleback	BC	May 2000	Extinct	NA
Gasterosteus aculeatus	Enos Lake Limnetic Threespine Stickleback	BC	May 2012	Endangered	Endangered
Gasterosteus aculeatus	Enos Lake Benthic Threespine Stickleback	BC	May 2012	Endangered	Endangered
Gasterosteus aculeatus	Misty Lake Lentic Threespine Stickleback	BC	November 2006	Endangered	Endangered
Gasterosteus aculeatus	Misty Lake Lotic Threespine Stickleback	BC	November 2006	Endangered	Endangered

Table 1. Continued.

Scientific name	Common name	Provincial range	Most recent assessment	Recommended status	SARA status
Hybognathus argyritis	Western Silvery Minnow	AB	November 2017	Threatened	Threatened
Lampetra richardsoni	Western Brook Lamprey (Morrison Creek population)	BC	April 2010	Endangered	Endangered
Myoxocephalus thompsonii	Deepwater Sculpin (Waterton population)	AB	April 2017	Special Concern	Decision Pending
Myoxocephalus thompsonii	Deepwater Sculpin (Western arctic populations)	NT, AB, SK	April 2017	Not at Risk	NA
Myoxocephalus thompsonii	Deepwater Sculpin (Western populations)	NT, AB, SK, MB, ON	April 2017	Not at Risk	NA
Oncorhynchus lewisi	Westslope Cutthroat Trout (Pacific population)	BC	November 2016	Special Concern	Special Concern
Oncorhynchus clarkii	Westslope Cutthroat Trout (Alberta population)	AB	November 2016	Threatened	Threatened
Oncorhynchus mykiss	Rainbow Trout (Athabasca River populations)	AB	May 2014	Endangered	Endangered
Prosopium coulterii	Pygmy Whitefish (Pacific populations)	BC, YT	November 2016	Not at risk	NA
Prosopium coulterii	Pygmy Whitefish (Southwestern Yukon Beringian populations)	BC, YT	November 2016	Data Deficient	NA
Prosopium coulterii	Pygmy Whitefish (Waterton Lake population)	AB	November 2016	Special Concern	Under Consideration
Prosopium coulterii	Pygmy Whitefish (Western Arctic populations)	AB, BC, NT	November 2016	Not at Risk	NA

Table 1. Continued.

Scientific name	Common name	Provincial range	Most recent assessment	Recommended status	SARA status
Rhinichthys cataractae smithi	Banff Longnose Dace	AB	May 2000	Extinct	NA
Rhinichthys cataractae ssp.	Nooksack Dace	BC	April 2007	Endangered	Endangered
Rhinichthys falcatus	Leopard Dace	BC	April 1990	Not at Risk	NA
Rhinichthys osculus	Speckled Dace	BC	November 2016	Endangered	Endangered
Rhinichthys umatilla	Umatilla Dace	BC	April 2010	Threatened	Not Listed
Salvelinus confluentus	Bull Trout (South Coast BC populations)	BC	November 2012	Special Concern	Special Concern
Salvelinus confluentus	Bull Trout (Western Arctic populations)	YT, NT, BC, AB	November 2012	Special Concern	Special Concern
Salvelinus confluentus	Bull Trout (Upper Yukon Watershed populations)	YT, BC	November 2012	Data Deficient	No Status
Salvelinus confluentus	Bull Trout (Saskatchewan–Nelson Rivers populations)	AB	November 2012	Threatened	Threatened
Salvelinus confluentus	Bull Trout (Pacific populations)	BC	November 2012	Not at Risk	NA
Spirinchus thaleichthys	Longfin Smelt (Pygmy populations)	BC	November 2004	Data Deficient	NA

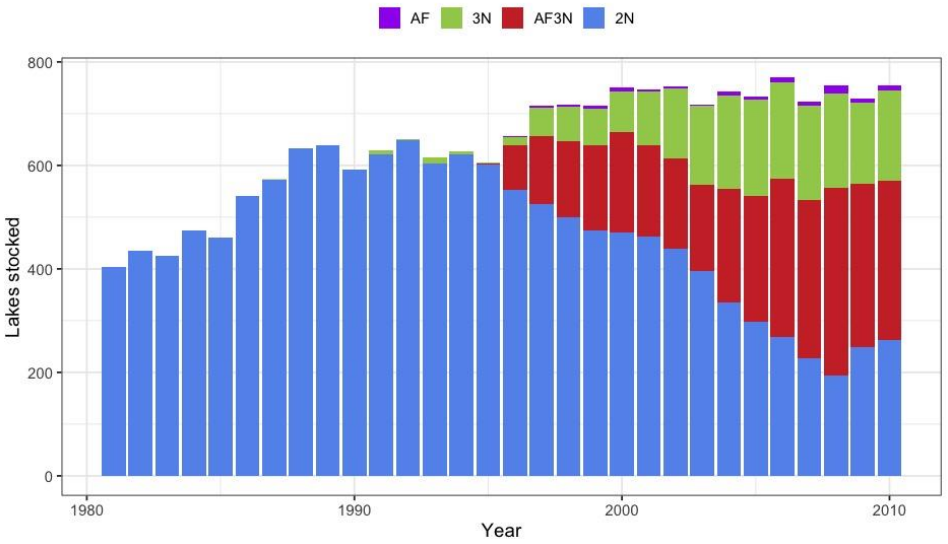

Figure 1. Number of lakes stocked in BC by year with diploid (2N), triploid (3N), all-female (AF), and all-female triploid (AF3N) fish.

place on lakes (Levey and Williams 2003). In Alberta, stocking trout is also used to create sport fisheries in areas with few natural fisheries. Approximately 240 waterbodies (often in urban or semiurban areas) are stocked primarily with Rainbow Trout, but also Brook Trout, Brown Trout, Westslope Cutthroat Trout, and tiger trout, almost always for put-and-take fisheries (Patterson and Sullivan 2013) and is also believed to support approximately 25% of sportfishing effort in the province (Government of Alberta 2021a). In addition to providing fishing opportunities, maintenance of angling opportunities via targeted stocking in otherwise fishless lakes is believed to attract anglers away from lakes with more vulnerable wild stocks. Stocking in the national parks has ceased other than for restoration of native species, and efforts are being taken to remove many introduced populations to reduce competition with indigenous species (Pacas and Taylor 2015).

Nongovernmental organizations have been important in the freshwater fisheries landscape in western Canada. The Freshwater Fisheries Society of British Columbia (FFSBC) is a not-for-profit organization formed in 2003 tasked with culturing and stocking hatchery fish on behalf of the province and promoting sportfishing to increase license sales. The FFSBC receives 100% of license revenues (excluding conservation surcharges) as well as funding from other partners and sponsors. Some of this funding is directed back to monitoring and research projects to improve management. The mandate, objectives, and goals of the FFSBC are aligned with the provincial government and focus on delivery of services needed to support provincial fish recreation and conservation objectives (Freshwater Fisheries Society of British Columbia 2017). This paired delivery model has meant the development of programs by the FFSBC aimed at increasing angling participation, such as learn-to-fish and urban fisheries programs. The Alberta Conservation Association (ACA) is a not-for-profit organization formed in 1997 aimed at monitoring and conserving wild populations of fish and wildlife. They are primarily funded through levies on fishing and hunting licenses. This revenue is used for promoting recreation through stocked fisheries, public education, habitat restoration, and some monitoring projects. This user-pay de-

livery model helps promote the conservation and restoration of well-used natural resources and has led to co-development of monitoring standards across the province.

Fisheries management across western Canada is designed to achieve a broad array of freshwater fisheries objectives aimed at conserving wild fish and providing opportunities for use, either for harvest, recreation or culture (British Columbia Ministry of Environment 2007a; Alberta Environment and Sustainable Resource Development 2014). The approach to achieving these two broad goals varies across fisheries. For example, stocked fisheries focus on providing a predictable fishing experience through direct control of stocking rates. Stocked water bodies include many reservoirs and small prairie and urban lakes in Alberta and many small (<1,000 ha) lakes in BC. In BC, stocked lakes are divided into trophy, quality, family, regional and urban fisheries, each providing a different experience, with the intent of matching to diverse angler desires (Freshwater Fisheries Society of British Columbia 2017). Wild fish populations provide satisfaction, but the management focus for many wild fisheries is to conserve the resource through regulations while still offering recreational opportunities where possible. For example, populations of concern, such as wild steelhead and White Sturgeon *Acipenser transmontanus*, are catch-and-release-only fisheries in BC, as are some populations of Bull Trout and native populations of Cutthroat and Rainbow trouts and Arctic Grayling *Thymallus arcticus* in BC. Similarly, Lake Sturgeon *A. fulvescens* and Bull Trout may not be harvested recreationally in Alberta.

Management decisions are made based on available data and balanced with acceptable levels of risk to achieve management objectives. In BC, waterbodies and fisheries are classified as rivers, large lakes (>1,000 ha), and small lakes (≤1,000 ha); monitoring protocols differ among these classifications. River fisheries (especially steelhead and Bull Trout) are often monitored using snorkel surveys for juveniles and adults. Steelhead is also broadly monitored via a yearly mail-out survey conducted annually since 1967, designed to gauge gross measures of catch and effort of wild and hatchery steelhead populations throughout BC (Ahrens 2006). Large lakes are monitored using depth-stratified gill nets and/or paired hydroacoustic and trawl surveys. Small lakes are monitored with standard pelagic and benthic gill net surveys (Ward et al. 2012). Additionally, fishing effort information, primarily on small lakes, is mainly collected using aerial surveys (Parkinson et al. 1988). Creel surveys are occasionally completed on both small and large lakes. Data from these surveys are summarized for length-at-age information, condition factor, and standard catch rates; these data are then used to make decisions regarding changes to fishing regulations or stocking rates (for small lakes currently being stocked). Any changes to regulations are then discussed in public consultations before being considered by the director of the Fisheries and Aquatic Habitat Branch within the BC-FLNRORD.

The Alberta management model is designed to identify issues with populations and chart a path to achieve objectives. Fish stocks are organized into management units, defined either into watershed units (for lentic populations) or lakes. The status of these units is defined with data from standard assessment protocols and assessments are made using a fish sustainability index (MacPherson et al. 2014), which reports on relative abundance, structure, ecological integrity, and threats. A formal evaluation of these outcomes has occurred (Cahill et al. 2022), but is not part of an ongoing, iterative process. Fisheries management objectives are defined by species management plans, which are developed for each species across the province. Quantitative models are used to evaluate the ability of different regulations to achieve the desired condition within a reasonable time frame. Regulation options usually are limited to

catch-and-release, minimum size limits that allow several years of spawning or lottery-based tags that set a maximum harvest level. Proposed regulations and the accompanying predictive simulation models are peer-reviewed by a provincial-level fisheries scientist and the committee of senior fisheries biologists (the Senior Fisheries Biologist Team [SFBT]). Final approval of all regulations lies with the Director of Fisheries (and ultimately with the provincial Minister of Environment and Sustainable Resource Development), but the scientific recommendation from the SFBT is weighted heavily within the broader social, economic, and political context. After a change in regulations, the outcomes of regulation changes are evaluated using standardized monitoring every five years to ensure population status or fishery recovery is meeting expectations. More intensively managed fisheries, such as those with lottery-based tag harvest, are often assessed more frequently.

Indigenous Fisheries

Indigenous fisheries in Alberta have remained culturally important since the loss of bison in 1870s. Almost all northern reserves are on major fish-producing lakes, specifically because the decline in bison (*Bison bison*) coincided with the period when treaties were written and reserves were being established. As such, fishes are a key part of the culture and have become even more important now that fisheries are recovering to give high catch rates and healthy food.

First Nations' people are entitled to fish for food in Alberta Crown waters, under obligations described in several federal treaties (primarily Treaties 6 and 8) and by government policy. Each treaty stipulates this right, with a provision that the right may be infringed by government regulations (Box 1), usually interpreted in recent rulings as for conservation reasons.

Domestic fishing licenses are available to First Nations, as well as recognized Métis harvesters and other persons who can demonstrate a need to fish for food. Each license allows the holder to fish by angling or by using 100 m of gill net, with specific conservation-oriented regulations, generally designed to protect vulnerable spawning aggregations (Alberta Environment and Parks 2018a). Fishes caught under the authority of a domestic fishing license may not be sold. Additionally, under current Alberta regulations, these fishes must be used only by the licensee and their immediate family. This poses some conflict with traditional uses of fish, such as community sharing and ceremonial uses. These other traditional uses are accommodated on a case-by-case basis through other legal mechanisms, such as special fishing licenses or research permits.

Because of treaty and government policy obligations to provide a food fishery, First Nations are consulted prior to all fisheries regulations changes that may infringe or affect their food fishery (including sport fishing regulations). Formal consultation is both a fiduciary responsibility, as well as government policy in both Alberta and BC and has been an instrumental legal aspect in upholding conservation-based fisheries restrictions, which have the potential to infringe Treaty rights or impact Aboriginal Interests.[1]

The domestic food fishery is widespread in Alberta. During a 5-year period (2008 to 2012), a total of 9272 domestic licenses were issued on 153 lakes. Monitoring of the domestic harvest is on a case-by-case basis, with no provincially coordinated program. Typically, the domestic fishery has been focused on harvesting Lake Whitefish *Coregonus clupeaformis*,

[1]Aboriginal Interests refers to claimed or proven Aboriginal rights (including title) and treaty rights that require consultation.

Box 1. Excerpt from Treaty 8, Signed in 1899

"And Her Majesty the Queen HEREBY AGREES with the said Indians that they shall have right to pursue their usual vocations of hunting, trapping and fishing throughout the tract surrendered as heretofore described, subject to such regulations as may from time to time be made by the Government of the country, acting under the authority of Her Majesty, and saving and excepting such tracts as may be required or taken up from time to time for settlement, mining, lumbering, trading or other purposes."

with small incidental catches of Walleye *Sander vitreus* and Northern Pike. As these two sport fishes have generally recovered from years of overfishing, however, more interest in harvesting the increasingly abundant Walleye and Northern Pike is being shown by Indigenous users. Conflicts between sport and domestic fishers are more perceived than realized, and considerable effort by provincial biologists is spent explaining the legal obligations and minor conservation consequences of the domestic food fishery to sport angler groups.

In BC, most First Nations fisheries target Pacific salmons, although winter-run steelhead are also sometimes targeted because they provide access to protein at times when most other salmon species are unavailable. First Nations with traditional territories within and outside of Pacific drainages often also target Burbot *Lota lota*, Lake Trout *Salvelinus namaycush*, and Bull Trout.

First Nations' fisheries in BC are often governed differently than in other parts of Canada. There are few treaties with First Nations in BC, meaning harvesting rights, as with all rights, are recognized by section 35 of the Canadian Constitution: "35(1): The existing aboriginal and treaty rights of the aboriginal peoples of Canada are hereby recognized and affirmed." First Nations' harvesters are not required to have provincial freshwater fishing licenses. When there are no conservation concerns, harvesting by a member of a particular First Nation within their traditional territory for FSC purposes is assumed to be managed sustainably by the First Nation. However, if harvesting is done in the territory of another First Nation, the harvester must usually follow provincial regulations, although a license is not required.

If there is a conservation concern for a particular fishery and the province is considering any actions that might impact or infringe a First Nation's ability to harvest fish, provincial regional managers must discuss options with any potentially impacted First Nations to determine the most effective and least impactful course of action. Where conservation concerns exist, the province engages with each potentially impacted First Nation on a case-by-case basis as many situations present unique challenges and opportunities. Some First Nations fisheries have limits set by their own fisheries managers due to conservation concerns (e.g., White Sturgeon and some steelhead populations).

State of the Resources

Recreational Fisheries

There are a wide range of recreational fishing opportunities in western Canada. Lakes in central and northern Alberta and the Peace region of BC provide opportunities for Walleye, Northern Pike, and Lake Trout. Lake fisheries in the remainder of BC provide access to

Cutthroat and Rainbow trouts, steelhead, Lake Trout, kokanee, and Burbot, including many stocked fisheries. Inland river fisheries in different parts of the region may provide trout, Arctic Grayling, Walleye, Goldeye *Hiodon alosoides*, and sturgeon fisheries. Large reservoirs in both Alberta and BC provide access to large-bodied piscivores such as Bull Trout, Lake Trout, and Rainbow Trout, as well as kokanee, Walleye, Pike, and Burbot. Some of the most prominent reservoirs in BC, which have undergone cultural oligotrophication following impoundment (Stockner et al. 2000), are artificially enhanced by active nutrient restoration programs aimed at providing sufficient food base to sustain kokanee and piscivore fisheries (Perrin et al. 2006). Finally, coastal, and larger inland rivers (such as the Fraser and Skeena rivers) allow for fisheries on anadromous salmonines such as Pacific salmon, steelhead, Bull Trout, Dolly Varden, and Coastal Cutthroat Trout.

Urban fisheries are being increasingly recognized as a novel means of introducing fishing to urban residents. In Alberta, most stocked urban fisheries are put-and-take fisheries using nonnative Rainbow Trout. These fisheries are very attractive and provide much recreation, despite being difficult to catch by the novice angler (Patterson and Sullivan 2013). British Columbia also provides urban fisheries by providing put-and-take fisheries that are stocked as often as every two weeks through the spring and fall. There is active promotion of these fisheries to the public with up-to-date stocking reports available online (https://www.gofishbc.com/Stocked-Fish.aspx#fish-stocking). This program has led to high effort composed of an ethnically diverse fishing community (Varkey et al. 2012). Popular wild or hatchery-supplemented fisheries are also found along the urban waterfronts of Calgary (the Bow River), Edmonton (the North Saskatchewan River), and Red Deer (the Red Deer River) (Zwickel 2012). Because of high fishing pressure and limited productivity, these fisheries are catch and release for vulnerable species. Coastal river fisheries around Vancouver and Victoria also provide popular fishing for Pacific salmon, Bull Trout, and steelhead. These fisheries are much more productive and often provide harvest opportunities (though not for wild steelhead). Inland river fisheries for Bull Trout, Cutthroat Trout, and steelhead are also quite popular outside urban centers such as Prince George, Smithers, and Fort St. John, though these fisheries are often catch and release.

Participation in the Alberta recreational fishery has seen a 20-year increase since a major decline from 1982 to 1996 (Zwickel 2012; Figure 2). The causes of the decline and increase are not clear but correspond to the decline and subsequent active management of the very popular Walleye sport fishery (Sullivan 2003). Participation in BC also experienced a decade-long decline prior to the mid-2000s, as was common in most other jurisdictions (Fedler and Ditton 2001; Freshwater Fisheries Society of British Columbia 2017). This has important implications for license revenue, which funds the hatchery program via the FFSBC and supports monitoring and research on fisheries. This decline in fishing participation prompted the FFSBC to engage in an active marketing campaign and several innovative angler engagement programs to increase and maintain participation closer to historic levels.

Commercial Fisheries

Gill-net fisheries, primarily targeting Lake Whitefish, have been common at many Alberta lakes since the late 1700s. During the 1800s, these fisheries were primary used for subsistence for humans and sled dogs, and were centered on large Alberta lakes near fur trading posts and religious missions (Rowell and Pybus 2005).

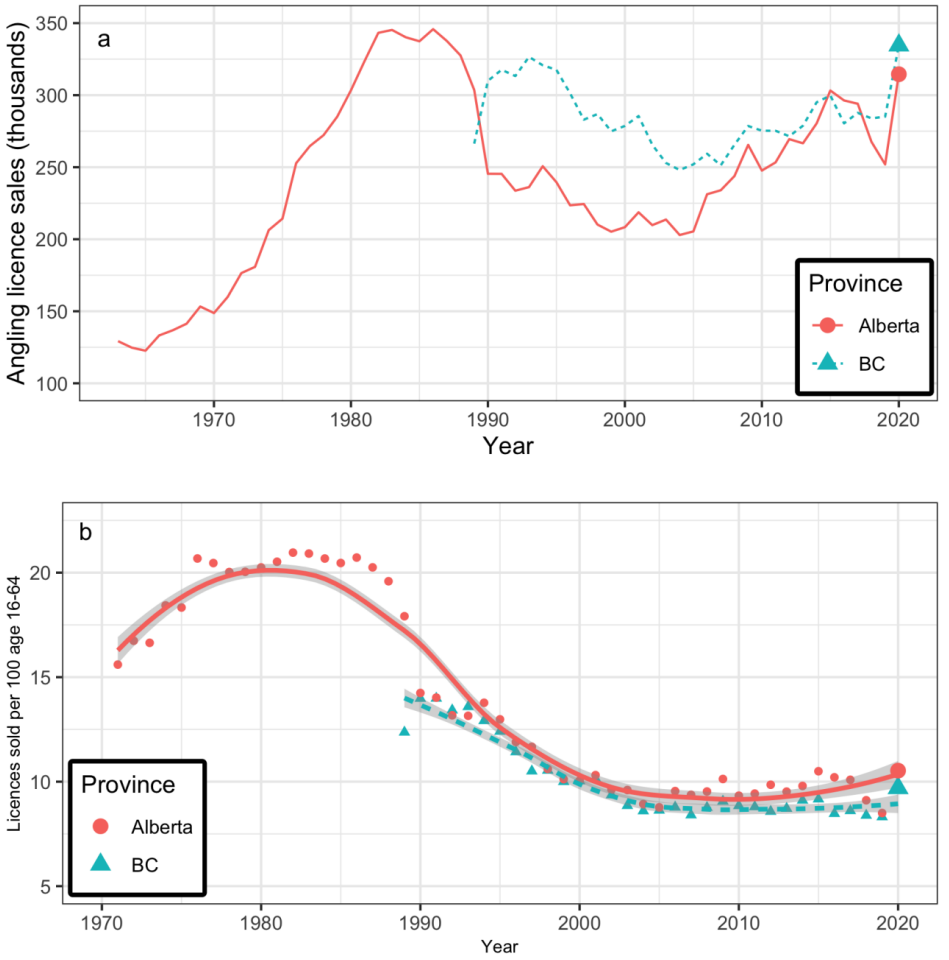

Figure 2. Trends in angling license sales in Alberta and BC. Panel **(a)** is total license sales; panel **(b)** is license sales per capita. Red dot represents sales for 2020, during the global COVID-19 pandemic.

The first commercial fishing licenses were issued for Alberta lakes in 1917. During the 1930s, some lakes were very heavily fished during the winter, apparently as economic opportunities for prairie farmers suffering from effects of drought and the Depression. By the 1940s, the fisheries were primarily winter gill-net fisheries targeting Lake Whitefish, with heavy year-round fisheries on a few large lakes targeting cisco for mink ranching. With the decline in mink ranching and an increase in sport fishing during the 1950s and 1960s, the commercial fisheries came under increasing social and economic pressure to catch high-quality Lake Whitefish for export sales and avoid catches of sport fish, particularly Walleye and Northern Pike. By the end of the 1970s, most Alberta lakes had commercial fishing seasons but were under increasing competition due to open-entry commercial license sales and a separation of quotas for Lake Whitefish from much smaller quotas for sport fish. During the 1980s, approximately 2,000 commercial fishing licenses were being sold annually, causing excessive competition, and resulting in the end of the open-entry license system.

Box 2. Restricted Sport Fish Quotas

The target quota for Lake Whitefish from Lac Ste. Anne in 1994 was 27,000 kg, with a tolerance (bycatch) quota for Walleye of 450 kg. That season was typical for many Alberta commercial fisheries at the time. It ran for 2 d, was attended by 43 commercial fishers who set 407 nets (40 km of gill net in a 54.5 km^2 lake), and harvested 34,000 kg of Whitefish and 14 kg of Walleye (the Walleye fishery at the time was collapsed, with an angling catch rate of 0.04 Walleye caught/h). The fisheries were intensively monitored, with enforcement officers and biologists present on the lake, counting fish in nets, and determining the daily harvests and closing the season when either the target or tolerance quotas were reached.

The 1980s and 1990s were marked by a period of intense changes in fisheries management in Alberta. Sport fish, especially Walleye and Northern Pike, were increasingly recognized as being collapsed with widespread, popular accusations of blame between sport, commercial, and First Nations fishers. Commercial fisheries were heavily restricted to large whitefish target quotas and steadily declining tolerance quotas of mostly collapsed populations of sport fish (Box 2). Distrust, anger, and controversy characterized this period, with quota setting meetings being closed to the public in the 1990s to reduce the conflicts and occasional threats and acts of violence.

By 2000, several years of heavy restrictions on the sport fisheries (mainly large size limits or total catch-and-release regulations) had greatly increased the abundance of Walleye and Pike in many Alberta lakes, resulting in much higher catches of sport fish in the commercial fishery. This resulted in commercial fisheries to fail to catch the target quota of Lake Whitefish because of closures on the low bycatch tolerance quotas of sport fish. The shortened seasons and repeated closures made many fishers abandon the increasingly uneconomical commercial fisheries, and participation at many fisheries declined. Anger and frustration boiled over at many commercial fisheries quota-setting meetings, with considerable political and senior-level bureaucratic involvement necessary to deal with contentious issues (see review by Colby 2012). The primary issues involved the increase in sport fish abundance and strong opinions voiced by commercial fishers that reductions in fish quotas and harvests were causing a variety of perceived problems, cited as lake winterkills and starving fish (with little to no supporting data), and loss of economic and ecological sustainability (Box 3).

Negotiations and ofttimes rancor-filled meetings between commercial fishers and senior provincial officials continued until July 2014, when the Minister of Environment and Sustainable Resource Development, Robin Campbell, announced the closure of all Alberta commercial fisheries on August 1, 2014. During December 2014, the remaining 143 commercial fishers in Alberta were offered a one-time ex-gratia payment (indexed to the amount of gill-net yardage each was licensed to set), with the stipulation that the Crown had no legal obligation or liability to make such a payment. Most fishers accepted the payment, and the commercial fishery has never been reopened.

British Columbia does not permit any commercial freshwater fisheries. However, there is a single experimental commercial fishery on Okanagan Lake targeting the freshwater opossum shrimp *Mysis diluviana*, colloquially referred to as Mysis. Mysis were introduced into

Box 3. Letter to the Editor, Edmonton Journal December 2014

Answer for loss of fisheries

"Since early April 2014, I have been trying to meet with the minister of sustainable resources to discuss the closures of the commercial fishery. All I get is the runaround. So in July I tried to meet with the premier. More runaround.

The government has virtually destroyed the small family lumber industry, the small family farm and has now closed the commercial fishery. Why?

They say there's more pressure on our lakes from anglers, but actually there is less. If our MLAs would actually think things through instead of rubber-stamping what the bureaucrats tell them, our small family industries would be thriving instead of dying. Allowing millions of fish to starve to death instead of harvesting is not management, it's mismanagement.

What happened to all the Pike in Snipe Lake? They died off. What happened to all the large Walleye in Winagami Lake? They died off. And this was between the time they had closed these fisheries and opened them this spring."

Name removed

many deep reservoirs across North America to bridge a trophic gap between zooplankton and pelagic prey such as kokanee and Lake Whitefish with the objective to improve large piscivore fisheries (Lasenby et al. 1986). Unfortunately, the introduction of Mysis had a negative impact on lakes in which it was introduced due to a naïve understanding of the ecology of Mysis. In Okanagan Lake, as in many other large reservoirs, introductions of Mysis preceded collapses of kokanee stocks and marked declines in larger piscivores (Whall and Lasenby 2009) due to Mysis outcompeting kokanee for shared zooplankton prey, being largely unavailable to predation due to extensive diel vertical migrations by Mysis, and largely altering nutrient dynamics (Lasenby et al. 1986; Martin and Northcote 1991; Chipps and Bennett 2000). In an attempt to reduce competition for zooplankton food by Mysis, the BC-ENV initiated an experimental commercial harvest on Mysis in 1999 that has continued to the present (Schindler et al. 2012). The aim was to reduce Mysis biomass to a level that improved kokanee growth and survival while avoiding kokanee bycatch. To date, the experimental Mysis fishery harvest rates are insufficient to reduce Mysis abundance or improve kokanee growth. However, the fishery has shown to be economically viable, although low harvest rates are largely driven by poor market demand. The fishery will likely continue on an experimental basis until such time as it is uneconomical, kokanee populations are negatively affected through bycatch or adequate harvest levels can be achieved to improve conditions for kokanee. If kokanee growing conditions improve, a permanent commercial fishery may be considered (Andrusak et al. 2011).

Nonnative Species

The spread of nonnative fish in western Canada is treated as a major threat to native species and their habitats as well as to recreational fisheries. Because of the differences in native

fauna, species that are native to some areas of western Canada are invasive in others. For example, Northern Pike are native to Alberta and northeastern BC yet are being controlled in the Columbia River as this invasive population spreads upstream from colonized areas in the United States (Runciman and Leaf 2009). In Alberta, invasive species planning and implementation is conducted by the Ministry of Environment and Parks. In BC, invasive species management and mitigation planning is conducted by the BC-ENV and implementation is carried out by the BC-FLNRORD.

The largest concerns in BC are centrarchids and percids (primarily black basses *Micropterus* spp. and Yellow Perch). Sources of invasive species vary. For example, bass were intentionally introduced into a number of BC systems near the turn of the century (McPhail 2007); Yellow Perch expanded their range from intentional introductions in Washington state (Brown et al. 2009a). Smallmouth Bass, Largemouth Bass *M. nigricans*, and Yellow Perch have now spread to over 90 lakes, mostly through illegal introductions (Brown et al. 2009b; Runciman and Leaf 2009), and are popular recreational fisheries, particularly on Vancouver Island. In Alberta, many of the mountain and foothill systems were stocked with nonnative trout to provide sport for early tourism in Canada's mountain parks (Donald 1987; Schindler 2000). Brook Trout and nonnative strains of Rainbow and Cutthroat trouts are now widespread throughout western Alberta, creating issues of competition and hybridization in management of Alberta's three native stream trouts (i.e., Bull Trout, Athabasca Rainbow Trout, Westslope Cutthroat Trout); all are managed with species-at-risk designations.

In the Alberta Northern Boreal and Parkland Prairie zones however, nonindigenous sport fish are uncommon. For example, virtually all of Alberta's Walleye populations are natural, although some ill-advised cross-watershed stocking of Walleye has occurred in a few lakes. Lake Trout in Alberta's boreal lakes are also almost exclusively native stock. Of note, one of Alberta's largest and most popular Lake Trout fisheries in Cold Lake had a lengthy history of stocking with nonnative strains of Lake Trout, but recent microsatellite studies suggest that the recovering population is of native ancestry (McDermid et al. 2020). Introductions of exotic species such as Smallmouth Bass, Largemouth Bass, and Coho Salmon *O. kisutch* have occasionally occurred in the past (and are often requested by angling groups), but no reproducing populations exist (Nelson and Paetz 1992; Joynt and Sullivan 2003; Sullivan et al. 2009). Illegal introductions of native Yellow Perch to stocked trout ponds is a recurring issue but are usually local fishing quality problems rather than conservation matters.

Recently, invasive Prussian Carp *Carassius gibelio* were discovered and are expanding into many Alberta prairie and parkland stream systems (Elgin et al. 2014). These fish have a high trait and life history overlap, with many native species in western Canada and beyond (Docherty et al. 2017), and have been shown to affect aquatic communities and their habitats (Ruppert et al. 2017). This invasion has perhaps been facilitated by a collapse of native predator species such as Walleye and Pike, coincident with eutrophication from agricultural activities (Stevens et al. 2010).

Management response to newly reported aquatic invasive species varies regionally, and the response is largely dependent on capacity and the scope of the problem (Box 4). Some regions in western Canada verify presence, close fisheries, and initiate eradication through piscicide treatments or physical removal, while others simply inform the public of the problem (Steve Maricle (retired), Scott Silvestri, Heather Lamson, Duane Jesson (retired), BC-FLNRORD, personal communication). The means of response depends on the native and nonnative community, size of the water body, type of waterbody (flowing or not) and wishes of the First Nations on whose territory

Box 4. Smallmouth Bass in Cultus Lake

Cultus Lake, one hour from Vancouver, has experienced a number of threats over the past 100+ years (Gauthier et al. 2021): increased sedimentation and oligotrophication, climate warming and effects on invertebrate communities, and declines in anadromous Sockeye Salmon (Putt et al. 2019). In 2018, Smallmouth Bass were discovered in the lake. The response of DFO, the BC-FLNRORD, and the BC-ENV was almost immediate. The BC Early Detection and Rapid Response Plan (BC IMISWG 2014) was followed, but the question of how best to conduct removals remained. Agencies quickly initiated a short structured decision-making workshop to determine objectives of control and the best combination of methods to control bass in the lake. Using a model parameterized with values gathered from the literature and from best professional judgment of workshop participants, it was determined that a combination of angling removals and nest destruction should be evaluated as long-term methods to reduce bass abundance (van Poorten and Beck 2021). These methods are now being evaluated using mark–recapture and telemetry to improve future inference and management of the system.

the treatment will take place. Conversely, some long-established invasive fish species are managed as fisheries. Brook Trout, which are not native to Alberta or BC, are currently stocked and actively managed as a sport fish in both provinces. Stocking of this species in BC has been limited to all-female triploid fish since 1996 to reduce the risk of introgression or reduced fitness of wild trouts such as Bull Trout and Cutthroat trouts (Durham et al. 2002; Kanda et al. 2002).

Species at Risk

The Committee on the Status of Endangered Wildlife in Canada has reviewed the status of 28 species of fishes in Alberta and BC (Table 2). Several of these species have been assessed as multiple designatable units (DUs), defined as components of species ranges containing discrete and significant units of evolution (Green 2005). Of the DUs assessed, 17 were recommended for listing as endangered, 15 as threatened, 12 as special concern, and 9 as not at risk. In addition, three species were assessed as extinct and three others as having insufficient information to make a recommendation. Status assessment can be challenging in western Canada because abundance data are often of low resolution and distributed sparsely across broad ranges, but Bayesian trend analyzes have provided probabilistic assessments of decline rates necessary for examining at risk thresholds (Post et al. 2022). Of the 32 species COSEWIC recommended for listing under the *Species at Risk Act* (SARA—those considered endangered or threatened), the Canadian federal government has listed 22. This results in legal protection for about two-thirds of those freshwater species in western Canada listed by COSEWIC.

Of these species assessed as at-risk by COSEWIC, several are targeted by recreational and Indigenous fisheries with at least part of their distribution in Alberta and BC: three species of sturgeon, Westslope Cutthroat Trout, Rainbow Trout (Athabasca River populations), and Bull Trout. Most have been listed for protection under SARA; Lake Sturgeon, Green Sturgeon *Acipenser medirostris*, and lower Fraser River White Sturgeon currently receive no federal protection from the act, apart from making fishing retention illegal.

Table 2. Mandate and goals of various management agencies involved in management of freshwater fisheries in western Canada.

Agency	Mandate related to freshwater fish and fisheries	Reference
Fisheries and Oceans Canada	• Protect freshwater ecosystems and species • Manage fisheries	(Fisheries and Oceans Canada 2020, 2021)
BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (BC-FLNRORD)	• Sustainable management of forest, wildlife, water, and other land-based resources • Work with Indigenous and rural communities to strengthen and diversify their economies	(Government of British Columbia 2021a)
BC Ministry of Environment and Climate Change Strategy (BC-ENV)	• Effective protection, management and conservation of water, land, air and living resources	(Government of British Columbia 2021b)
Alberta Ministry of Environment and Parks	• Balanced, common-sense, and results-based approach to stewardship of environment • Enable sustainable resource development	(Government of Alberta 2021b)
Freshwater Fisheries Society of BC	• Enhance and conserve BC's freshwater fisheries for public benefit	(Freshwater Fisheries Society of British Columbia 2021)
Alberta Conservation Association	• Implement and support fish habitat projects • Implement and support restoration or re-introduction projects • Implement and support population monitoring • Stock selected waterbodies	(Alberta Conservation Association and Alberta Ministry of Environment and Sustainable Resource Development 2014)

There are several widespread threats in Alberta and BC that have been found to influence species-at-risk status. Fishing may seem an obvious threat, but contemporary regulations largely protect against threatening wild populations with extinction (Sinnatamby et al. 2020). For example, Bull Trout in the Nelson River watersheds are listed as threatened (COSEWIC 2012); virtually all populations are regulated as catch and release, though release mortality is still perceived as a primary threat (Joubert et al. 2020). Historical commercial and consumptive recreational fisheries on sturgeon led to collapses that some populations have not recovered from (McLeod et al. 1999; Walters et al. 2006). Dams in some areas of the Fraser and Columbia watersheds alter flow and substrates, which has led to recruitment collapse on White Sturgeon at the northern part of their range (McAdam et al. 2005; McAdam 2011; Crossman and Hildebrand 2014). Many stream species are threatened by deteriorated water quality associated with agriculture, forestry, urbanization, industrialization, and resource extraction. These threats are likely being exacerbated by climate change and increasing frequency of water deficits, in particular in the drier regions of both provinces (Schindler 2001). Introduction of nonnative species is also a substantial threat in many areas of Alberta and BC as a result of a combination of competition, predation and hybridization with native species (Dextrase and Mandrak 2006). An extensive spatial threats assessment has been completed for three at-risk salmonids of the eastern slopes of the Rocky Mountains in Alberta, all of which are popular targets for sport fishers (Sinnatamby et al. 2020). Westslope Cutthroat Trout (threatened), Bull Trout (threatened) and Athabasca Rainbow Trout (endangered) have all been listed under the *Species at Risk Act* and are exposed to multiple threats to varying intensities across their ranges. Other species with only very small population sizes or small restricted spatial distributions are threatened by unidentified but potentially devastating stochastic events. Recovery plans for endangered species here and elsewhere are complex and can be hindered by multiple threats, and new threats may arise from recovery efforts. For example, White Sturgeon in the Nechako River, BC has undergone recruitment failure and the population is being partially supported by a conservation hatchery. However, the release of hatchery Sturgeon has led to high predation rates by river otters *Lontra canadensis*, whose population may be bolstered and therefore represent an increased predation risk on wild Sturgeon as well (Babey et al. 2020). Looking to the future, the combined impacts of human population growth, further expansion of development into natural environments, and climate change will continue and likely exacerbate these threats to many of the fish species of Alberta and BC, including those providing commercial, recreational, and Indigenous fisheries.

Current Issues

Below, we include several issues that have emerged in recent years. By no means are these inclusive, but they give a flavor of challenges and opportunities faced in the region.

Harvest Management

Appropriate management is necessary to limit harvest in situations where effort is exceedingly high, fish resources cannot sustain current harvest levels, or current effort or harvest levels compromise angler satisfaction. Over the years, increasingly restrictive combinations of bag and size limits have been implemented across western Canada to sustain

fisheries. For example, Alberta implemented complete catch and release on all Bull Trout in 1995 (Post and Johnston 2002). Likewise, a pervasive overharvest issue on BC trout streams was recognized in the early 1980s (Slaney et al. 1984) and special regulations have been implemented to sustain these fisheries (e.g., Oliver 1991). Daily bag limits have generally declined based on a perceived need for restrictions in harvest. For example, the general daily limit on kokanee has declined from >10 in 1990 to <5 in 2013, but the need for, and effectiveness of, this type of change has typically not been evaluated except in specific fisheries (e.g., van Poorten and MacKenzie 2020). Effort management on BC lakes has been proposed (Cox et al. 2003) but never implemented except inadvertently through decommissioned access roads.

Alberta Walleye fisheries are very popular, so opportunities to harvest Walleye are carefully managed. Angler numbers and catchability are high compared to the regional productivity of Walleye (Mogensen et al. 2014); in order to control angling mortality, a lottery-style tag harvest has been implemented on popular lakes (i.e., three lakes initially in 2007, increasing to 15 lakes as of 2020). Anglers enter a randomized draw in April of each year, applying for a license to harvest Walleye on a specific lake and for a specific size-class of Walleye. Successful applicants are allotted two tags per license for small (<43 cm TL) and medium-size (43–50 cm TL) Walleye, and two tags for large (>50 cm TL) Walleye (Figure 3). These are controlled harvest fisheries but not limited-entry fisheries, meaning all tag-harvest lakes are open to catch-and-release fishing by all licenced anglers. This controlled harvest system is data intensive and requires standardized index netting to determine the relative density and structure of the Walleye population, and estimates of angling bycatch mortality, and of cumulative fishing mortality of Indigenous and recreational fishing. Harvest is allocated using a simple accounting model, limiting cumulative fishing mortality on the three size-classes of Walleye to either 5% or 10% to achieve desired densities of size-classes of Walleye. More tags are issued than are expected to be filled, based on observed and expected rates of tag purchase and angler success. Enforcement officers have reported relatively few violations involving tag harvest anglers.

Anglers initially showed mixed acceptance of this tag harvest system. Within a few years, its popularity increased, and the system has been requested on many lakes and for other species (notably Bull Trout, Lake Trout, and Northern Pike). Because of the intensive data requirements, however, it may not be feasible to greatly expand the program, particularly on small lakes (i.e., high monitoring costs with benefits to relatively few anglers).

Classified Waters

Western Canada is home to some iconic fishing experiences. In BC, catch-and-release fishing for steelhead in the late 1980s was attracting many anglers to many rivers, especially the Dean, Bulkley and Skeena rivers. Competition between guides, nonguided residents, and nonresidents was leading to crowding, conflict, and reduced satisfaction. The Classified Waters Licensing System was designed to reduce crowding and preserve fishing opportunities for resident anglers. The system imposes different limits on which days and the number of days that resident and nonresident anglers may fish with and without a guide. Limits exist for the number of guided days, but there are no limits to the total number of licenses. This program has now expanded to 52 highly productive streams, primarily steelhead and trout/char streams in all regions except the Lower Mainland, Okanagan, and Peace regions.

Figure 3. Walleye harvested at Pigeon Lake Alberta under regulation of the lottery-style tag program. Photo from M. G. Sullivan.

Fraser River White Sturgeon Fishery

First Nations communities have been fishing White Sturgeon in the Fraser River for thousands of years. When colonial expansion began in the mid-1800s, sturgeon were first caught in salmon nets and by the 1880s were increasingly the target of their own fishery. Sturgeon caviar and flesh were sold locally and by 1894 were exported to eastern markets (Semakula and Larkin 1968; Perrin et al. 2003; Nelson et al. 2013). In a classic overfishing scenario, catches of this very large, long-lived species saw rapid growth followed by overharvest and collapse (Semakula and Larkin 1968; Echols 1995; Walters et al. 2006). Harvest continued at a low level for nearly a century until the commercial fishery was closed in 1991. Recreational harvest continued until 1994, when regulations were changed to catch and release. In the same year, commercial fisheries were mandated to release all incidentally caught White Sturgeon and First Nations voluntarily ceased all directed fisheries and released all incidentally captured White Sturgeon captured in salmon fisheries (Nelson et al. 2013). Fishing mortality since then has been limited to gill-net bycatch release mortality, sport fish catch-and-release mortality, and a perceived low level of poaching (Walters et al. 2006; Nelson et al. 2013). In 2003, COSEWIC set the status of all Canadian sturgeon as endangered, although the popula-

tions in the lower and mid-Fraser River were not declining. In 2012 COSEWIC re-evaluated and reclassified Fraser River sturgeon into two DUs: the Lower Fraser and Upper Fraser (the latter is comprised of the mid-Fraser, Nechako, and upper-Fraser populations). The Lower Fraser DU is currently classified as threatened, and the Upper Fraser DU is classified as endangered by COSEWIC (COSEWIC 2003).

An effort was made in the mid-1990s to establish a basic demographic understanding of the dynamics and demographics of the populations in the lower- and mid-Fraser River, which would form the basis of future management. Unfortunately, efforts to collect data were difficult due to classic complications in sampling widely dispersed low abundance populations (McKenzie 2000; Perrin et al. 2003). In response to this data need, the Fraser River Sturgeon Conservation Society, in collaboration with BC, began a comprehensive mark–recapture program in 2000 using volunteers to implant passive induced transponder (PIT) tags and collect biological information on White Sturgeon captured by fishing guides trained in biological sampling. By January 2012, over 50,000 individual sturgeon had been tagged and over 90,000 assessed for the presence of tags (Nelson et al. 2013). The information from the data-rich, volunteer-led tagging program has spawned numerous studies on abundance (Walters et al. 2006; Whitlock and McAllister 2009, 2012; Nelson et al. 2013; Challenger et al. 2019), which provides important support for management and evaluation of the population and fishery. For example, current estimates suggest the population is declining due to a persistent reduction in recruitment over the past 15 years (Challenger et al. 2019).

Water Extraction and Reservoirs

Water is well used in western Canada for hydroelectric power generation, agriculture, flood control, and industry. These uses often require reservoirs and dams, which act to dampen and regulate water flows downstream. In the Peace River system, this has led to reduced flow variation, changes in vegetation, and changes to the fish community (Prowse et al. 2002, 2006). In coastal rivers, dams have led to impacts or cessation of anadromy for populations and species where migration between marine and freshwater environments is necessary (van Poorten et al. 2018). This leads to loss of marine-derived nutrients, which contributes to increasing oligotrophication of these coastal streams following impoundment (Scott et al. 2017). Conversely, small dams are regularly used to aid in water storage in drier areas of the BC interior, where the expanded lake creates opportunities for stocked fisheries. However, direct extraction from rivers and impounded lakes in drier areas of the interior has led to increasing water shortages in summer months. Grandfathered water licenses historically governed under the "rule of capture" (a quasi-property right; Brandes and Curran 2017) in many drier areas of western Canada have been overallocated, leading to severe drawdown and even complete drying of some streams (R. Ptolemy, BC-ENV, personal communication). Water extraction from large rivers and reservoirs for agriculture or industrial purposes also leads to entrainment and loss from donor systems (Post et al. 2006); if this significantly affects recruitment or natural mortality, it may reduce abundance and potential catch rates for these fish populations.

Whirling Disease

Whirling disease (infections of the parasite *Myxobolus cerebralis*) was detected in 2016 in fish of the upper Bow River, Alberta. Prior to this, testing during the late 1990s and 2000s

had suggested Alberta was free of whirling disease. Following the first detection, a large-scale testing program was implemented throughout much of Alberta, and by 2019, infected fish had been found in various rivers of the Saskatchewan River system (Barry et al. 2021). No infected fishes were found in the Athabasca and Peace rivers. A modest testing program was also conducted in BC; to date, no detections have been found. An extensive public information campaign of preventing the spread of the parasite was implemented, including boat and gear decontamination stations located in popular fishing areas. The monitoring and decontamination program in Alberta was halted in 2019, primarily due to funding issues. As of 2021, fisheries assessments of trout and whitefish populations along Alberta's east slopes rivers suggest that population-level effects of whirling disease (i.e., loss of young fish) are not widespread. However, local effects have been observed in important sport fisheries, such as the Crowsnest River (James et al. 2021). Public education remains an important tool to prevent further spread of this parasite.

Cumulative Effects of Land Use

Alberta has consistently led Canada in terms of economic and population growth for several decades. This growth has primarily been fueled by a burgeoning petrochemical industry involving widespread conventional oil and gas extraction (Baccante 2012) and localized oil sands mining near Fort McMurray (Schneider 2002; Schwalb et al. 2015). Likewise, BC has a well-developed natural resource industry in much of the province. However, land use throughout western Canada extends far beyond impacts from just the petrochemical industry, with agriculture dominant in the south and central prairie and plateau portions of the region, and forestry industries extensive across the southern half of the region. Road development, deforestation, urbanization, and land conversion contribute to a variety of threats to fish populations (Sinnatamby et al. 2020). This leads to several potentially overlapping threats to fisheries conservation that must constantly be addressed.

The cumulative effects of these threats have resulted in a widespread loss of sustainability of many of Alberta's most valued fishes. For example, comparing the historical versus current status of Bull Trout (Figure 4) and Arctic Grayling (Figure 5) suggests a significant loss of distribution and abundance across most of these species ranges in Alberta. To manage these types of cumulative effects, the provincial government is working with a process called the Land-Use Framework. Briefly, the province is divided into major watersheds with each assigned a group of local stakeholders tasked with determining the acceptable trade-offs between environmental health and economic development. Extensive use of local participation and knowledge as well as complex computer simulations of land use and water use effects are being used to communicate these trade-offs. Stakeholders, with assistance from various levels of government, including biologists and local First Nations members, are expected to develop environmental and economic objectives with indicators, thresholds, and actions to achieve those goals (MacPherson et al. 2020).

An important aspect of these models, plans, and discussions is the involvement of fisheries biologists presenting dose–response relationships quantifying the probable effects of development on fish status. These correlations between development and fish status may be derived from, ideally, empirical data (Ripley et al. 2005) or, more often, from "best-guesses" in expert workshops (e.g., Fisheries and Oceans Canada 2019a). Combining dose–response curves across several of the most important aspects of development allows

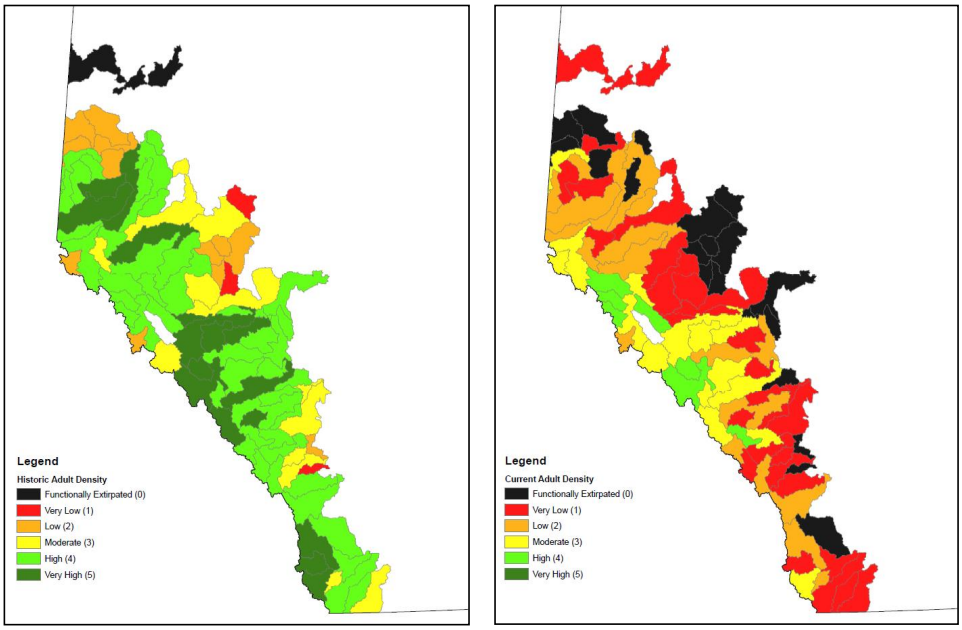

Figure 4. Historical (pre-1950) and current (2008–2013) density of Bull Trout in Alberta's watersheds (Alberta Environment and Parks 2018b, 2018c). Density ranking according to Alberta's fish sustainability index (MacPherson et al. 2014).

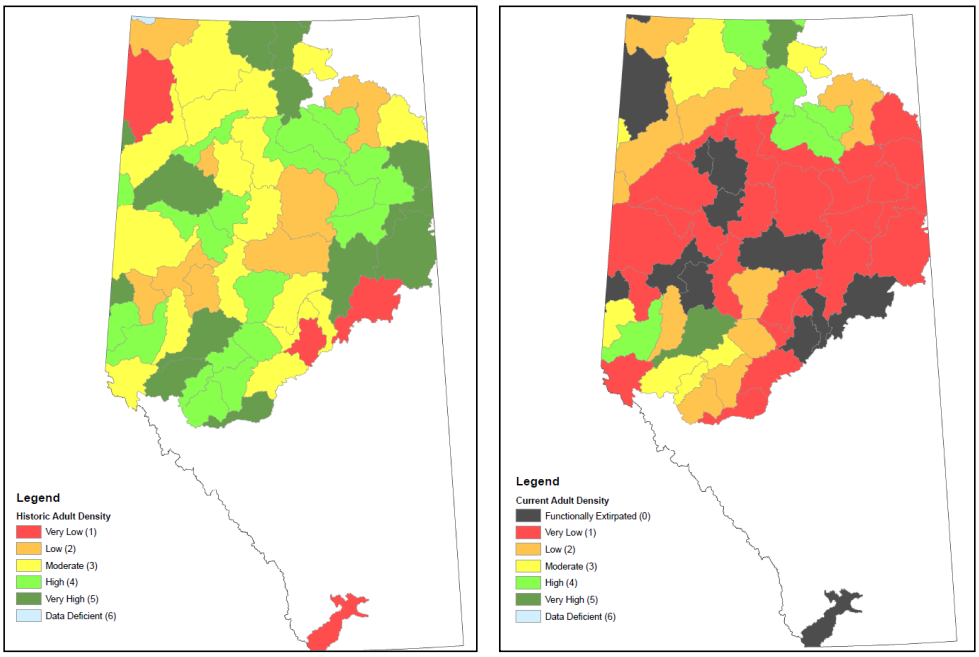

Figure 5. Historical (pre-1950) and current (2008–2013) density of Arctic Grayling in Alberta's watersheds (Alberta Environment and Parks and Alberta Conservation Association 2015). Density ranking according to Alberta's fish sustainability index (MacPherson et al. 2014).

stakeholders to understand and explore potential trade-offs between scenarios of future development and valued fisheries. A commercially available cumulative effects simulation program, ALCES©, has been used extensively in Alberta to provide predictions of land use and habitat conditions in these discussions and land use planning exercises (Schneider et al. 2003; Carlson et al. 2010). This process is currently being expanded for use in other areas, including BC.

Oil Sands Development and Its Impacts on Fisheries

The Alberta oil sands and their effects on environmental health are a controversial, publicized issue (Schindler 2010). From a fisheries perspective, major potential detrimental effects are from effluents, land disturbance, and increased human presence in the area. Extensive monitoring and research has been directed towards the effects of effluents (Heuvel et al. 1999; Tetreault et al. 2003; Kelly et al. 2009, 2010), with relatively little work on the effects of changes to land use (Jordaan 2012) and effects of overfishing (Schwalb et al. 2015). In overview, however, the overwhelming fisheries issues in the oil sands areas are unrelated to effluents and oil spills, and strongly related to human access. Alberta boreal streams are affected by fragmentation caused by extensive road building and hanging culverts (Park et al. 2008). Land use, especially clearing for oil development and forestry is correlated with low oxygen in streams (Norris 2012). These cumulative effects of fish habitat degradation and increased access (fishing pressure) appear responsible for the loss of these fisheries; however, the popular media focus is on the potential effects of oil sands effluent-related fish and human health. For example, tailings ponds in the Fort McMurray area receive extensive media attention despite no major leaks or spills over the past three decades. In contrast, virtually no media attention is given to the collapse of the 18 natural Walleye lakes in the backcountry between Fort McMurray and Lake Athabasca, or to the loss of once-popular Arctic Grayling, fisheries such as the Christina and Muskeg rivers (Schwalb et al. 2015). In spite of the media attention given to the significant environmental issues of the Alberta oil sands, however, it is important to place these fisheries effects into a larger perspective; for example, by virtually all relevant metrics (e.g., area cleared, riparian habitat affected, road density, nutrient run-off), agriculture has had a vastly larger effect on Alberta's fish habitat (Stevens et al 2010), being over a much larger area and somewhat less regulated.

Synthesis and the Future

Fisheries in western Canada are quite diverse, with opportunities for various types of fishing experiences in every area of the region. While some species and populations are imperiled and have uncertain futures, conditions are improving for many populations through strict fishing and land use regulations and continually adapting processes.

Western Canada is continuing to develop in terms of human demographics, industrial and agricultural expansion, and road networks. Patterns of human population distribution are quickly changing towards a largely urbanized society where people's understanding and time spent in nature are becoming increasingly decoupled (Hurner et al. 2004; Arlinghaus et al. 2021), leading to challenges with participation and retention in fisheries. Meanwhile, resource extraction in the form of logging, mining, and oil and gas development means all areas of the region are becoming more accessible as roads and access are developed. A great deal of work

has occurred in the past few decades to get a better understanding of how anglers interact with the fishery resource. As with many regions, the slow adoption of human dimensions into fisheries models and plans means our understanding of where anglers will redistribute and react to changing conditions continues to be a challenge, especially with the rapid pace of development.

The greatest uncertainties facing fish populations in western Canada is likely to be land use development and the difficult to clearly quantify and predict the impacts from climate change. The impact of large-scale developments on social and ecological systems remains uncertain. Both provinces are heavily invested in extractive industries (forestry and petrochemical), and our tools for dealing with multiple, cumulative effects are constantly changing and improving. Both provinces have plans in place or in development to try to deal more strategically with cumulative effects and incorporate climate change impacts into natural resource management. However, this area of research and applied management is largely in its infancy and there will be many bumps (or detours) on the road ahead.

Acknowledgments

In many ways, this chapter is the first time much of the history discussed herein has been written down. It is important to recognize the time taken by individuals to discuss how things were and how everything has changed over the years. Special thanks go to Heather Lamson, Scott Silvestri, Duane Jesson, Steve Maricle, Jennifer Smith (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development), Steve McAdam, Don Morgan, Matthias Herborg (BC Ministry of Environment and Climate Change Strategy), Adrian Clarke and Wallace Cheung (Freshwater Fisheries Society of BC). In Alberta, much is owed to our pioneers of fisheries management: R. B. Miller, Joe Nelson, and Martin Paetz. We, as their students, continue their passion: Hugh Norris, George Sterling, Jim Stelfox, Vance Buchwald, Lorne Fitch, Jordan Walker, Craig Johnson, Myles Brown, John Tchir, Mike Bryski, Dave Park, Bill Patterson, Sierra Sullivan, Ward Hughson, Stephen Spencer, and so many others. Extended discussions with David Close (formerly at Fisheries Centre, University of British Columbia) were invaluable for informing our discussions of Indigenous fisheries and the issues faced by Indigenous people.

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