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Ontario and Prairie Region

Preliminary assessment of the State of Fish and Fish Habitat in Fisheries and Oceans Canada's Ontario and Prairie Region

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

With the modernization of the *Fisheries Act*, DFO committed to producing 'State of Fish and Fish Habitat' (SOFFH) reports for Canada's freshwater ecosystems. As part of this initiative, DFO's Ontario and Prairie (O&P) Region selected the Lake Erie and Lake Ontario drainage basins (Lower Great Lakes Area; LGLA) and the Alberta East Slopes Area (AESA) as focal areas for reporting on in 2023. A Canadian Science Advisory Secretariat meeting was held June 29–30, 2021, to elicit input from academic, environmental practitioners, FFHPP, and DFO Science on the appropriate indicators, metrics, and data that could be used for the O&P SOFFH report. The five indicators selected by DFO O&P were: Biodiversity, Water Quality, Connectivity, Land Use and Land Cover, and Climate Change. Data for up to six metrics per indicator were summarized for each of the reporting areas.

The findings indicated that LGLA has high fish species richness. However, a number of fishes and mussel species have been listed as species at risk. Water quality parameters often exceeded thresholds in areas with the greatest urban and agricultural development, and there was also an absence of natural riparian cover in those areas. Ninety-two per cent of the barriers within the LGLA are known to prevent fish movement. Forward and backward bioclimatic velocities were found to be highest in the assessment units surrounding the Greater Toronto Area and assessment units in the Lake Ontario basin. Flood forecasts showed variable changes in the location and heights of 100-yr floods with climate change.

The AESA has lower fish species richness relative to the LGLA and a correspondingly, lower number of species at risk. Water quality parameters were often consistent with guidelines for the protection of aquatic life and connectivity varied amongst watercourses in the area. Land use and land cover in the AESA showed high spatial variance, with rangeland and crops in the southeast and trees and snow/ice in the western and northeastern regions. Due to the presence of large national and provincial parks, entire assessment units were protected in the mountainous regions of AESA. Forward bioclimatic velocities were two times faster and flood heights were also higher in the AESA compared to LGLA.

This report provides insight into the SOFFH within the AESA and LGLA. However, limited data were available for some metrics, resulting in high uncertainty related to the SOFFH in some assessment units. As such, we identified key data gaps and limitations of the selected indicators and metrics. This information could be used to prioritize spatial extents and items for future research and monitoring projects. The process outlined in this report demonstrates how a quantitative approach to reporting on the SOFFH could be applied by DFO in other regions.

GLOSSARY

State of Fish – the diversity, composition, and/or abundance of fish relative to the naturally occurring community.

State of Fish Habitat – the ability of areas to support the life processes of aquatic organisms relative to the natural function of the area.

Indicator – Physical, chemical and biological features of aquatic ecosystems used to describe the SOFFH. Based on DFO (2022a), the primary Indicators of interest for the SOFFH Reporting within Ontario and Prairies Region will be Biodiversity, Water Quality, Connectivity, Land Use and Climate Change.

Metric(s) (DFO 2022a) – are variables that are directly measured to quantify an Indicator. Indicators may have one or multiple Metrics to describe them. For example, the Metric 'dissolved oxygen' may be used to quantify the Indicator, 'water quality'.

Reporting thresholds – are values of a Metric or Indicator used to define the upper and/or lower limits of categories used in classification schemes.

Reporting Areas (DFO 2022a) – The geographical areas of focus for reporting on the State of Fish and Fish Habitat.

Assessment Unit (DFO 2022a) – The geographic area where Metrics are assessed against thresholds. The scale of the Assessment Units is dependent upon the scope and scale of the Reporting Area and data available. These units can range from individual lake or stream segments to entire watersheds (e.g., Tertiary Watershed level, HUC 8).

INTRODUCTION

On August 28, 2019, a new *Fisheries Act* came into force with modernizations to help safeguard fish and protect the environment. Specifically, the purpose of the Act is to “provide a framework for a) the proper management and control of fisheries; and b) the conservation and protection of fish and fish habitat, including by preventing pollution” (section 2.1). To implement the modernized *Act*, Fisheries and Oceans Canada’s (DFO’s) Fish and Fish Habitat Protection Program (FFHPP) and the Ecosystem and Oceans Science sector (‘DFO Science’) were revitalized with new resources. These resources have enabled DFO to increase its capacity to work with partners and stakeholders in freshwater, marine and coastal environments to improve the conservation, protection and restoration of fish and fish habitat.

With these additional resources, DFO also plans to improve how it reports to Canadians on its own activities related to fish and fish habitat protection, as well as on the overall ‘state’ or health of aquatic habitats and species. This initiative, called the ‘State of Fish and Fish Habitat’ (SOFFH) report, will be initially released in 2023 with a focus on Canada’s freshwater ecosystems. This report will therefore complement DFO’s State of the Oceans reports (e.g., DFO 2020) and freshwater ecosystem reporting being conducted by other organizations (e.g., Conservation Ontario 2018, ECCC and US EPA 2019, WWF-Canada 2020). As part of the SOFFH reports, FFHPP in the Ontario & Prairie region have selected two reporting areas to be the focus of their contributions towards the 2023 national report. These reporting areas are the Lower Great Lakes Area (LGLA) in Ontario, and the Alberta East Slopes Area (AESA).

Due to the complexity of aquatic ecosystems and the mosaic of natural and anthropogenic pressures that affect them, it is not possible to report on every component of fish and fish habitat within each reporting area. Therefore, ecosystem reporting typically focuses on a set of indicators that characterize the state of the ecosystems being considered. Within freshwater systems, ecological function is related to physical and chemical characteristics such as water temperature, water chemistry, channel structure, light availability, and substrate characteristics (Vannote et al. 1980, Sterner et al. 1997, Wolters et al. 2017). In addition, biological features such as species richness, abundance, and trophic interactions are key determinants of important ecosystem processes including fisheries productivity (Cusens et al. 2012). These relationships suggest many indicators that could be used to report on the SOFFH in freshwater environments. In a review of previous studies assessing freshwater ecosystem ‘health’ or ‘integrity’, O’Brien et al. (2016) found that indicators based on fish and macroinvertebrate community structure or richness, nutrient levels, and water physio-chemistry (e.g., turbidity, dissolved oxygen, pH, temperature) were most common.

A Canadian Science Advisory Secretariat (CSAS) meeting was held June 29–30, 2021, to elicit input from academic, environmental practitioners, FFHPP, and DFO Science on the appropriate indicators, metrics, and data that could be used to report on the SOFFH within the Ontario and Prairie reporting areas. A draft list of indicators and metrics was discussed, and a final list selected based on input from participants and FFHPP’s expertise.

The five indicators selected for SOFFH reporting in the Ontario and Prairies region are: (1) Biodiversity, (2) Water Quality, (3) Connectivity, (4) Land Use, and (5) Climate Change. Within each of these indicators, 2–6 metrics have been selected as the specific variables to be quantified. This document outlines the data compilation, analyses, and thresholds used to synthesize information on the state of fish and fish habitat in the O&P reporting areas.

The key objectives of this document are to:

(i) present a synthesis of the available data and status of each environmental metric within the Lower Great Lakes and Alberta East Slopes reporting areas

(ii) identify uncertainties and knowledge gaps with respect to data availability and the methods used for developing classification schemes for the SOFFH.

These objectives correspond to objectives 1 and 4 described in the Terms of Reference for this CSAS process (DFO 2022b), with objectives 2 and 3 being addressed in Dey and Chu (2023).

METHODS

STATE OF FISH AND FISH HABITAT REPORTING AREAS

Two reporting areas were selected by FFHPP for O&P SOFFH reporting. These reporting areas are the: (i) LGLA and (ii) AESA.

Lower Great Lakes Area (LGLA)

The LGLA is located in southern Ontario and includes the watersheds that drain into Lake Ontario and Lake Erie (Figure 1). This area is part of the Mixedwood Plains ecozone (Agriculture and Agri-Food Canada, 2013), which is characterized by mixed deciduous-evergreen and hardwood forests. However, much of the area has now been converted to cropland, pasture or (sub)urban areas, as this area contains the highest density human population in Canada. Large urban centers in the reporting area include: the Greater Toronto Area, Hamilton, Windsor, Peterborough, St. Catherines, London, Kitchener-Waterloo, Guelph and Kingston.

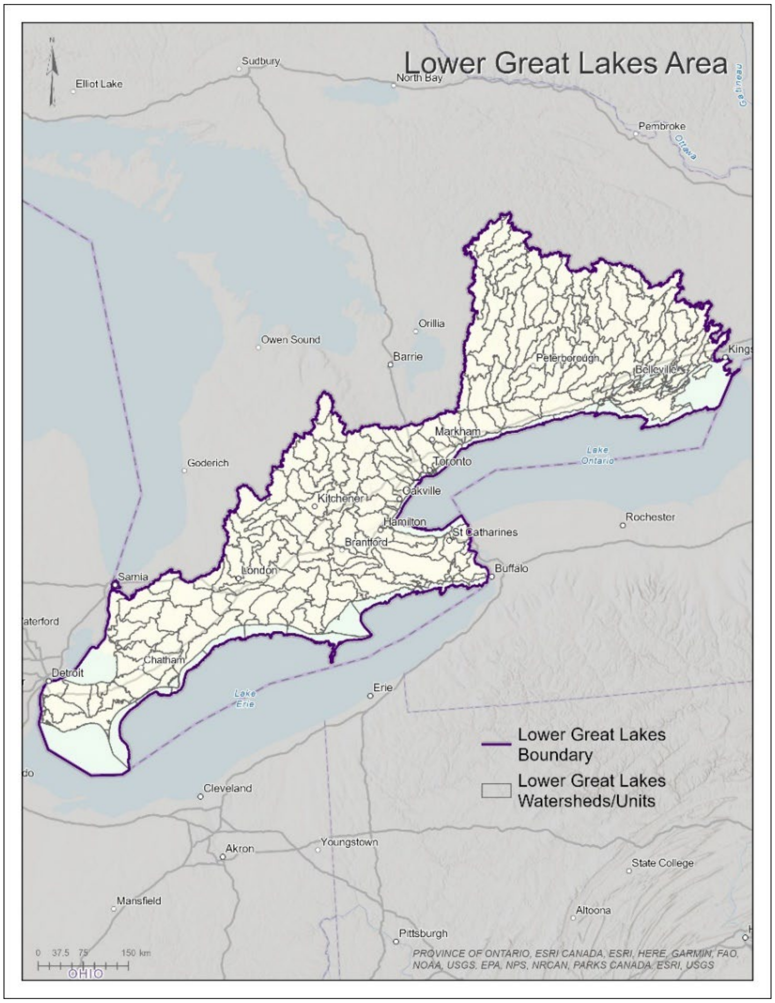

Figure 1. Lower Great Lakes Area (LGLA) and assessment units.

The 59,077 km^2 reporting area falls entirely within the Laurentian Great Lakes freshwater ecoregion (WWF 2019, Abell et al. 2000), which holds over 20% of the world's surface freshwater and is drained by the St. Lawrence River to the Atlantic Ocean. Within the reporting area, major rivers include the Detroit, Thames, Niagara, Grand, Credit, Don, Humber and Trent rivers. The reporting area also includes Niagara Falls, which has the highest flow rate of any waterfall in North America. In addition, the reporting area contains many natural and man-made lakes (i.e., reservoirs), the largest of which are found in the northeastern part of the reporting area with the exception of Lake St. Clair in the western part of the area.

Table 1. Distribution of aquatic habitats in the LGLA.

Aquatic habitat type	**Aquatic habitat subtype**	**Area / Length**
Lakes, ponds and reservoirs	-	1,404 km^2
Watercourses	-	-
-	Strahler Order 1 - 2	57,129 km
-	Strahler Order 3 - 4	16,386 km
-	Strahler Order 5 - 6	4,660 km
-	Strahler Order > 6	884 km
Wetlands	-	5,079 km^2

The LGLA contains some of Canada's highest terrestrial and aquatic biodiversity (ESTR Secretariat 2016). The area contains many aquatic mussels and fishes found nowhere else in Canada, as well as a diverse mix of sport fishes including smallmouth and largemouth bass (*Micropterus dolomieu* and *M. salmoides*), northern pike (*Esox lucius*), brook trout (*Savelinus fontinalis*), and several naturalized salmonid species (*Oncorhynchus spp.* and *Salmo trutta*).

Unfortunately, aquatic habitats (Table 1) in the LGLA are threatened by a number of factors associated with development and other human activities. Many of the aquatic systems are also impacted by multiple, co-occurring stressors because of the density of the human population in the area.

Specific threats of concern include:

- changes in flows due to dams and impoundments and water withdrawals from agricultural, industrial, and urban activities;
- declines in water quality from changes in sediment regimes and other contaminants (e.g., fuel, manure, nutrients, oils, pesticides, road salts, and sewage effluents) and increased water temperatures due to a loss of riparian vegetation;
- habitat fragmentation from dams and other barriers;
- habitat loss and degradation from agricultural and urban development (e.g., dock and marina construction, dredging, construction and operation of impoundments, municipal drain maintenance and repair activities, riparian vegetation removal, shoreline hardening);
- impacts of climate change on water quantity, flow and water temperature; and
- the introduction of aquatic invasive species.

Alberta East Slopes Area (AESA)

The AESA is located in Alberta and contains the east slopes of the Rocky Mountains and immediate downstream areas within the province (Figure 2). The area forms the headwaters of the Saskatchewan River, which flows northeast into Lake Winnipeg and eventually into Hudson Bay, as well as the Athabasca and Smoky River basins, which drains into the Peace River and eventually into the Arctic Ocean. Major rivers in the reporting area include the Oldman, Bow, Red Deer, and Smoky rivers that flow through the urban centers of Lethbridge, Calgary, Red Deer and Grand Prairie, respectively, as well as the Athabasca and North Saskatchewan rivers, which begin in the Columbia Icefield before leaving the reporting area to the northeast.

Figure 2. Alberta East Slopes Area (AESA) and assessment units.

This 150,571 km^2 reporting area falls within the Montane Cordillera, Prairies and Boreal Plains ecozones (Agriculture and Agri-Food Canada, 2013), and is characterized by diverse terrestrial habitat including high alpine slopes, mountain foothills, boreal forest and parkland, and prairie habitat. The reporting area also falls within the Upper Saskatchewan and Upper Mackenzie freshwater ecoregions (WWF 2019, Burridge and Mandrak 2019a,b). The former ecoregion is predominantly composed of glacier fed rivers, many beginning as high-gradient streams that become slower and wider as they move eastward off the mountains, as well as several large lakes, including Waterton Lake, which is the source of the Oldman River. The latter freshwater ecoregion is predominantly composed of temperate floodplain rivers set in broad, rolling valleys and including many boreal wetlands. Notable sportfishes in the reporting area include bull trout (*Salvelinus confluentus*; the provincial fish of Alberta), westslope cutthroat trout (*Oncorhynchus clarkii lewisi*), mountain whitefish (*Prosopium williamsoni*), Arctic grayling (*Thymallus arcticus*) and northern pike, as well as non-native brook trout and rainbow trout (*Onchorhynchus mykiss*).

Table 2. Distribution of aquatic habitats in the AESA.

Aquatic habitat type	Aquatic habitat subtype	Area / Length
Lakes, ponds and reservoirs	-	2,157 km^2
Watercourses	-	-
-	Strahler Order 1 - 2	132,133 km
-	Strahler Order 3 - 4	32,232 km
-	Strahler Order 5 - 6	10,853 km
-	Strahler Order > 6	3,689 km
Wetlands	-	9,455 km^2

Aquatic habitats (Table 2) and fishes in the AESA are threatened by development and other human activities including the introduction of non-native fish species. In particular, agriculture and urbanization have altered the land cover in much of the southern and eastern portions of the reporting area, while transportation and recreational infrastructure and activities are common in the mountainous regions. In addition, natural resource extraction, including oil and gas exploration and extraction have impacted parts of the reporting area. Specific threats from these activities include:

- habitat fragmentation from dams and watercourse crossings associated with transportation infrastructure;
- changes in flows due to dams and impoundments and water withdrawals from agricultural, industrial, and urban activities;
- declines in water quality associated with agricultural runoff, urbanization and the development of natural resources;
- impacts of climate change on water quantity, flow and water temperature; and
- the introduction of aquatic invasive species, including invasive trout species.

INDICATORS AND METRICS

The five indicators selected for SOFFH reporting in the Ontario and Prairies region are: (1) Biodiversity, (2) Water Quality, (3) Connectivity, (4) Land Use, and (5) Climate Change. Within each of these indicators, 2–6 metrics have been selected for quantification (Table 3).

Biodiversity

Metrics of biodiversity, such as species richness and community composition, can be monitored to determine the health of ecosystems and assess whether communities are changing over time. They can also be tracked to understand the drivers of natural environmental variation, determine the effects of anthropogenic activities on ecosystems, evaluate the effectiveness of management actions, and identify areas for restoration or protection (Chu et al. 2016, Montgomery et al. 2020).

Biodiversity metrics included in the SOFFH report are: (1) fish species richness, (2) a benthic invertebrate (EPT) index, based on the percentage of *Ephemeroptera* (Mayflies), *Plecoptera* (Stoneflies), and *Trichoptera* (Caddisflies) in the community of aquatic invertebrates, (3) species at risk (SAR) richness, and (4) aquatic invasive species (AIS) richness.

Fish species richness patterns in Canada are related to species habitat preferences, the availability of different types of habitats, community dynamics, and post-glacial colonization (Mandrak and Crossman 1992). Quantification of fish species richness across the reporting areas allows for the identification of general biodiversity patterns as well as biodiversity hotspots that may inform conservation and management planning.

The EPT index is a taxonomic metric that describes the proportion of *Ephemeroptera* (Mayflies), *Plecoptera* (Stoneflies), and *Trichoptera* (Caddisflies) relative to the total number of individuals in the benthic invertebrate community. The EPT index is also a widely applied water quality metric in watershed assessments because EPT are sensitive to pollution and disturbance such that high-quality habitats usually have the greatest species richness or high EPT values (Wallace et al. 1996, Gazendam et al. 2011). Therefore, the EPT index provides a measure of not only the benthic invertebrate community composition but also habitat condition in the reporting areas.

Species at risk may be listed for a number of reasons including declines in population size, high sensitivity to human activity, small spatial ranges, or a high probability of extinction (COSEWIC 2021). Species can be designated as Endangered, Threatened, Special Concern, Data Deficient or Not at Risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) after evaluation of the information available for them. However, only those species listed on Schedule 1 (the official federal list of wildlife species at risk), receive legal protection under the *Species at Risk Act (2002)*. For the SOFFH report, Schedule 1 fish, mussel, and aquatic mollusc SAR richness were summarized for each assessment unit. The presence of SAR can be an indicator of good quality habitats and knowledge of the patterns in SAR biodiversity can inform conservation planning and management actions.

Aquatic invasive species are fish, invertebrate or plant species that have been introduced into a new aquatic environment, outside of their natural range. Species listed as AIS have known negative effects on native biota (DFO 2019). These effects can materialize because the AIS populations may not have any natural predators, which allows their populations to establish, grow, and spread quickly. They can outcompete and or prey on native species. AIS can also alter habitats to make them inhospitable for the native species (Gallardo et al. 2016). As a threat to native species and habitats, listed AIS richness has been included for each SOFFH reporting area.

Water Quality

Water quality is the chemical and physical characteristics of water. In streams and lakes, it is influenced by climate, geology of the watershed, flow regime and land use and can be affected by the discharge of substances in effluents associated with human activities. Water quality is a key habitat component and can be monitored to determine the health of aquatic ecosystems, condition of drinking water, suitability for swimming, and the extent of water pollution.

The water quality metrics included in the SOFFH report are: (1) conductivity, (2) total phosphorus, (3) chloride, (4) nitrates, (5) temperature, and (6) dissolved oxygen. Conductivity is a measure of the ability of water to pass an electric current and is affected by the number of concentrated ions such as alkalis, chlorides, sulfides, dissolved salts, and inorganic material in the water. Aquatic habitats tend to have relatively constant range of conductivity that, once established, can be used as a baseline for comparison with regular conductivity measurements. Changes in conductivity can be indicative of discharge or pollution that may make the ecosystem inhospitable for some species. For fishes, conductivity is associated with intercellular ion-transport mechanisms regulating osmoregulation and acid/base balance in freshwater organisms (Griffith 2014). Phosphorus is an essential nutrient in aquatic ecosystems influencing the growth of phytoplankton and macrophytes and the overall freshwater productivity (Caraco 1993). Too much phosphorus can lead to eutrophication and reduction of suitable habitat for many aquatic organisms. Chloride concentrations are typically low in freshwater ecosystems (Dugan et al. 2017), but elevated levels, such as those associated with the application of road salt in the reporting areas, can disrupt osmoregulation in aquatic organisms, which can lead to reductions in growth, survival, reproduction, and death. Like phosphorus, nitrates are essential plant nutrients, but excess amounts can accelerate eutrophication and change the suitability of habitats for aquatic plants and animals. Temperature has been classified as a master variable in aquatic ecosystems because it influences the growth, survival, distribution, and phenology of many aquatic species (Caissie 2006). In Canada, warmwater thermal conditions can limit the biological processes of stream organisms and overall ecosystem productivity (Cushing and Allan 2001). Lastly, dissolved oxygen is used by all forms of aquatic life and low concentrations of dissolved oxygen in water can affect the suitability of the habitat for fishes.

Connectivity

Connectivity refers to the degree to which the landscape facilitates or impedes movement among resource patches. Connections between a waterway and its floodplain (lateral connectivity), and between that waterway and the waterways upstream and downstream (longitudinal connectivity) of it, influence how water, sediments, nutrients, carbon, and animals move through a river system. These connections are important to maintain the health of waterways (Fuller and Death 2018). Fragmentation of connectivity can disrupt the flow of energy and other resources within aquatic ecosystems, alter natural flow and water temperature regimes, block fish from accessing important habitat patches (e.g., spawning areas), and decrease ecosystem resilience by limiting immigration and gene flow. While natural barriers (e.g., waterfalls) and man-made structures may cause fragmentation of habitat, in certain situations, they are used by fishery managers as a management tool to impede movement of aquatic invasive species, prevent the spread of disease, prevent the release of contaminated sediment, or to protect populations of fish that may be susceptible to competition or introgression (Walter et al. 2021). In the AESA, several subpopulations of westslope cutthroat (*Oncorhynchus clarkii lewisi*) remain genetically pure primarily because of the barriers that impede upstream invasions by non-native species such as rainbow trout (The Alberta Westslope Cutthroat Trout Recovery Team 2013). In the LGLA, a number of dams block the migration of adult sea lampreys (*Petromyzon marinus*), which prevent them from accessing upstream spawning and rearing habitat. Although waterfalls are natural features that may impede connectivity, they have been included in the SOFFH report because they represent realized connectivity i.e., knowing their distributions informs the maximum connectivity possible within a watershed given natural and man-made barriers.

Connectivity metrics for the LGLA include the density of waterfalls, dams, and fishways, and the passability of those barriers. In addition, we quantify the density of crossings of aquatic systems by roads and railways within each assessment unit. This latter metric was included because previous studies suggest that there are 38 times more road crossings than dams within the Great Lakes basin, and that only 36% of crossings are fully passable to fish (Januchowski-Hartley et al. 2013). Connectivity in the AESA was assessed using the density of waterfalls, dams, and fishways, and the passability of those barriers as well as the Alberta Environment and Parks' (AEP) stream connectivity metric, and road and rail crossing density. Note: This assessment is not intended to identify natural or man-made barriers that should be removed to improve connectivity.

Land Use and Land Cover

The land use and land cover metrics included in this report are: (1) land use and land cover types in the reporting areas, (2) proportion of disturbed (non-natural i.e., built areas and cropland) cover within 30 m of waterbodies within the assessment units, (3) proportion of protected areas within the assessment units, and (4) road and rail density within the assessment units. The influence of land use and land cover on the biological and physical condition of fish and fish habitat is well documented (Klein 1979, Steedman 1988, Stanfield and

Kilgour 2013). Changes in stream hydrology, water quality, and temperature occur when landscapes are converted from forests and wetlands to agricultural and urban areas (Leopold 1968). Furthermore, roads increase human access and use of aquatic ecosystems, provides corridors for invasive species, and supports additional human development (Trombulak and Frissell 2000). The resulting physical and chemical alterations can affect biological assemblages, often in predictable ways (Vannote et al. 1980, Wang et al. 2003a,b, Frimpong et al. 2005). Many studies have demonstrated a threshold response in the relationship between biotic indicators and measures of land use and land cover in north temperate streams (Wang et al. 2003a, King et al. 2005, Stanfield and Kilgour 2006).

Riparian buffers provide significant benefits for fish and fish habitat. Trees and large shrubs can provide overhead cover with shade that helps to moderate water temperature. Woody vegetation provides leaf litter and other organic debris, which benefits aquatic invertebrates by providing habitat and food, while larger woody debris provides habitat (e.g., cover, nursery, spawning) for invertebrates and fishes. Vegetation within a riparian buffer can also slow the overland movement of water, reducing erosion and sediment inputs during flood events. Vegetation along waterbodies can also reduce the amount of nutrients entering the water.

Protected areas are permanently protected ecosystems and significant natural and cultural heritage elements within defined regions (Ontario Ministry of Environment, Conservation and Parks 2021). They include national, provincial, territorial parks, wildlife areas, and private land holdings that are managed to limit the impacts of human activities and stem the loss of biodiversity and ecosystem services, provide safe habitat for species, maintain ecological processes, and provide spaces for people to connect with nature. The level of protection and enforcement of protections vary among the different types of protected areas with some having more restrictions on human activities (e.g., hunting or development) than others. Although many protected areas within the reporting areas are terrestrial in nature, they often encompass or are connected to freshwater ecosystems and can confer some spillover benefits to those aquatic ecosystems (Chu et al. 2018, Lamothe et al. 2019). As such, the SOFFH report includes summaries of the proportion of protected areas within the assessment units.

Climate Change

Climate change is altering global hydrological cycles and warming some aquatic habitats. Regional and local effects include the alteration of flow and thermal regimes, changes in ice phenology, sediment dynamics, and nutrient fluxes. These habitat changes have cascading effects on the distribution, community dynamics, demography, phenology and evolution of many freshwater fish species (Lynch et al. 2016, Myers et al. 2017). Climate velocities and floodplain projections have been included as climate change metrics in the SOFFH report. Climate velocities are estimates of the instantaneous rate ($km \cdot yr^{-1}$) at which climate conditions are changing. They can be thought of as the speed at which climate is moving across the landscape and can be used to identify where historic or current climatic conditions are projected to be on the landscape under future climate scenarios (Loarie et al. 2009). Flow and flood regimes have also been changing with climate change, and extreme floods can negatively affect aquatic ecosystems and cause significant destruction of property and infrastructure (Talbot et al. 2018). However, flooding is also a fundamental environmental process in aquatic systems that enhances lateral connectivity within floodplains, recharges groundwater supplies and has positive effects on a number of ecosystem services (Talbot et al. 2018). In this document, we report on the estimated extent, depth and volume of a 1 in 100-year flood under current and future climatic conditions, to estimate the impacts of climatic changes on flood dynamics.

Table 3. Indicators and metrics for State of Fish and Fish Habitat reporting in the Lower Great Lakes Area (LGLA) and AESA (Alberta East Slopes Area) of Ontario and Prairies Region (see Appendix A for data sources).

Indicator	LGLA metric	AESA metric
Biodiversity	Fish species richness	Fish species richness
	EPT index	EPT index
	Species at risk richness	Species at risk richness
	Aquatic invasive species richness	Aquatic invasive species richness
	Chloride	Chloride
	Conductivity	Conductivity
Water Quality	Dissolved oxygen	Dissolved oxygen
	Nitrates	Temperature
	Total phosphorus	-
	Temperature	-
Connectivity	Waterfall density	Waterfall density
	Dam density	Dam density
	Fishway density	Fishway density
	Barrier passability	Barrier passability
	Stream crossing density	Stream crossing density
	-	Stream connectivity metric
Land use and land cover	Land use and land cover types	Land use and land cover types
	Riparian cover	Riparian cover
	Protected areas	Protected areas
	Road density	Road density
Climate change	Bioclimatic velocity	Bioclimatic velocity
	Projected flood area/height	Projected flood area/height

DATASETS, ANALYSES, AND THRESHOLDS

The assessment units (i.e., the spatial scale at which metric data were summarized) were quaternary watersheds and nearshore regions in the LGLA (n = 195) and Hydrologic Unit Code (HUC 8) watersheds in the AESA (n = 107). These scales were selected to be consistent with provincial watershed reporting and management standards. Jurisdictional scans and participant knowledge from Part 1 of the State of Fish and Fish Habitat CSAS (DFO 2022a) were used to identify data sources for each of the metrics. Readily available data were then compiled for each reporting area.

In many cases, data for a given metric were only available for a small number of sampling sites within each assessment unit, which may or may not represent the true state of the metric across all aquatic habitats within the assessment unit. Furthermore, some datasets only included samples collected over short time-periods or collected during certain seasons (e.g., summer). We highlight specific challenges associated with uncertainty and representativeness of data further on in this section, as well as within the 'Discussion' section of this report.

Unless otherwise indicated, the same methods were used to analyze the metric data from each reporting area. To report on the current state of fish and fish habitat, data for many of the metrics were filtered to recent time periods e.g., 2015–2020. Available thresholds and basic classification schemes were applied for different metrics, when appropriate. Further guidance in developing thresholds and classification schemes is available in Dey and Chu (2023).

Biodiversity

Fish species distribution data for LGLA and AESA were acquired from several data sources (Appendix A) including e.g., an Ontario stream fish database (Smith et al. 2023) and a national fish distribution dataset (Anas and Mandrak 2022). Fish species richness (the total number of species per watershed) were summarized for each assessment unit using zonal statistics in ArcGIS® (version 10.2 ESRI Redlands, California). Richness values for the assessment units were then categorized using Jenks natural breaks. Jenks natural breaks is a classification approach that maximizes among group variance while minimizing within group variance (Jenks 1967).

The quality of the fish species data was assessed using species accumulation curves (Colwell and Coddington 1994). Cumulative species richness was plotted against the number of sites sampled. Assessment units for which the species curves reached an asymptote were classified as having *high* data quality because enough sites were sampled to be confident that complete or near complete fish community was represented in the data. Curves that did not reach an asymptote were assigned *low* data quality. The species accumulation curves were fitted in R using the function specaccum in the package vegan (Oksanen et al. 2019).

The presence of mussel and fish SARA Schedule 1 were acquired from a DFO database for the LGLA, and SAR fishes and aquatic molluscs were acquired from the FWMIS for the AESA (Appendix A). The SAR distribution data were spatially joined to the assessment units in each reporting area, and SAR richness (the number of species per assessment unit) was summarized using zonal statistics. The richness values were classified using Jenks natural breaks. Lists of species designated as Special Concern, Threatened or Endangered by COSEWIC were also generated for LGLA and AESA, but generation of the distribution maps for each species, and subsequently summaries by reporting area, were beyond the scope of this report. Inclusion of the proportional extent of the assessment units designated as critical habitat was also considered for this report. However, interpretation of these proportional extents is complicated by the fact that only Endangered or Threatened species can have such designation made and not all Endangered or Threatened species have critical habitats designated. Therefore, the proportions of the assessment units with critical habitat were not included in this report.

Invasive fishes in this report (Appendix B and C), are those fishes listed federally and or provincially as AIS due to the detrimental effects they have on aquatic ecosystems. Fish AIS distribution data were acquired from the Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry (NDMNRF) AIS team for LGLA and Alberta Environment and Parks (AEP), Government of Alberta AIS Alberta team. The LGLA list included species data available via EDDMAPs Ontario and General Regulation of *Ontario Invasive Species Act*. The list for Alberta included the prohibited species found under the Fisheries (Alberta) Act. The information provided was cross-referenced against the national fish species list (Anas and Mandrak 2022) and DFO's fish AIS list. Fish AIS distributions were then mapped onto each assessment unit, and the number of fish AIS in each assessment unit was summarized using zonal statistics. Fish AIS richness was categorized using Jenks natural breaks.

The fish communities in each assessment unit were summarized as the percentage native, percentage non-native, percentage SAR, and percentage AIS to provide more detailed understanding of the composition of each community in each assessment unit. Native species richness included both SAR and non-SAR species. Non-native species are either introduced outside their native range in North America or native to another continent but introduced and established within an assessment unit and not listed as AIS. The national atlas of fish species distributions (Anas and Mandrak 2022) was cross-referenced with the fish distribution data to determine whether a species is considered native or non-native within each assessment unit.

Benthic macroinvertebrate data were acquired from the Ontario Benthic Biomonitoring Network (OBBN) for LGLA and the Canadian Aquatic Biomonitoring Network (CABIN) for the AESA (Appendix A). The EPT index was calculated by summing the number of distinct taxa within these three pollution-sensitive orders and expressing as a percentage of the total. Because many assessment units (in both LGLA and AESA) had few samples (and therefore uncertainty about the expected EPT within each assessment unit was high) and site-level habitat conditions influence EPT, we present the EPT index data as site-level summaries rather than summarizing within each assessment unit. EPT index was categorized by 5 and 10% increments.

Water quality

Data from the Ontario Provincial Water Quality Monitoring Network (PWQMN; MECP, Great Lakes DataStream), and Great Lakes Nearshore water chemistry (MECP) were used to quantify the concentrations of chloride, conductivity, nitrates, total phosphorus, dissolved oxygen, and water temperatures in rivers, lakes, and nearshore regions of the LGLA (Appendix A). Data from AEP's Long Term River Station Data, Lake Water Quality Data, and Tributary Monitoring Network (Appendix A) were used to quantify the concentrations of chloride, conductivity, dissolved oxygen, and water temperature in AESA rivers and lakes. The data included sampled site location, date, and measured metric value. Data for each metric were not available at every sampled site. The available water chemistry data were filtered to the 2015-2020 (inclusive; 6-year period) to reflect the current state of water quality. They were also filtered to measurements available between April and November because many stations lacked winter data. To achieve a sufficient power to detect change in the water quality metrics (i.e., conventionally set at an 80% likelihood of detecting a 50% change; Cohen 1988, Lester et al. 2021), assessment units would require a sample size of at least 25 sites. None of the assessment units in either AESA or LGLA met this threshold therefore, we present these data as site level, rather than assessment unit level summaries. To address uncertainty within a site, stations with a minimum of 10 samples over the 5-year period were included in further analyses. Median values were calculated for the water chemistry variables. The median water chemistry values were compared to existing environmental guidelines for the protection of aquatic life (Table 4). The water chemistry results were mapped and also summarized as the proportion of sites consistent (or inconsistent) with the protection of aquatic life in the LGLA or AESA. The median values were classified using Jenks natural breaks with the inclusion of the environmental guidelines values as one of the breaks between classes. It is noted that the threshold values represent the upper tolerances for aquatic life, with the exception of the threshold for dissolved oxygen, which is a lower limit. However, in AESA and LGLA there are also regionally-specific lower and upper limits that are not well described and should be considered for future SOFFH reporting. For example, while very high values of conductivity are thought to be problematic for freshwater ecosystems, in AESA conductivity can also be sufficiently low to limit fish growth because of an inverted-U shaped relationship between conductivity and productivity (Knaepkens et al. 2002, Zhang et al. 2019). Future reports should explore the development and application of habitat suitability curves that relate the water chemistry and thermal conditions to the fish species inhabiting LGLA and AESA. Other water chemistry parameters known to be important in aquatic ecosystems such as total dissolved solids, total suspended solids, and selenium were not readily available for this report, but data for them should be compiled and summarized in the future.

It was not possible to calculate common water temperature metrics such as Maximum Weekly Average Temperature (MWAT), rate of change or trimean weekly maximum temperature (Baldwin 1957, Mohseni et al. 1998, Moore et al. 2013) for either reporting area because the temperature data that were readily available are measured at monthly intervals. Continuous data (e.g., hourly) do exist for some sites (e.g., stream temperature monitoring being conducted by Trout Unlimited in AESA, and conservation authorities in LGLA (Credit Valley Conservation), but the compilation of such datasets from multiple agencies is beyond the scope of this SOFFH report. However, such efforts should be pursued if there are future iterations of SOFFH. Average monthly values during July and August (period of warmest water temperatures in both reporting areas) were calculated from the temperature data and reported as the *average July-August temperature* for each site. Sites that were measured at least 8 times during July and August of 2015–2020 were included in the analyses. Thermal guilds for Canadian fishes have been defined as coldwater (species that prefer < 19°C in summer); coolwater (prefer 19–25°C), and warmwater (prefer > 25°C) (Coker et al. 2001), but these categories may not be appropriate for the AESA where most species are adapted to cold alpine streams and lakes. Therefore, the average July-August temperatures reported here show the variation in thermal conditions across the reporting areas rather than species-specific or guild-specific thermal habitats. As with the water chemistry variables, future research is needed to define the upper and lower thermal tolerances of fishes and apply them to define the amount of thermal habitat within LGLA and AESA.

Table 4. Water quality thresholds for the protection of aquatic life.

Water quality parameter	Threshold	Threshold source
Chloride	120 mg Cl·L^{-1}	Canadian Council of Ministers of the Environment 1999
Conductivity	500 µS·cm^{-1}	Carr and Rickwood 2008
Dissolved oxygen	6 mg·L^{-1}	Canadian Council of Ministers of the Environment 1999
Nitrates	3.0 mg NO3-N·L^{-1}	Canadian Council of Ministers of the Environment 1999
Total phosphorus	0.03 mg·L^{-1}	Canadian Council of Ministers of the Environment 1999

Connectivity

Connectivity metrics for the LGLA and AESA include the density of waterfalls, dams, and fishways, and number of barriers that are passable, impassable or have unknown passability. These metrics were summarized from the barrier information available in the Canadian Aquatic Barrier Database (CABD; Appendix A). The CABD is one of the most up-to-date syntheses of barriers across Canada. Within CABD, waterfalls are natural potential barriers to fish movement. Although waterfalls are natural features, they have been included in this report because their presence can affect the maximum connectivity possible within each assessment unit. Dams are defined as: small (i.e., having a height of < 5 m), medium (i.e., having a height between 5 and 15 m), or large (i.e., height ≥ 15 m or a height between 5 and 15 m that impounds more than 3 million m^3). Fishways are structures that are constructed to facilitate the passage of fish up and or downstream (CWF). Densities (number per 10 km river length) were calculated as the number of waterfalls, dams, or fishways divided by the total length of rivers and streams within each assessment unit ×10. The densities were classified using Jenks natural breaks. The total number of dams and waterfalls that are barriers or partial barriers to fish movement and the number of with unknown passage were summarized for each reporting area.

We also analyzed the density of road and rail crossings of watercourses (rivers and streams) within both reporting areas. The CABD dataset described above does not include crossings (e.g., culverts) as barriers, however previous analyses have suggested that many crossings may not be fully passable by fishes. Within each assessment unit, we calculated the number of road and rail crossings of watercourses by intersecting the hydrological layer with the road and rail layers in each reporting area. These results are presented as the number of stream crossings per 10 km of watercourses within each assessment unit and are classified using Jenks natural breaks.

Finally, connectivity in AESA was also assessed using AEP's stream connectivity indicator, where connectivity ranges from 100%; stream network is fully connected, to 0%; completely disconnected (AEP 2022). The stream connectivity indicator is based on a graph-theory method proposed by Diebel et al. 2015, and measures functional connectivity while accounting for habitat type and species dispersal limitations. AEP's application of this method includes using a culvert passability model in conjunction with data on linear features (road and rail), dams and other barriers, and the provincial stream network. Importantly, this metric focuses on the impact of artificial barriers on connectivity, such that areas with high stream connectivity indicator values may still contain natural barriers that impede fish movement. Stream connectivity indicator values for each assessment unit from 2018 (the most recent available data) were used and summarized for each assessment unit.

Land use and land cover

Land use/land cover (LULC) data were obtained from ESA Sentinel-2 imagery at 10 m resolution. The imagery is updated annually and results from Impact Observatory's deep learning AI land classification model, which uses a training dataset of billions of human-labeled image pixels developed by the National Geographic Society (Karra et al. 2021). Ten classes of LULC predictions are generated by: water, trees, flooded vegetation, crops, built area, bare ground, snow/ice, clouds, and rangeland. 'Water' includes areas of permanent water presence such as lakes, rivers and ponds. Wet areas with rock outcropping or significant vegetation generally do not get defined as water. Significant groups of dense vegetation 15 feet or higher are classified as 'trees'. 'Flooded vegetation' areas are indicative of wetlands. 'Crops' refers to active or fallow human-planted plots of cereals, grasses, etc. that are not at tree height. Any large uniform and impervious surfaces were categorized as 'Built Area', including major road and rail networks and dense metropolitan areas. 'Bare ground' refers to any areas with little to no vegetation annually, such as deserts, dried lake beds and mines. Large homogenous areas of permanent snow and/or ice are classified as 'snow/ice' and generally only appear at the highest latitudes. The 'Rangeland' category is used for open areas with consistent grasses where human planting is not obvious. Lastly, areas where no land cover information was available due to persistent cloud cover appear as 'clouds'. Overall accuracy of the classification is 85%, with water, tree, crops and built area classifications performing particularly well (Karra et al. 2021). LULC types were mapped across the LGLA and AESA.

In addition, the density of roads within each assessment unit was quantified using provincial and national road network layers (Appendix A). These densities were calculated because although roads represent a small proportion of land cover in most areas, they can have wide ranging ecological effects including acting as predictors of future land use change, and they can increase access to fisheries resources and the likelihood of exploitation (Forman and Alexander 1998, Hunt et al. 2011).

Watercourse (rivers and streams) and the LULC data were spatially analyzed to determine the state of riparian zones within the reporting areas. Vegetated riparian zones at least 30 m wide on either side of watercourses and along at least 75% of the extent of a watercourse have been recommended for the provision and protection of aquatic habitat (Environment Canada 2013). For this report, we considered the percentage of the 30 m buffer surrounding each watercourse that was composed of natural (trees, flooded vegetation, bare ground, snow/ice and rangeland) versus disturbed (built area, crops) land cover types. The Sentinel-2 dataset was selected for both LGLA and AESA because the data coverage was complete for all watersheds. Pixels labelled as trees, flooded vegetation, bare ground, snow/ice and rangeland were considered natural land cover, whereas pixels labelled as built areas and crops were considered disturbed land cover. Areas covered by clouds were removed from the calculation. Riparian coverage was classified as < 25, 25–50%, 50–75% and > 75% natural cover, with the last category being the recommended threshold for the provision and protection of aquatic habitat.

National, provincial, and private protected lands were acquired from the Canadian Protected and Conserved Area Database (Appendix A). These data include protected areas, as defined by Canada Target 1 Accounting for Protected and Other Conserved Areas, as well as other effective area-based conservation measures (OECMs). The protected areas included federal and provincial parks, conservation reserves, wilderness areas as well as parcels of protected areas held by non-governmental organizations. The different types of protected areas and OECMs were summarized within each reporting area because the level of protection varies among them. The proportion of land protected within the quaternary watersheds and nearshore areas of the LGLA, and percentage of land protected within the HUC 8 watersheds of the AESA were summarized using zonal statistics. The percentages were classified as 0, 2, 5, 10, 17, 30, and >50% so it was easy to identify watersheds with no protected areas, and those meeting the 17% Aichi and 30% post-2020 biodiversity targets set out by the Convention on Biological Diversity and High Ambition Coalition for Nature and People (UN-CBD 2010, ECCC 2021).

Climate change

Climate change metrics included in the report are forward and backward bioclimatic velocities and floodplain areas and heights. For both metrics, projected changes in the 2050s were reported because this is the time horizon often used for conservation and management planning (Pers. Comm. J. Gleeson, Senior Climate Change Policy Advisor, NDMNRF). Analyses of both metrics were based on predictions made using global climate models that are subject to considerable and multisource uncertainty, including uncertainty in emission scenarios, uncertainty in the structure and parametrization of models, and the internal (process) variation in the global climate system (Zhang and Chen 2021). Forward and backward bioclimatic velocities for the ensemble Coupled Model Intercomparison Project Phase 5 (CMIP5) and emissions scenarios projected for the Representative Concentration Pathway (RCP) 4.5 (moderate emissions) and 8.5 (high emissions) in the 2050s were acquired from the Adaptwest climate platform (Adaptwest Project 2015, Carroll et al. 2015, Hamann et al. 2015). Forward velocities represent exposure to climate change and can be thought of as the speed at which organisms will have to migrate to maintain their climatic conditions. Backward velocities represent the minimum distance, given the projected future conditions at a site, that an organism would have to migrate from multiple sites to colonize that site (Carroll et al. 2015, Hamann et al. 2015). The velocities included in this document are the change in bioclimatic conditions from the 1981-2010 climate normals period to the projected 2050s time period. Bioclimatic velocities that would reflect climatic changes in recent years e.g., change between 1981 and 2010 or between 1991 and 2020, were not readily available. The velocities are based on 11 climatic variables, such as mean annual temperature (°C), mean annual precipitation (mm), degree-days above 5°C (growing degree days), the number of frost-free days, Hargreave's reference evaporation, and Hargreave's climatic moisture index that are known to influence terrestrial and aquatic ecosystems. The velocities were summarized for the assessment units in each reporting area using zonal statistics. The velocities were classified for LGLA by 1 $km \cdot yr^{-1}$ increments and 2 km·yr^{-1} increments for AESA to show the variation within the reporting areas and between RCP 4.5 and 8.5 emissions scenarios.

The extent and depth of a 1 in 100-year flood for recent conditions (1980-2019) and under two future climate scenarios (CMIP6 ensemble and Shared Socioeconomic Pathway (SSP) and RCP 4.5 and 8.5) for the 2050s were acquired from Floodmapviewer (Mohanty and Simonovic 2021, Simonovic et al. 2021). The flood maps were generated using the CaMa-Flood global hydrodynamic flood model, which uses inputs such as 100-year or 200-year run-off values, forecasted precipitation conditions, and river basin physical and topographic information to simulate floodplain inundation outputs such as river channel floodwater and overland floodwater water levels. For this report, we summarized the total area flooded, and corresponding heights (i.e., water depth) of those flooded areas for the recent time period and each emissions scenario. The differences in flood heights between the recent and projected SSP2 4.5 and SSP5 8.5 2050s scenarios were also mapped for each reporting area using raster calculator in ArcGIS.

RESULTS

LOWER GREAT LAKES AREA (LGLA)

Indicator: Biodiversity

Fish species richness in the LGLA varied over 10-fold, from 8 to 103 species per assessment unit (Figure 3; Appendix B), with a median value of 47 species. Species richness was generally higher in Lake Erie assessment units relative to Lake Ontario assessment units and was highest near the Greater Toronto Area, and Lake St. Clair. Species richness was lowest in the northern areas of the reporting area. Data quality varied across the reporting area with southern and central assessment units having greater data quality than assessment units in the northern part of the reporting area (Appendix D).

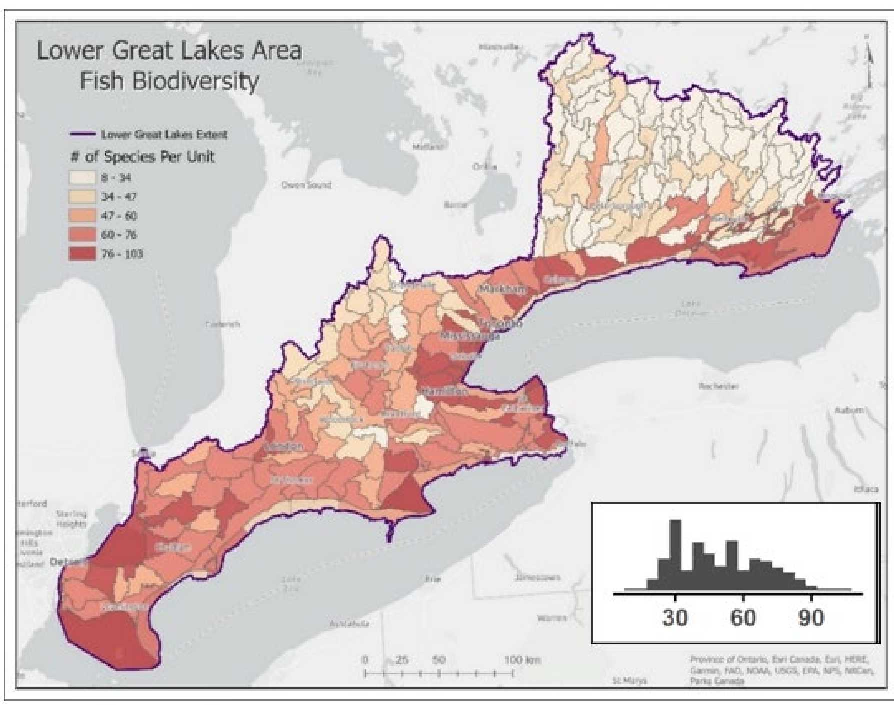

Figure 3. Number of fish species in each assessment unit within the LGLA.

EPT data were available for 1630 sites in the LGLA (Figure 4), many of which were concentrated around major urban centers. Median %EPT across all assessment units was 23.4%, with 75% of sites having EPT values below 54%.

Fish and mussel SAR richness in LGLA was highest in assessment units in the southwest of the reporting area and was generally higher in the Lake Erie watershed relative to the Lake Ontario watershed (Figure 5). Many assessment units in the northern part of the reporting area have no SAR, which contrasted with assessment units in the southwest that have up to 31 SAR. See Table 5 for a complete list of SAR in the LGLA.

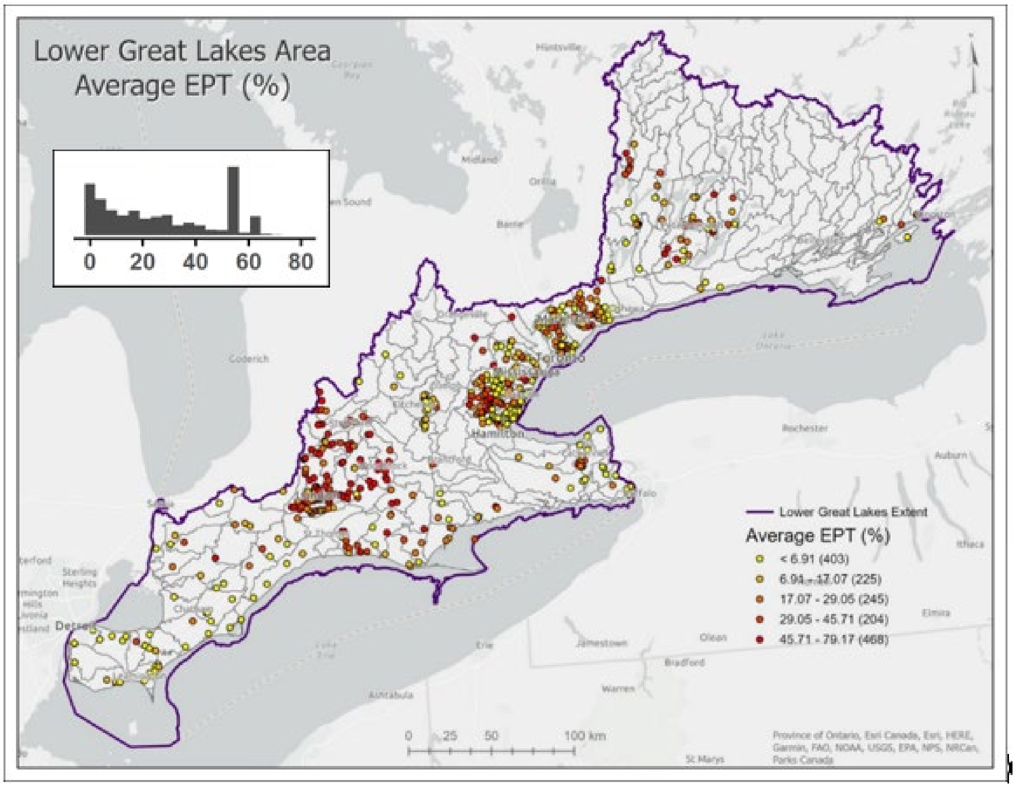

Figure 4. Site-level EPT index values within the LGLA.

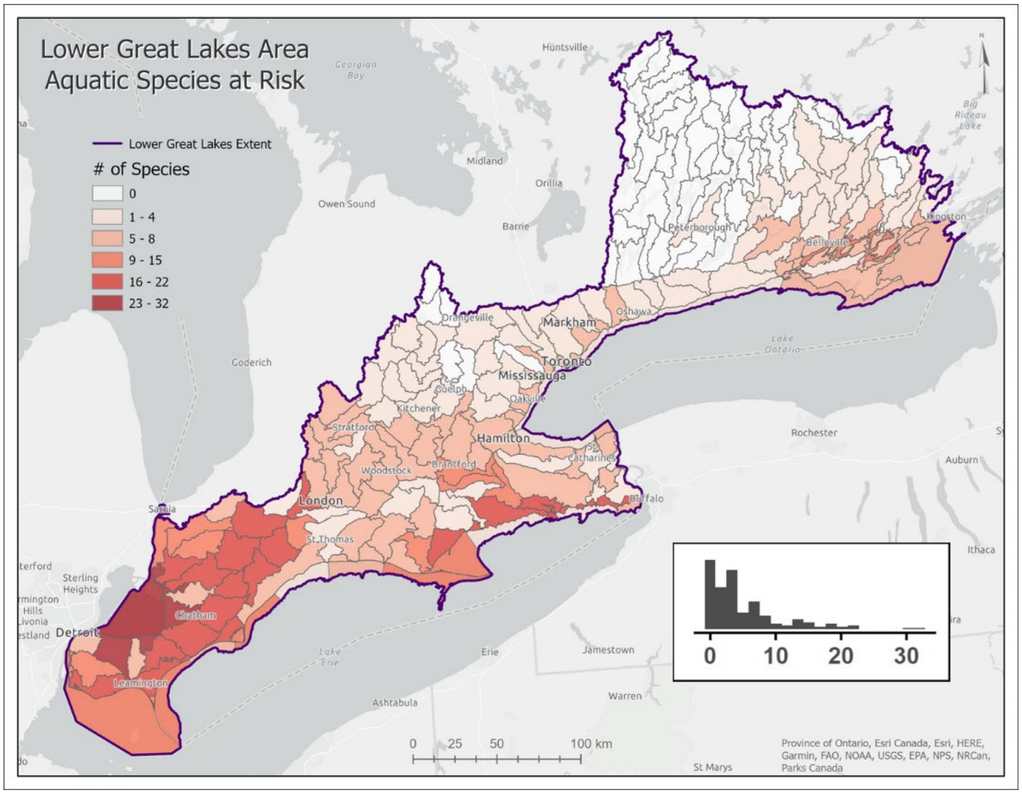

Figure 5. Number of fish and mussel species at risk in each assessment unit within the LGLA.

Table 5. Fish and mussel species at risk within the LGLA listed under SARA Schedule 1 and COSEWIC that are Extinct (Ext), Endangered (End), Extirpated (Exp), Special Concern (SpC) or Threatened (Thr).

Species (and population where designated)	**SARA status**	**COSEWIC status**
American Eel (*Anguilla rostrata*)	-	Thr
Atlantic Salmon (*Salmo salar*), Lake Ontario population	-	Ext
Black Redhorse (*Moxostoma duquesnei*)	Thr	Thr
Blackstripe Topminnow (*Fundulus notatus*)	SpC	SpC
Blue Walleye (*Sander vitreus glaucus*)	-	Ext
Bridle Shiner (*Notropis bifrenatus*)	SpC	SpC
Channel Darter (*Percina copelandi*), Lake Erie populations	End	End
Channel Darter (*Percina copelandi*), Lake Ontario populations	End	End
Deepwater Sculpin (*Myoxocephalus thompsonii*), Great Lakes - Western St. Lawrence populations	SpC	SpC
Eastern Sand Darter (*Ammocrypta pellucida*), Southwestern Lake population	Thr	Thr
Eastern Sand Darter (*Ammocrypta pellucida*), West Lake population	Thr	Thr
Grass Pickerel (*Esox americanus vermiculatus*)	SpC	SpC
Gravel Chub (*Erimystax x-punctatus*)	Exp	Exp
Lake Chubsucker (*Erimyzon sucetta*)	End	End
Lake Ontario Kiyi (*Coregonus kiyi orientalis*)	-	Ext
Lake Sturgeon (*Acipenser fulvescens*), Great Lakes - Upper St. Lawrence populations	-	Thr
Northern Brook Lamprey (*Ichthyomyzon fossor*), Great Lakes - Upper St. Lawrence populations	SpC	SpC
Northern Madtom (*Ichthyomyzon fossor*)	End	End
Northern Sunfish (*Lepomis peltastes*), Great Lakes – Upper St. Lawrence populations	SpC	SpC
Paddlefish (*Polyodon spathula*)	-	Exp
Pugnose Minnow (*Opsopoeodus emiliae*)	Thr	Thr
Pugnose Shiner (*Notropis anogenus*)	Thr	Thr
Pygmy Whitefish (*Prosopium coulterii*), Great Lakes - Upper St. Lawrence populations	-	Thr
Redside Dace (*Clinostomus elongatus*)	End	End
River Darter (*Percina shumardi*), Great Lakes - Upper St. Lawrence populations	-	End
River Redhorse (*Moxostoma carinatum*)	SpC	SpC
Shortnose Cisco (*Coregonus reighardi*)	End	End
Silver Chub (*Macrhybopsis storeriana*), Great Lakes - Upper St. Lawrence populations	End	End
Silver Lamprey (*Ichthyomyzon unicuspis*), Great Lakes - Upper St. Lawrence populations	SpC	SpC
Silver Shiner (*Notropis photogenis*)	Thr	Thr
Spotted Gar (*Lepisosteus oculatus*)	End	End
Spotted Sucker (*Minytrema melanops*)	SpC	SpC
Warmouth (*Lepomis gulosus*)	SpC	End
Eastern Pondmussel (*Ligumia nasuta*)	SpC	End
Fawnsfoot (*Truncilla donaciformis*)	End	End
Hickorynut (*Obovaria olivaria*)	End	End
Kidneyshell (*Ptychobranchus fasciolaris*)	End	End
Lilliput (*Toxolasma parvum*)	End	End
Mapleleaf (*Toxolasma parvum*), Great Lakes - Upper St. Lawrence population	SpC	SpC
Northern Riffleshell (*Epioblasma rangiana*)	End	End
Rainbow (*Villosa iris*)	SpC	SpC

Species (and population where designated)	SARA status	COSEWIC status
Rayed Bean (*Villosa fabalis*)	End	End
Round Hickorynut (*Obovaria subrotunda*)	End	End
Round Pigtoe (*Pleurobema sintoxia*)	End	End
Salamander Mussel (*Simpsonaias ambigua*)	End	End
Snuffbox (*Epioblasma triquetra*)	End	End
Threehorn Wartyback (*Obliquaria reflexa*)	Thr	Thr
Wavy-rayed Lampmussel (*Lampsilis fasciola*)	SpC	SpC

LGLA AIS richness was also high in assessment units in the southwest of the reporting area, with additional AIS hotspots being found in western Lake Ontario watersheds (Figure 6). Across the reporting area, 61% of assessment units contained at least one AIS with a maximum value of 6 AIS.

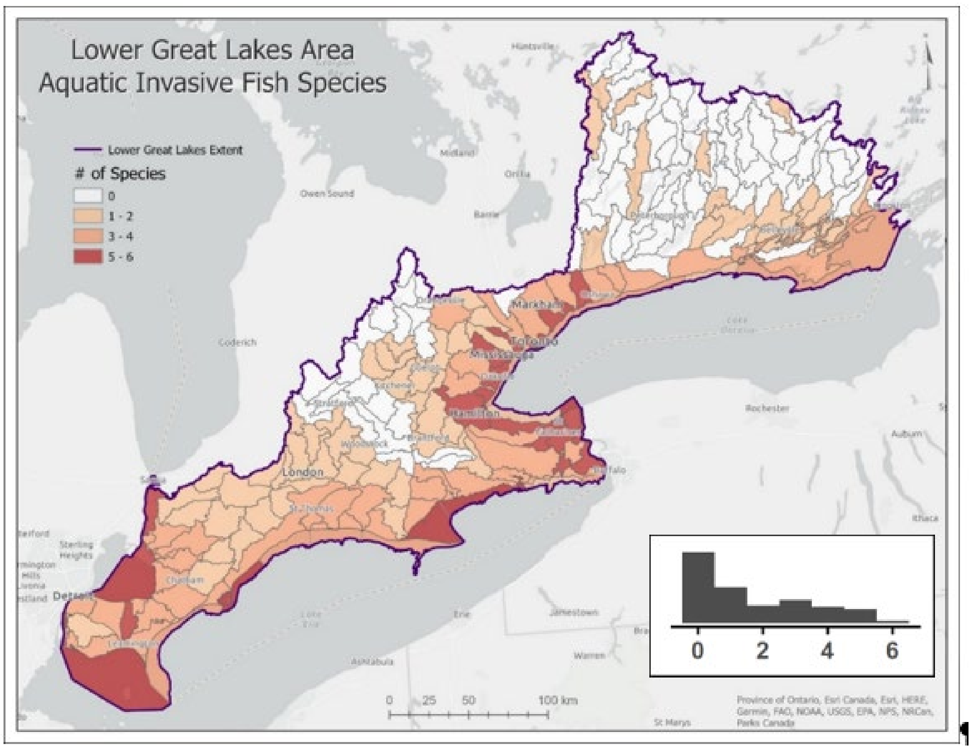

Figure 6. Number of aquatic invasive species within each assessment unit in the LGLA. AIS are listed in Appendix B.

Across assessment units, the percentage of fish species that were native had a median value of 93% (Figure 7), with higher percentages of native species found in the northern part of the reporting area relative to the southern and western parts of the reporting area. Across assessment units, invasive species composed a median of 2% of the fish community, while non-native fish species composed a median of 4% of the fish community. Southern and southwest assessment units tended to have higher percentages of non-native, invasive and species at risk, relative to northern assessment units (Figure 7).

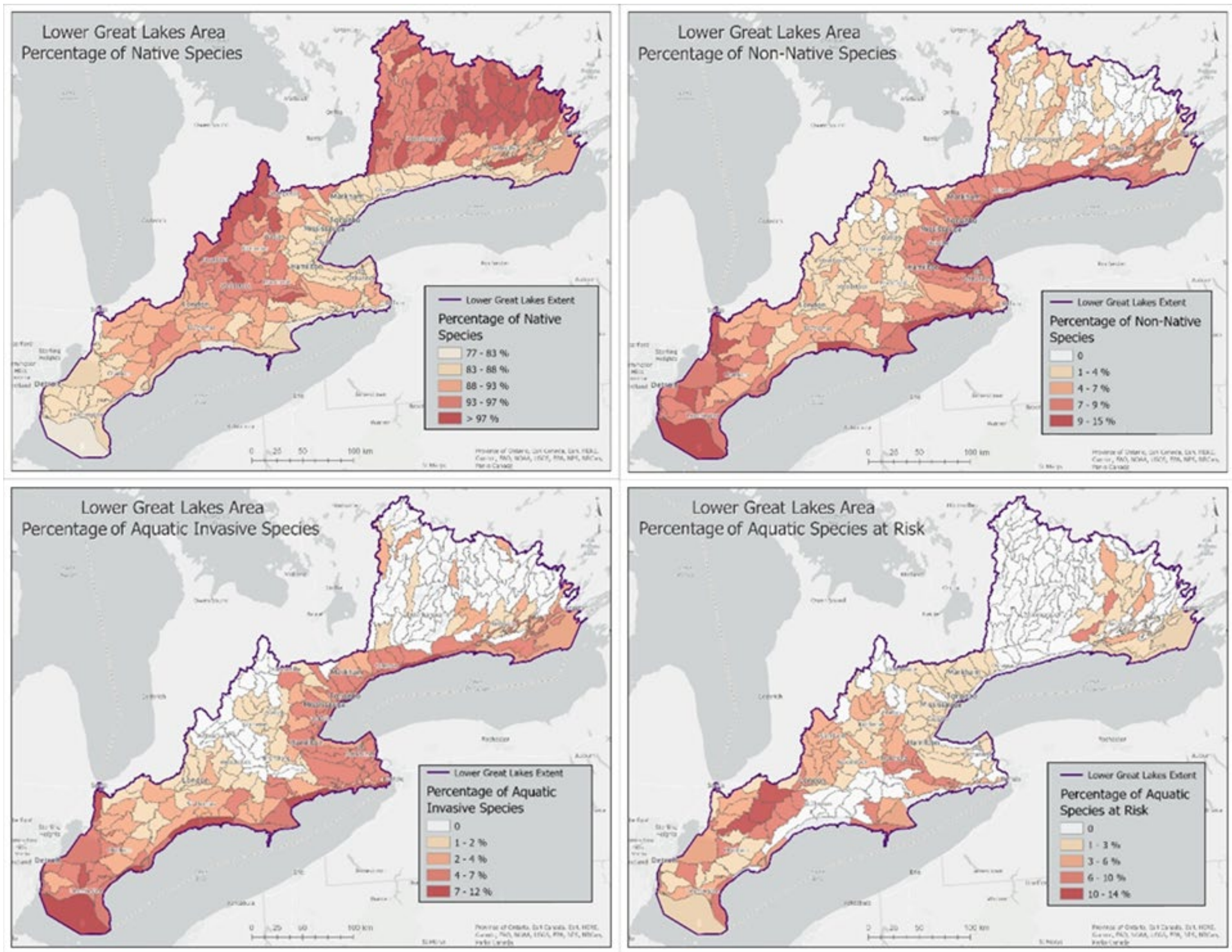

Figure 7. Percentage of the fish community within each assessment unit that is composed of native species (top left), non-native species (top right), fish species at risk (bottom left), and invasive species (bottom right).

Indicator: Water Quality

Chloride concentrations were measured at least 10 times at 362 sites between 2015-2020. The median concentrations ranged from 0.395 to 606 mg·L^{-1} (average; 79.287 mg·L^{-1}). Concentrations were greater in the western and central regions than in the eastern region of the LGLA, and concentrations around urban centers in the Greater Toronto Area and Windsor were the greatest (Figure 8). Approximately 81.8% of the sites had median chloride concentrations suitable for the protection of aquatic life (CCME 1999) (Figure 9).

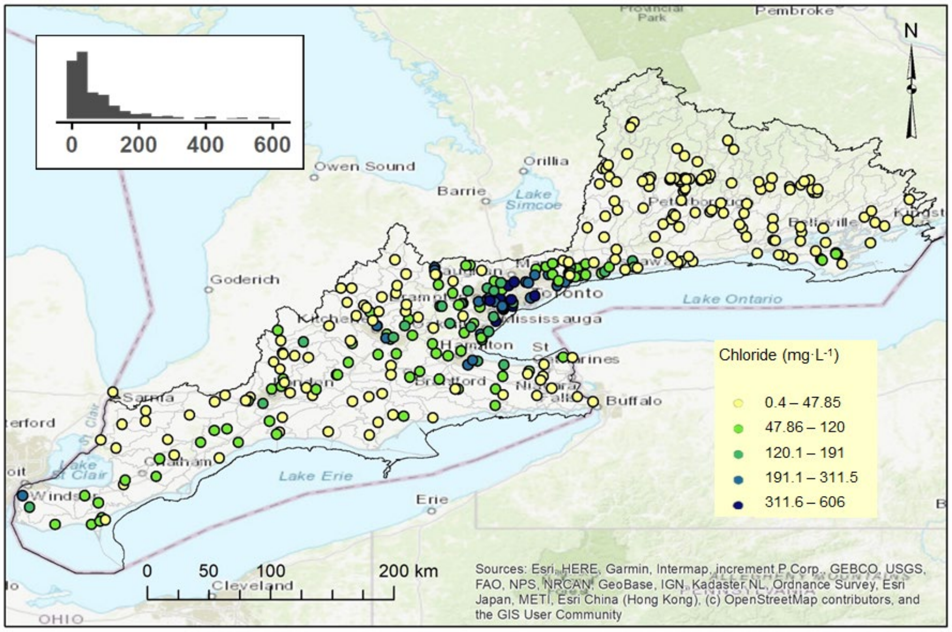

Figure 8. Median chloride concentrations (mg·L^{-1}) measured in rivers, lakes, and nearshore areas of the LGLA.

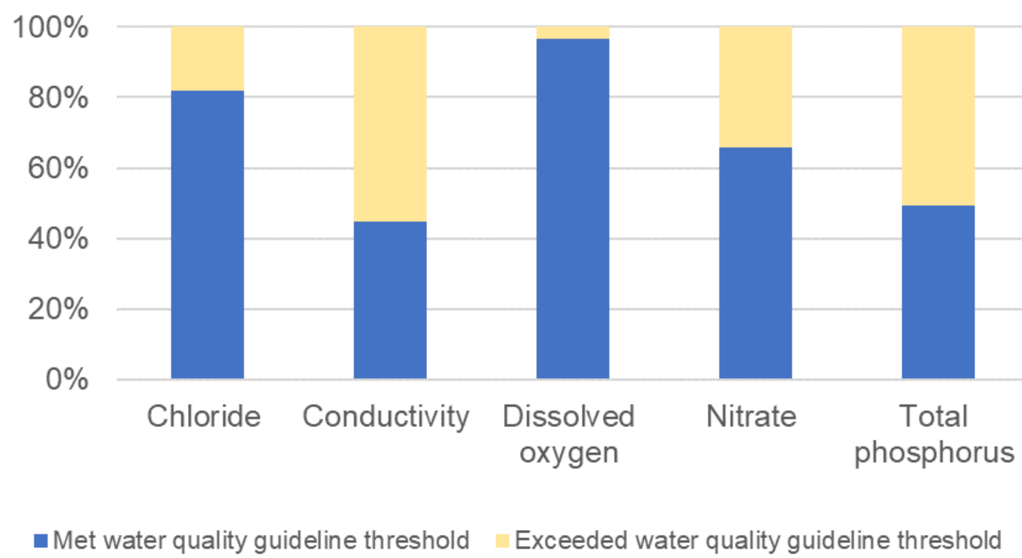

Figure 9. Percentage of water quality sampling sites in the LGLA that met or exceeded water quality guidelines.

Conductivity was measured at 346 sites throughout the LGLA and ranged from 7.95 to 2405 µS·cm^{-1} (average; 495.97 µS·cm^{-1}) (Figure 10). Sites in the eastern region had lower conductivity than those in the west. Most western sites exceeded the 500 µS·cm^{-1} recommended for healthy systems (Carr and Rickwood 2008) and across the LGLA, 52% of the sites exceeded this value (Figure 9). Dissolved oxygen (DO) was measured at 396 sites and ranged from 2.3 to 13.38 mg ·L^{-1} (average 9.64 mg·L^{-1}) (Figure 11). It was also the water chemistry metric most often consistent with thresholds for the protection of aquatic life, with

~97% of sites having DO values greater than the minimum 6 mg·L^{-1} required for the maintenance of healthy aquatic ecosystems (Figure 9). Concentrations that could impair aquatic life were recorded in Windsor and Prince Edward County in the southeastern region of the LGLA.

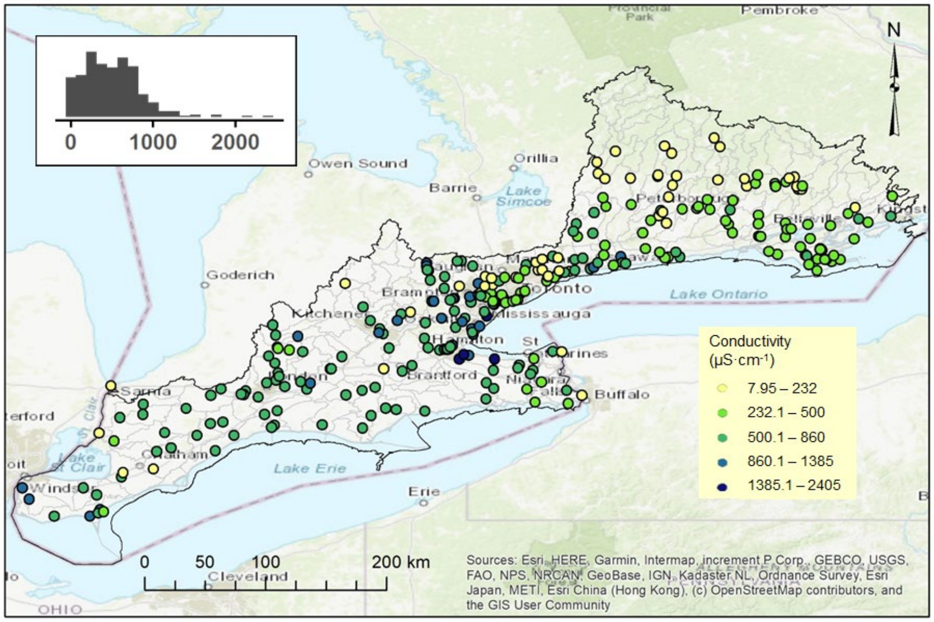

Figure 10. Median conductivity (µS·cm^{-1}) measured in rivers, lakes, and nearshore areas of the LGLA.

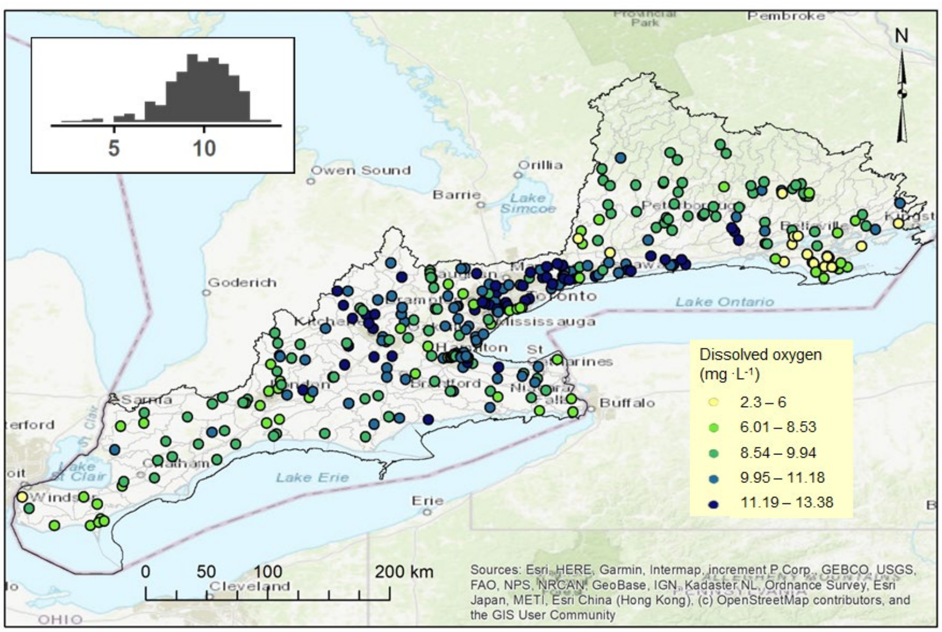

Figure 11. Median dissolved oxygen concentrations (mg·L^{-1}) measured in rivers, lakes, and nearshore areas of the LGLA.

Nitrate data were available for 105 sites and averaged 2.18 NO_3-N·L^{-1} across the LGLA with individual site concentrations ranging from 0.118 to 11.7 NO_3-N·L^{-1} (Figure 12). Concentrations were highest in the western region of the LGLA. Approximately 65.7% of the sites had nitrate concentrations less than the environmentally healthy 3 NO_3-N·L^{-1} threshold (Figure 9). Total phosphorus (TP) was measured at 307 sites and averaged 0.06 mg·L^{-1} (range; 0.005–2.38 mg·L^{-1}) (Figure 13). This average exceeded the 0.03 mg·L^{-1} environmental threshold with ~51% of the sites exceeding this value (Figure 9). Many of the sites with TP values that exceeded the threshold were in the southern region of the LGLA.

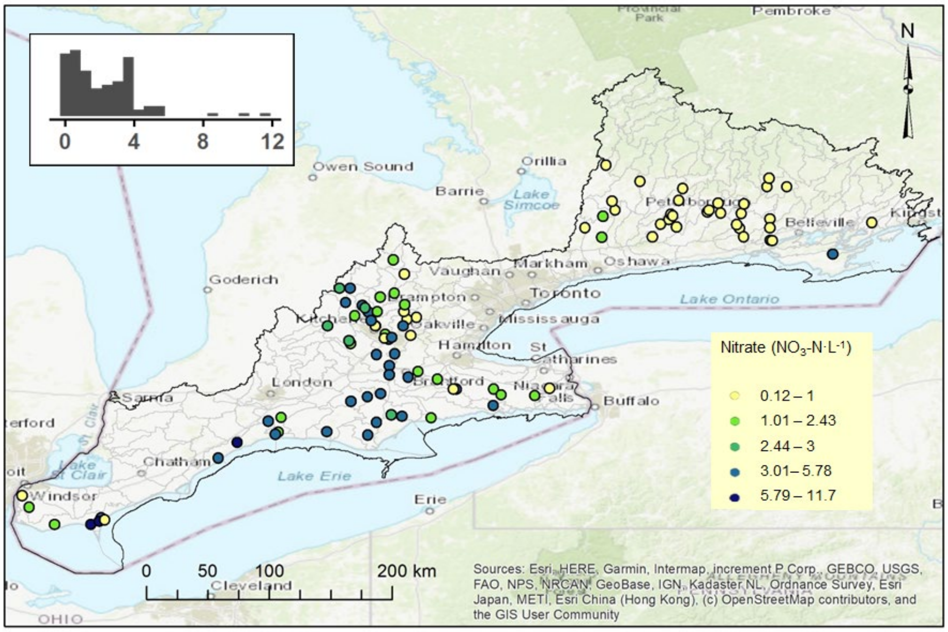

Figure 12. Median nitrate concentrations (NO_3-N·L^{-1}) measured in rivers, lakes, and nearshore areas of the LGLA.

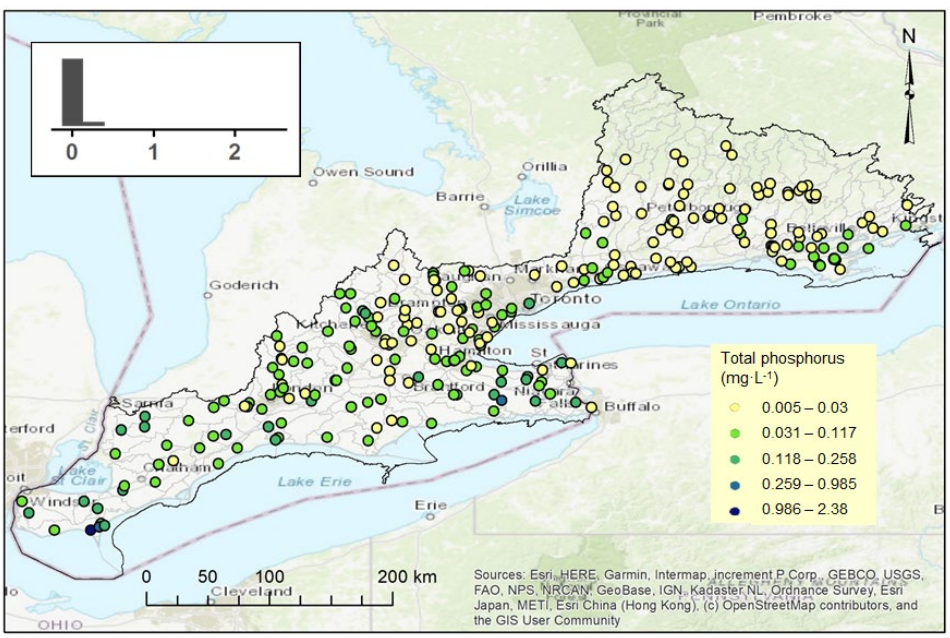

Figure 13. Median total phosphorus concentrations (mg·L^{-1}) measured in rivers, lakes, and nearshore areas of the LGLA.

Water temperatures were variable across the LGLA. Data on the summer (July-August) average temperature were available for 421 sites, with a median of 10 samples per site. Average summer temperatures ranged from 11.2°C to 26.1°C among sites, with 21.8 °C as the median average temperature value (Figure 14).

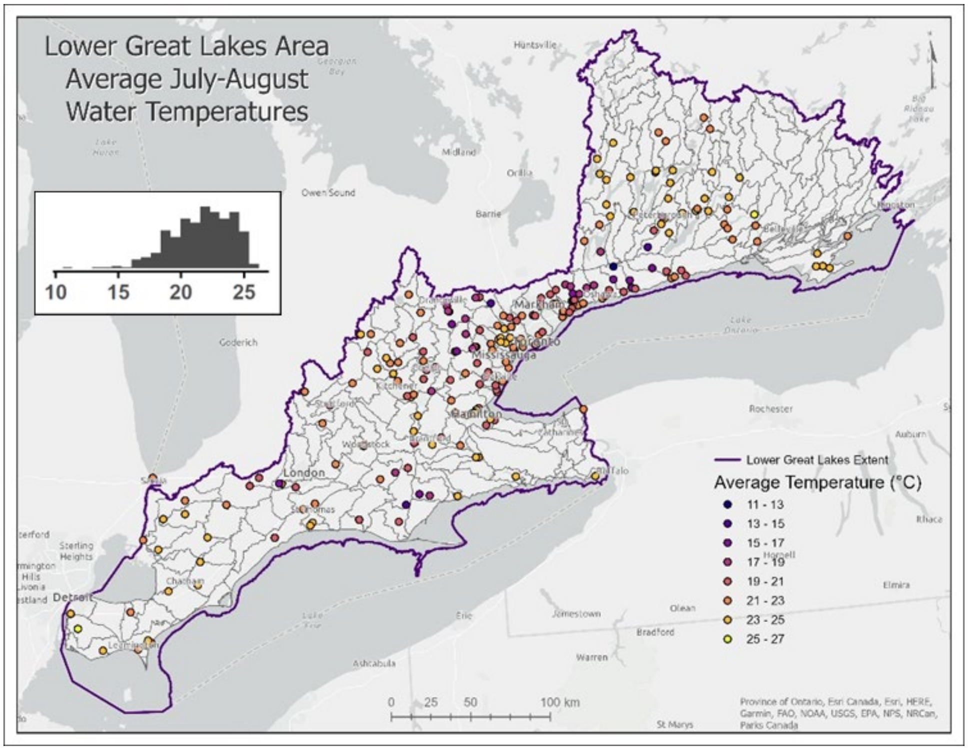

Figure 14. Average July-August water temperatures (°C) measured in rivers, lakes, and nearshore areas of the LGLA.

Indicator: Connectivity

Waterfall density within the LGLA varied from 0 to 0.278 waterfalls per 10 km of river length with most assessment units having no waterfalls (Figure 15). Waterfall density was high in assessment units near the Niagara escarpment (i.e., to the west and north of the Greater Toronto Area), and in the northern part of the reporting area. Waterfalls were predominantly found within the Lake Ontario watershed, with very few being found in the Lake Erie watershed.

Dam density was greater than waterfall density in 78% of assessment units, with a maximum value of nearly 4 dams per 10 km (Figure 16). Dam density was particularly high in the area of the Upper Grand and Upper Credit rivers, and in assessment units near the Kawartha Lakes, and was relatively lower in the southwest and northeast of the reporting area. Relatively few fishways were present in the reporting area, with most located in the assessment units near the Greater Toronto Area (Figure 17). Of the 2,452 barriers in the LGLA, 2,262 are known to be barriers to fish movement, 34 are partial barriers, and it is not known whether fish can move through 156 of the barriers (Figure 18).

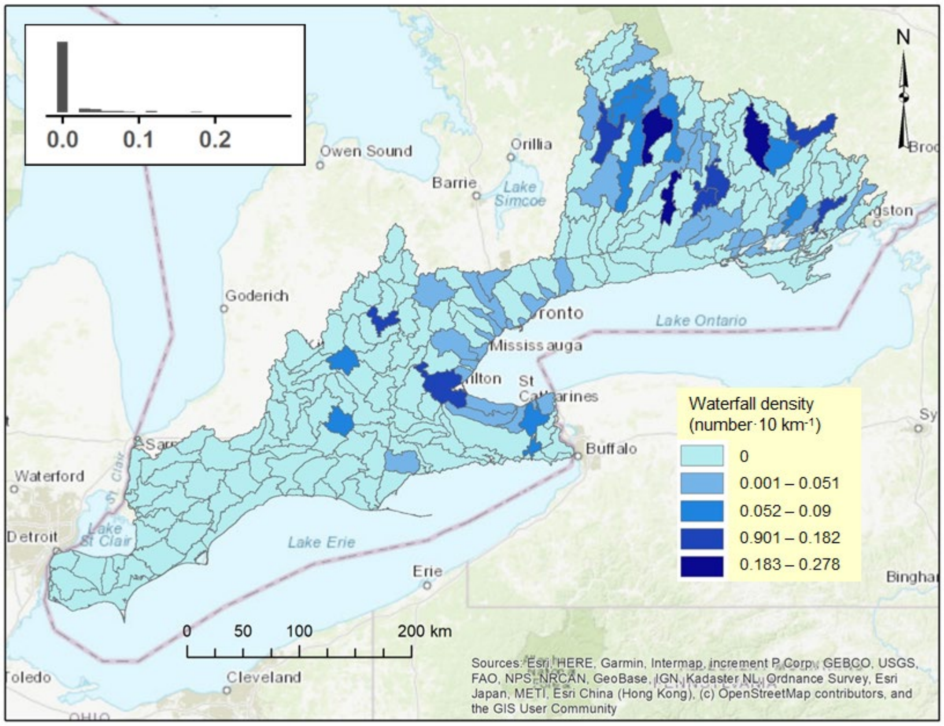

Figure 15. Density of waterfalls (number·10 km^{-1}) within the LGLA.

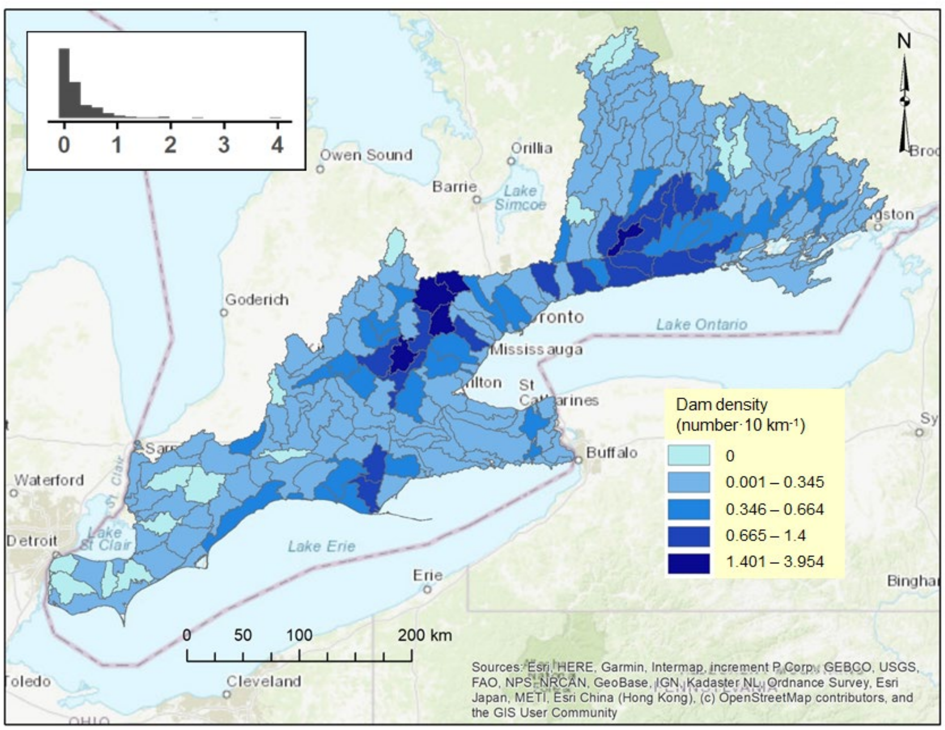

Figure 16. Density of dams (number·10 km^{-1}) within the LGLA.

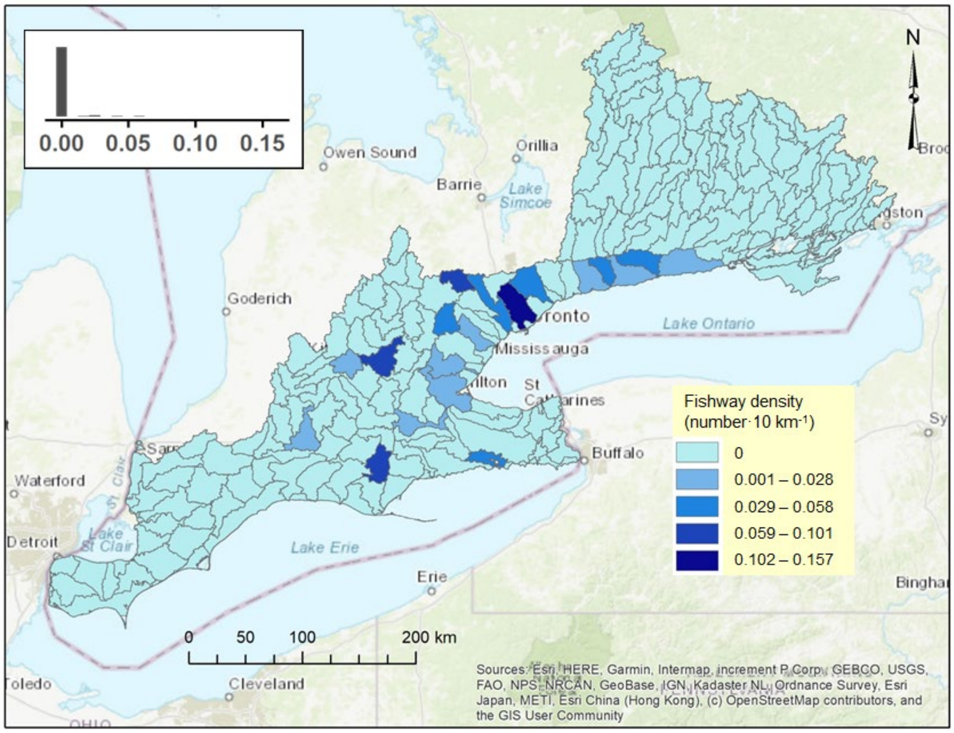

Figure 17. Density of fishways (number·10 km^{-1}) within the LGLA.

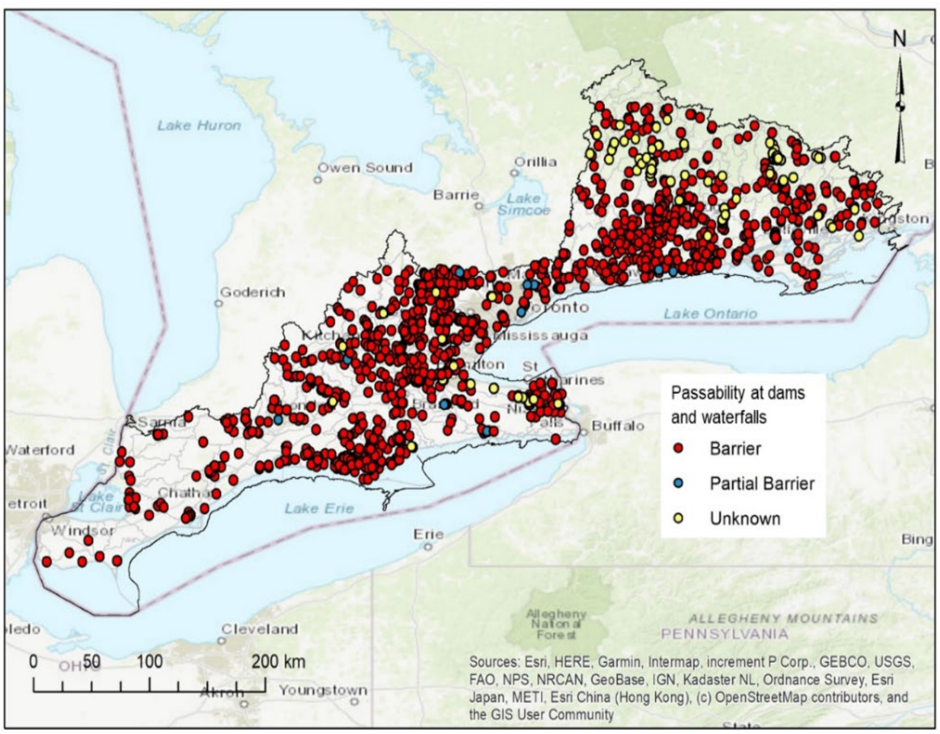

Figure 18. Passability of barriers (waterfalls and dams) within the LGLA.

The density of stream crossings varied between 0 and 30.3 crossings per 10 km stream length within the LGLA (Figure 19), with a median value of 5.3 crossings per 10 km stream length. 75% of assessment units within the LGLA had a crossing density greater than 3.7 per 10 km stream length.

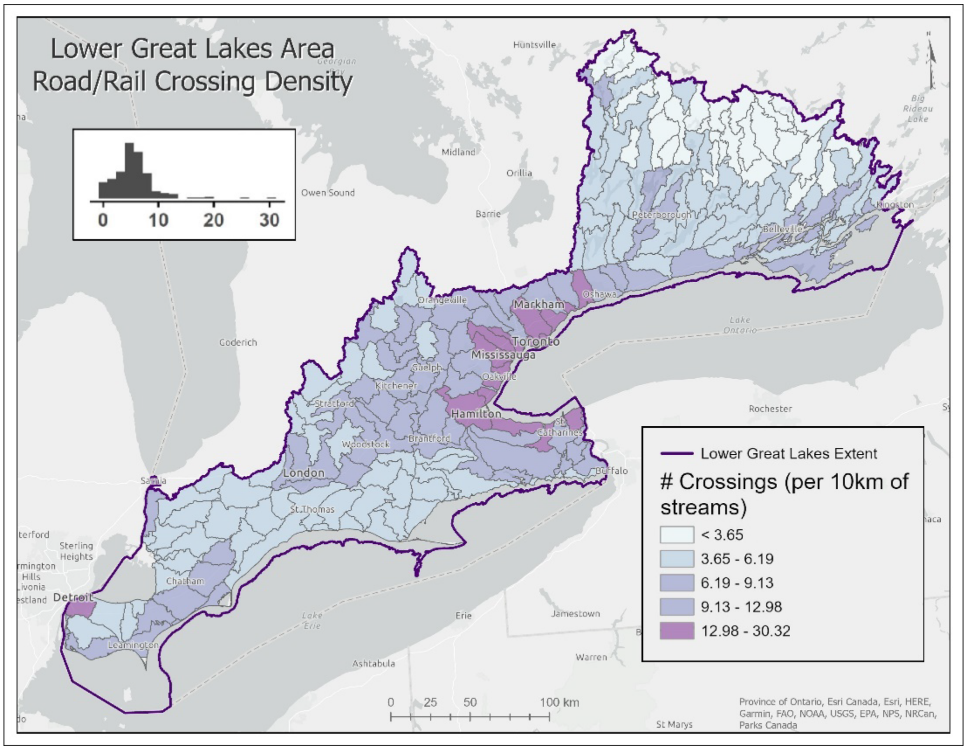

Figure 19. Density of road and rail stream crossings (number·10 km^{-1}) within the LGLA.

Indicator: Land use and land cover

Land use and land cover in the LGLA varied geographically (Figure 20). Northern portions of the Lake Ontario watershed were dominated by tree cover and flooded vegetation, but crop land was the dominant land cover type in the Lake Erie watershed. A significant amount of built area occurs within the reporting area associated with numerous large urban centers, including the Greater Toronto Area, Hamilton, Kitchener-Waterloo, London and Windsor.

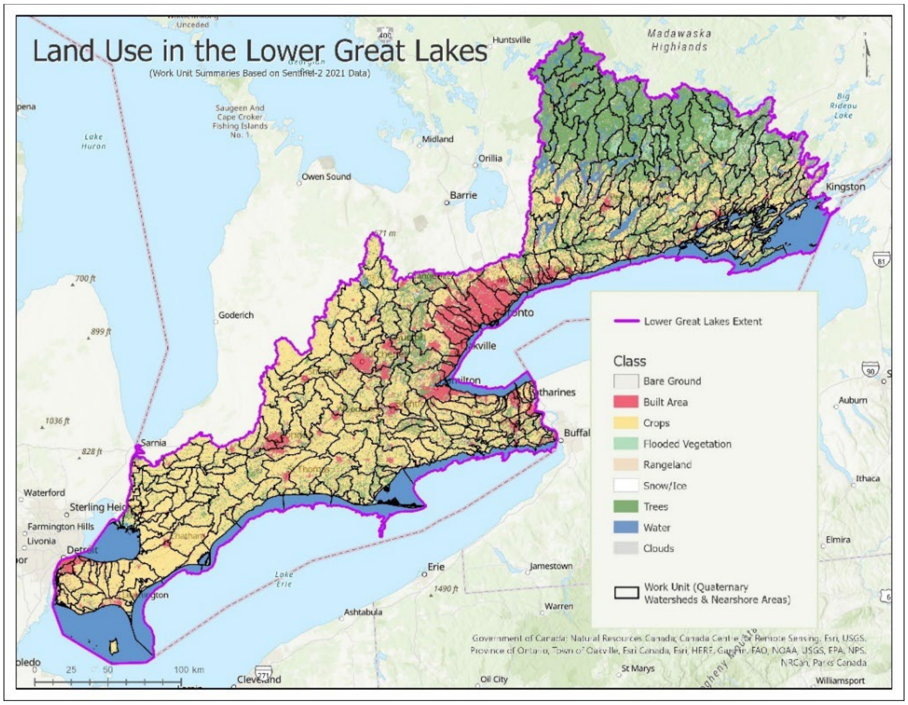

Figure 20. Land use and land cover in the LGLA.

Road density in LGLA ranged from 0.14 to 9.88 kms of road per km^2 assessment unit area, with a median value of 1.24 km/km^2 (Figure 21). Assessment units with the highest density of roads were found in western Lake Ontario and eastern Lake Erie areas.

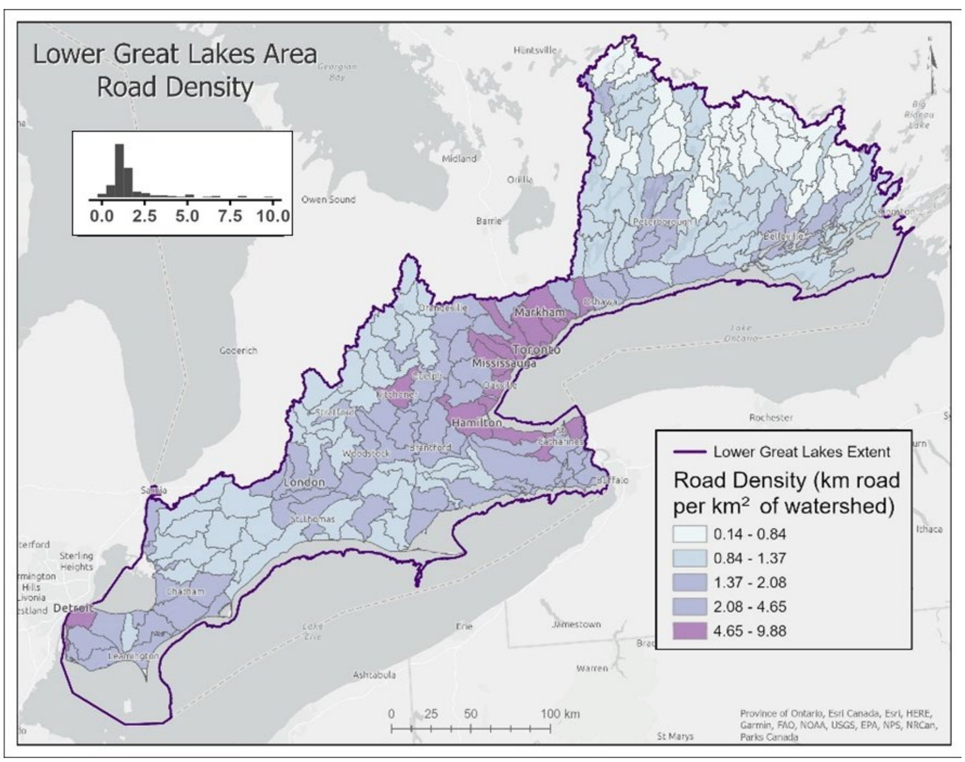

Figure 21. Density of roads within assessment units in the LGLA.

Across assessment units, riparian areas had a median percentage of natural land cover of 47.8%. Only 25.1% of assessment units in the LGLA had less than 25% disturbed land cover within riparian areas, most of which were concentrated in the northeastern part of the reporting area (Figure 22).

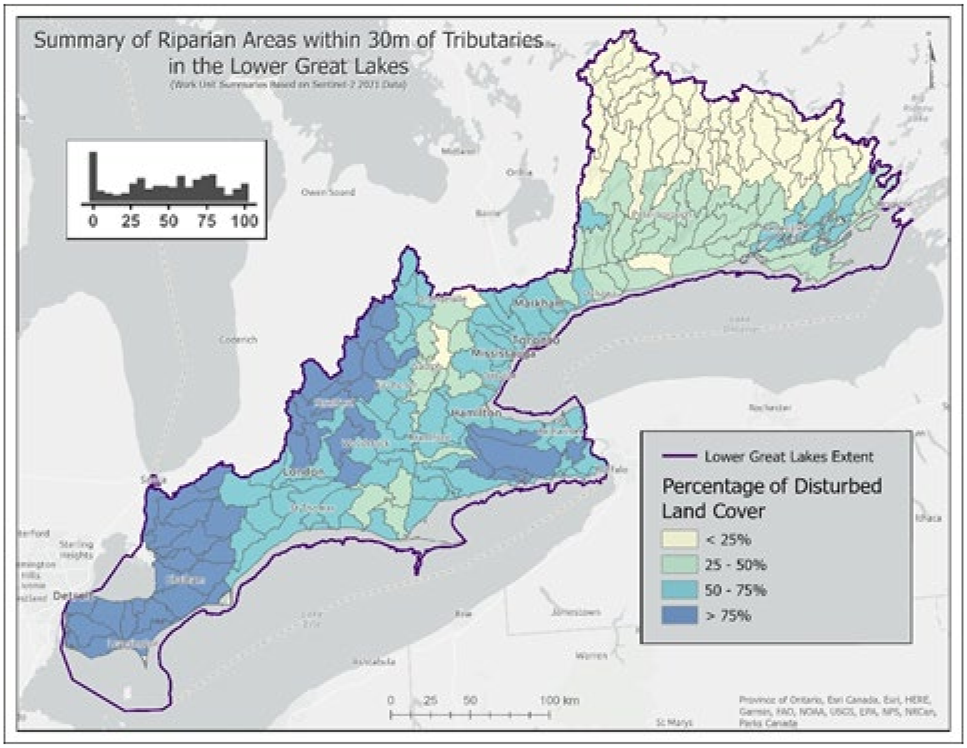

Figure 22. Percentage of riparian areas (30 m buffer around all watercourses) with disturbed land cover (built areas and or cropland) within each assessment unit in the LGLA.

Additionally, protected area coverage in the reporting area was low (Figure 23; Table 6), with 48.2% of assessment units having no protected area coverage. Relatively higher values of protected area coverage were concentrated in the northern part of LGLA.

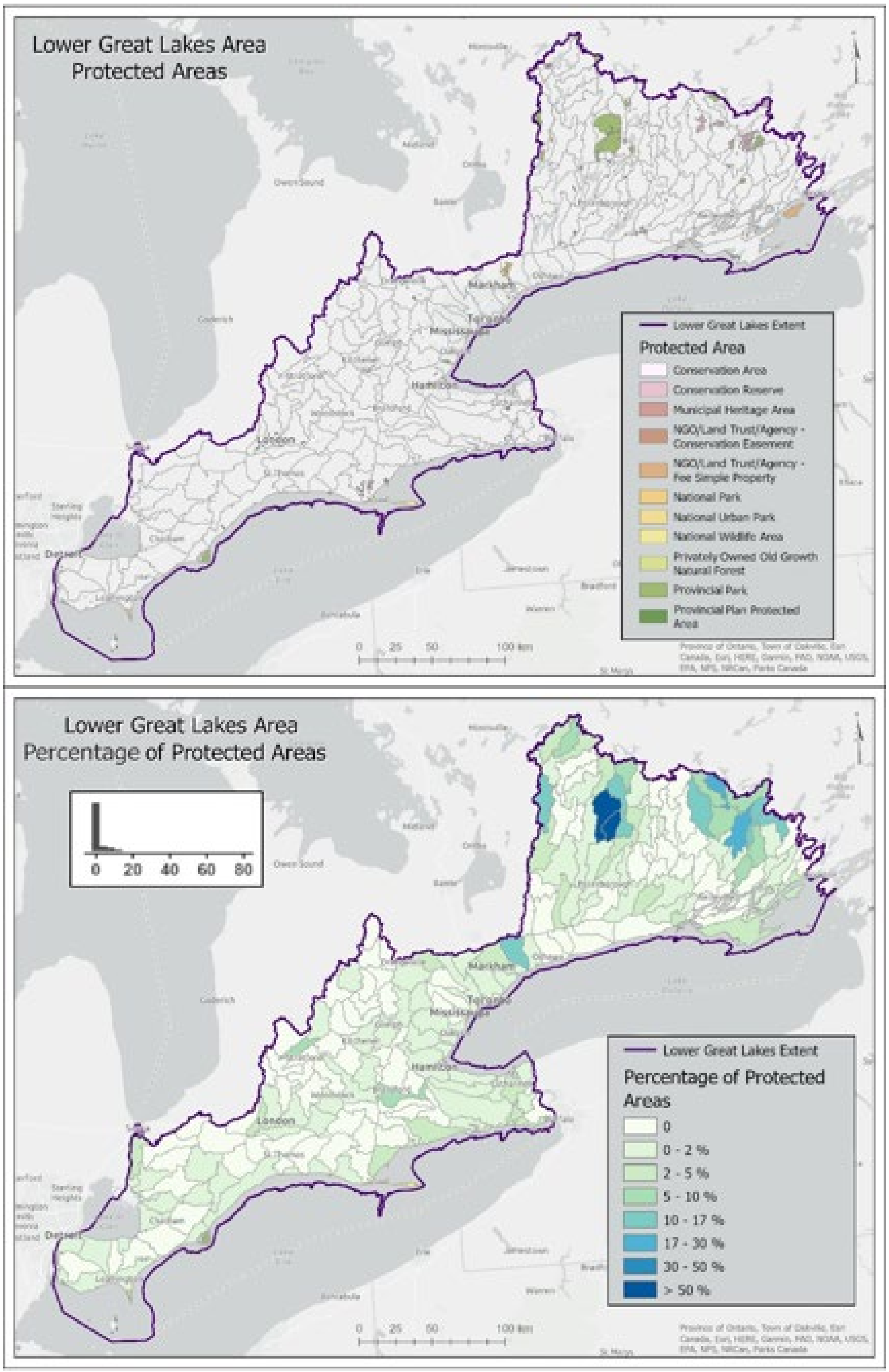

Figure 23. Protected area coverage with the LGLA by type of protected area (upper panel), and by percentage of coverage within each assessment unit (lower panel).

Table 6. Total areas (km^2) of different types of protected areas within LGLA.

Protected area type	Area (km^2)
Conservation Area	80.10
Conservation Reserve	446.15
Municipal Heritage Area	43.81
National Park	31.82
National Urban Park	90.06
National Wildlife Area	93.08
NGO/Land Trust/Agency - Conservation Easement	1.56
NGO/Land Trust/Agency - Fee Simple Property	280.83
Privately Owned Old Growth Natural Forest	0.40
Provincial Park	1,382.07
Provincial Plan Protected Area	13.42
Total	2,463.30

Indicator: Climate change

In the LGLA, forward bioclimatic velocities ranged from 1.6 to 9.8 km·yr^{-1} depending on the assessment unit and emissions scenario (Figure 24). Velocities were faster under high emissions (RCP 8.5) versus the lower emissions scenario (RCP 4.5). Forward velocities were fastest in the assessment units surrounding the Greater Toronto Area. Backward velocities ranged from 1.6 to 11.1 km·yr^{-1} with faster velocities in the southwestern assessment units and assessment units along the shore of Lake Ontario.

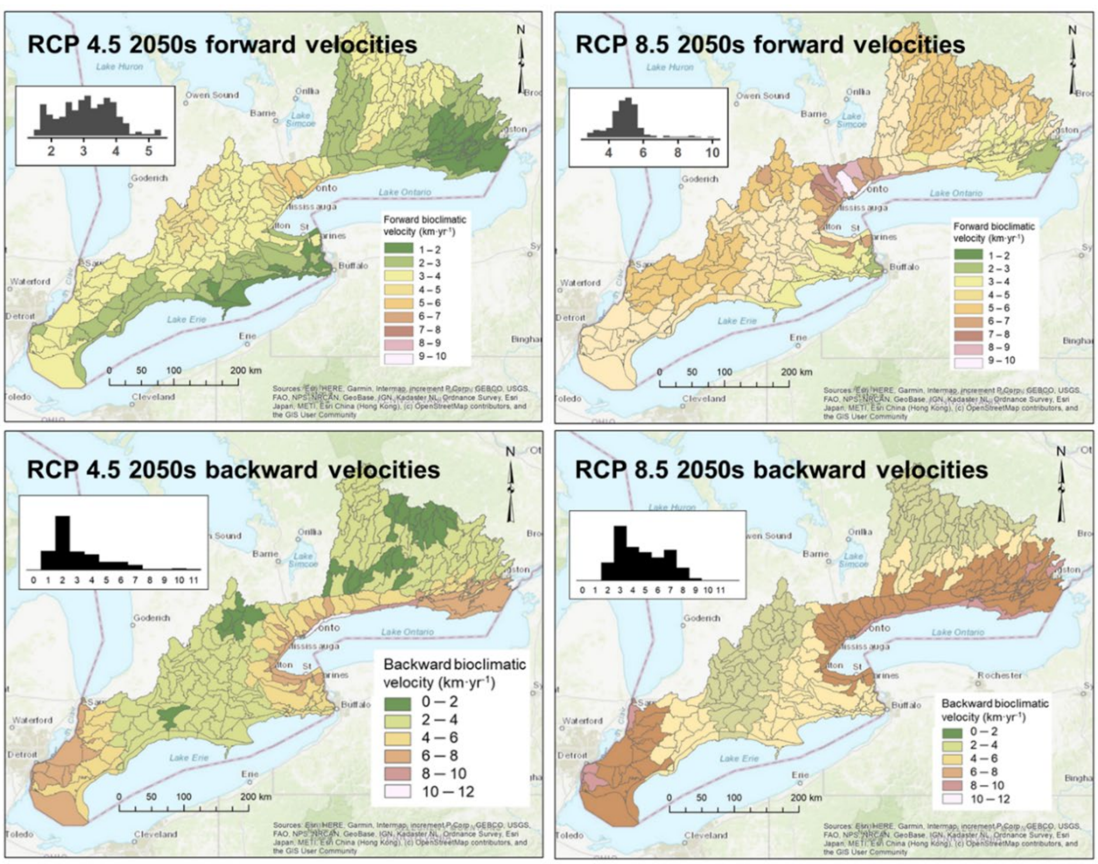

Figure 24. Forward and backward bioclimatic velocities (km·yr^{-1}) for each assessment unit in the LGLA under the 2050s RCP 4.5 and RCP 8.5 emissions scenarios.

Climate change is predicted to alter the extent of flooding in the LGLA (Figure 25). Under both the RCP 4.5 and RCP 8.5 scenarios, the total flood volume is expected to increase in comparison with the current climate scenario, with a particular increase in area covered by flooding > 5 m in depth (Figure 26). Relative to current floods, 100-year flood volume was predicted to increase to a greater extent under the RCP 4.5 emission scenario (+10.3 cubic kilometres) compared to the RCP 8.5 emission scenario (+4.7 cubic kilometres).

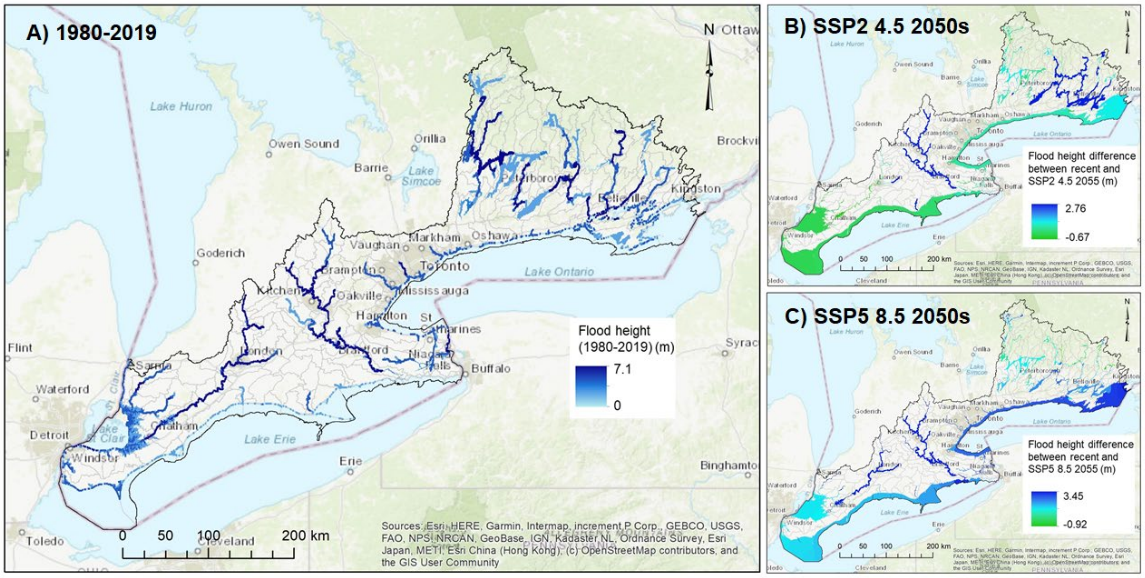

Figure 25. Change in flood height from current (A) to future climate scenario (B, C) for a 100-year flood. Panel A shows flood heights for a 100-year flood between 1980 and 2019, while panel B and C show the change in flood height (green = decrease in height, blue = increase in height) under low (SSP2 4.5) and high (SSP5 8.5) emissions scenarios by the 2050s.

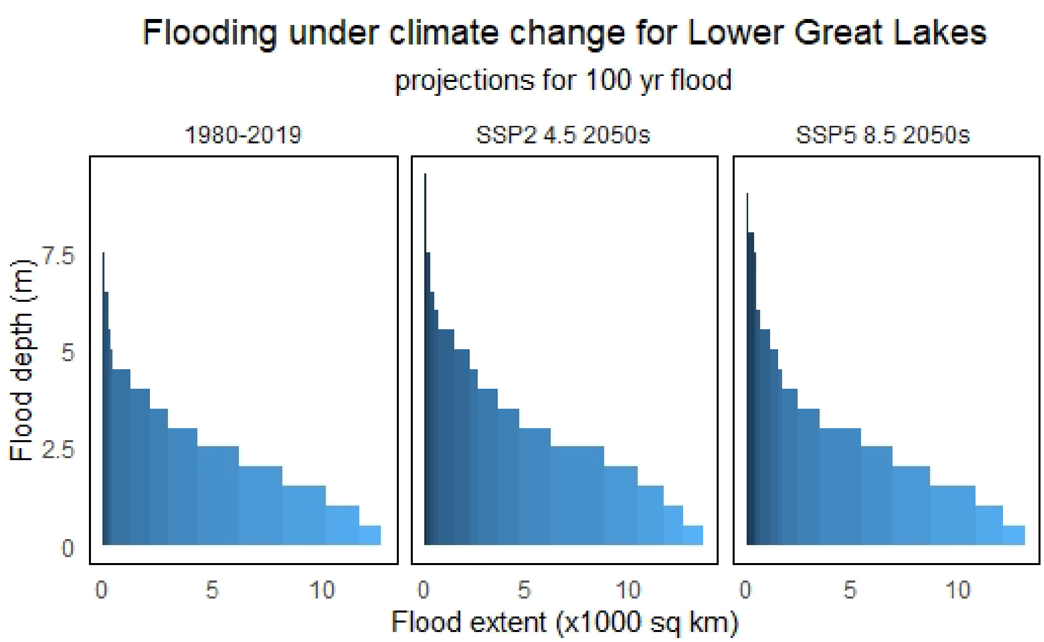

Figure 26. Projected flood heights and extents for a 100-year flood under current (1980-2019), SSP2 4.5 and SSP5 8.5 climate scenarios for the LGLA.

ALBERTA EAST SLOPES AREA (AESA)

Indicator: Biodiversity

Fish species richness in the AESA varied between 1 and 32 species per assessment unit (Figure 27; Appendix C). Lower values were found in (western) mountainous assessment units, and higher values were found in eastern assessment units in foothills and prairie area. Across assessment units, the median fish species richness was 17. Fish species data quality varied across the reporting area with generally more information available in the central and southern versus northern assessment units (Appendix E). Data were not readily available for three assessment units in Jasper National Park.

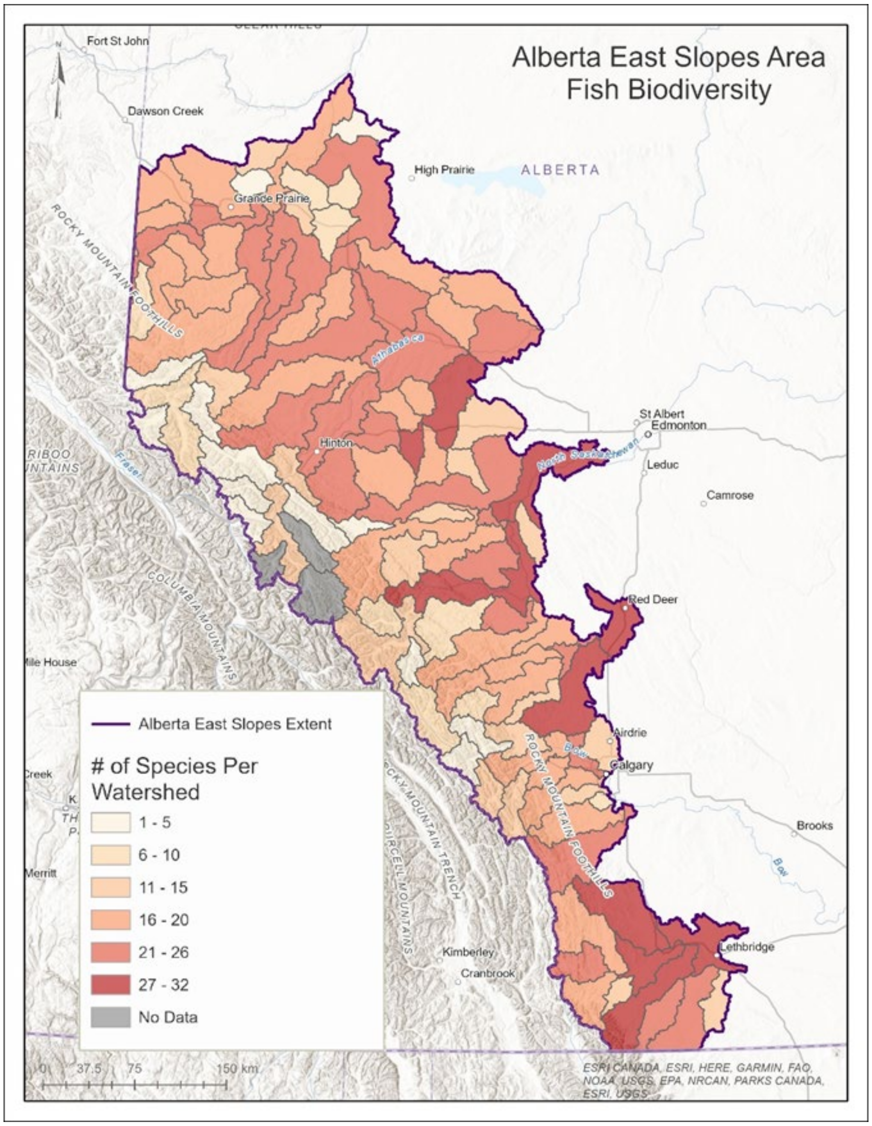

Figure 27. Fish species richness in each assessment unit within the AESA.

Data on benthic invertebrate communities were available for 326 sites within the AESA (Figure 28), the majority of which were found in western parts of the reporting area. EPT% was high at most sites, with 75% of sites having an EPT% above 66.7%. Median EPT index across all sites was 86.9%.

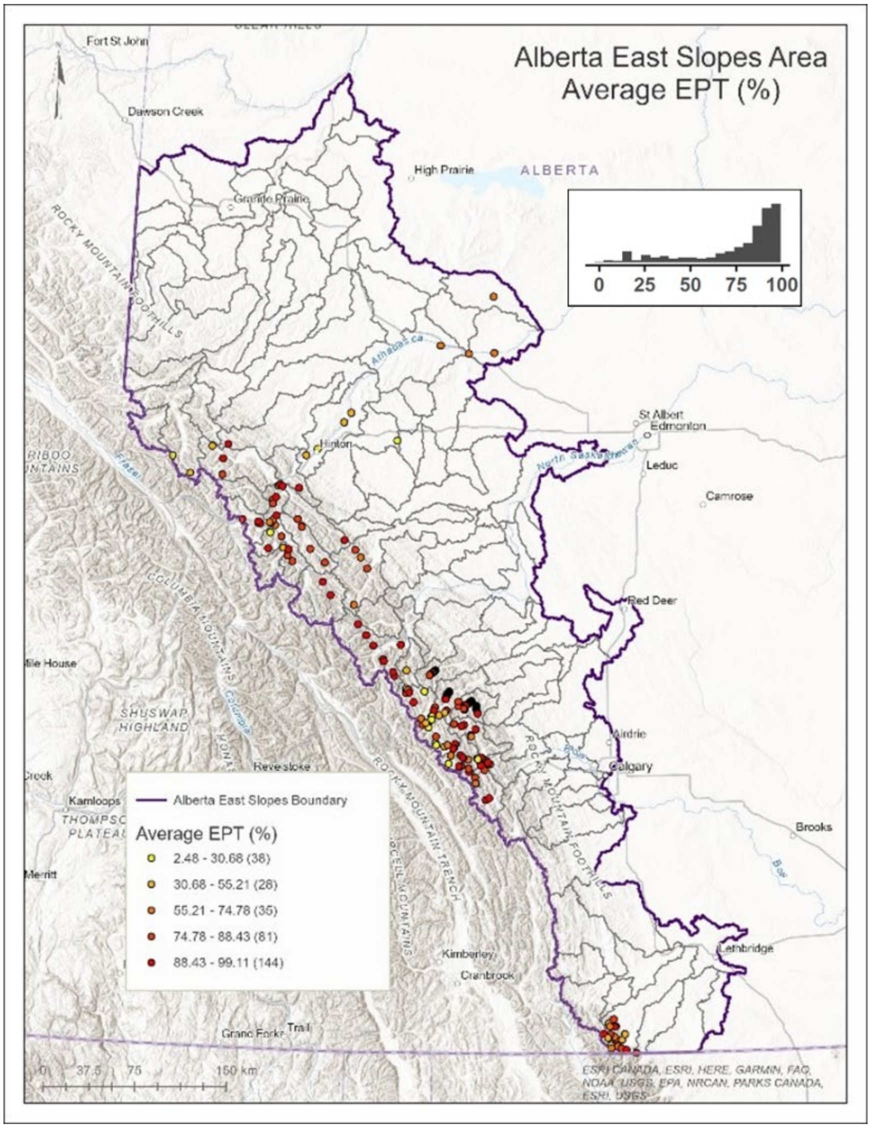

Figure 28. EPT index values at sites within the AESA.

SAR richness was generally low across the AESA, with a maximum of 3 SAR per assessment unit, and a median value of 1 SAR per assessment unit (Figure 29; Table 7). However, because overall fish richness is low, SAR composed a median of 8.9% percent of the fish community (Figure 30). Aquatic invasive fishes in the AESA were limited to Prussian Carp (*Carassius gibelio*) and Goldfish (*Carassius auratus*), which were found in only 9 assessment units (Figure 31). Rare occurrences of other invasive fishes (e.g., black bullhead) were not included in our analysis.

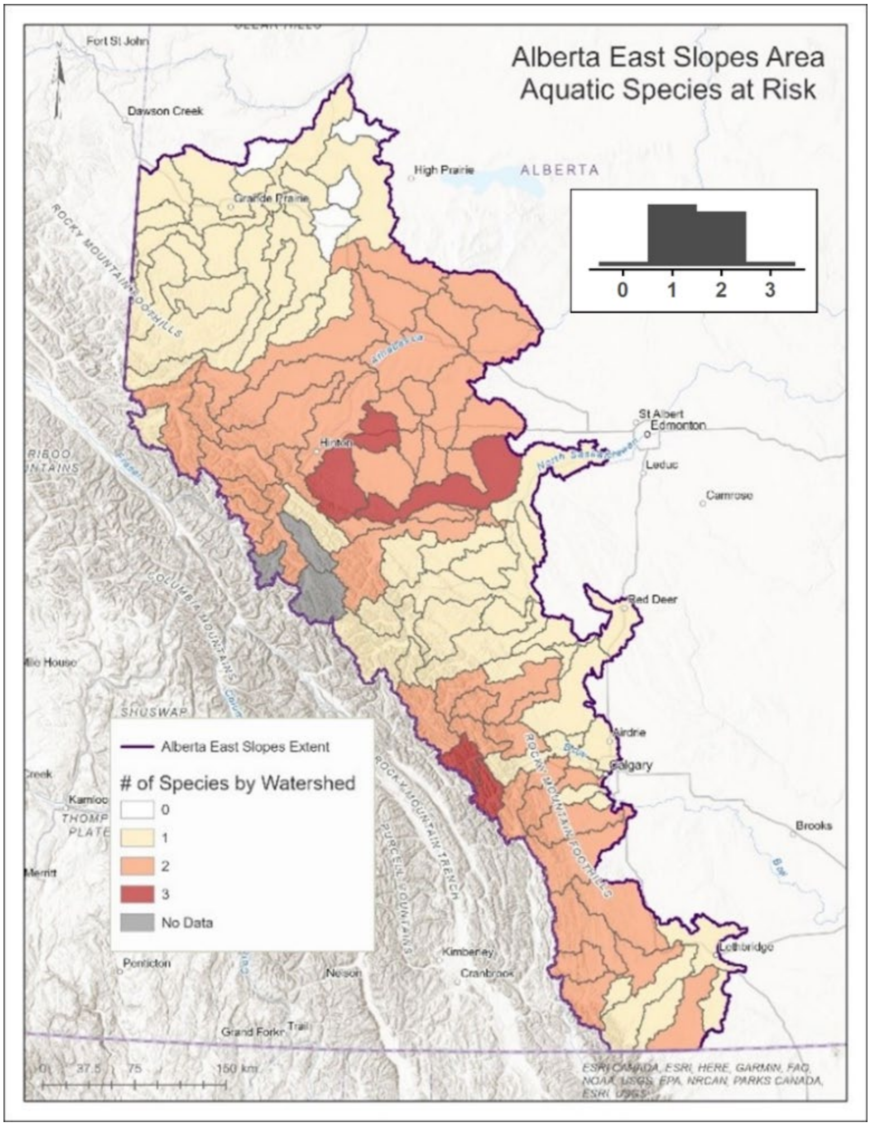

Figure 29. Number of fish and aquatic mollusks at risk in each assessment unit within the AESA.

Table 7. Fish and aquatic mollusk species at risk within the AESA listed under SARA Schedule 1 and COSEWIC that are Extinct (Ext), Endangered (End), Extirpated (Exp), Special Concern (SpC) or Threatened (Thr).

Species (and population where designated)	**SARA status**	**COSEWIC status**
Bull Trout (*Salvelinus confluentus*), Saskatchewan-Nelson Rivers populations	Thr	Thr
Bull Trout (*Salvelinus confluentus*),Western Arctic populations	SpC	SpC
Lake Sturgeon (*Acipenser fulvescens*), Saskatchewan - Nelson River populations	-	End
Rainbow Trout (*Oncorhynchus mykiss*), Athabasca River populations	End	End
Pygmy Whitefish (*Prosopium coulterii*), Waterton Lake population	-	SpC
Rocky Mountain Sculpin (*Cottus* sp.), Eastslope population	Thr	Non-Active
Rocky Mountain Sculpin (Cottus sp.), Saskatchewan - Nelson River populations	-	Thr
Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*), Alberta population	Thr	Thr
Banff Springs Snail *(Physella johnsoni)*	End	End

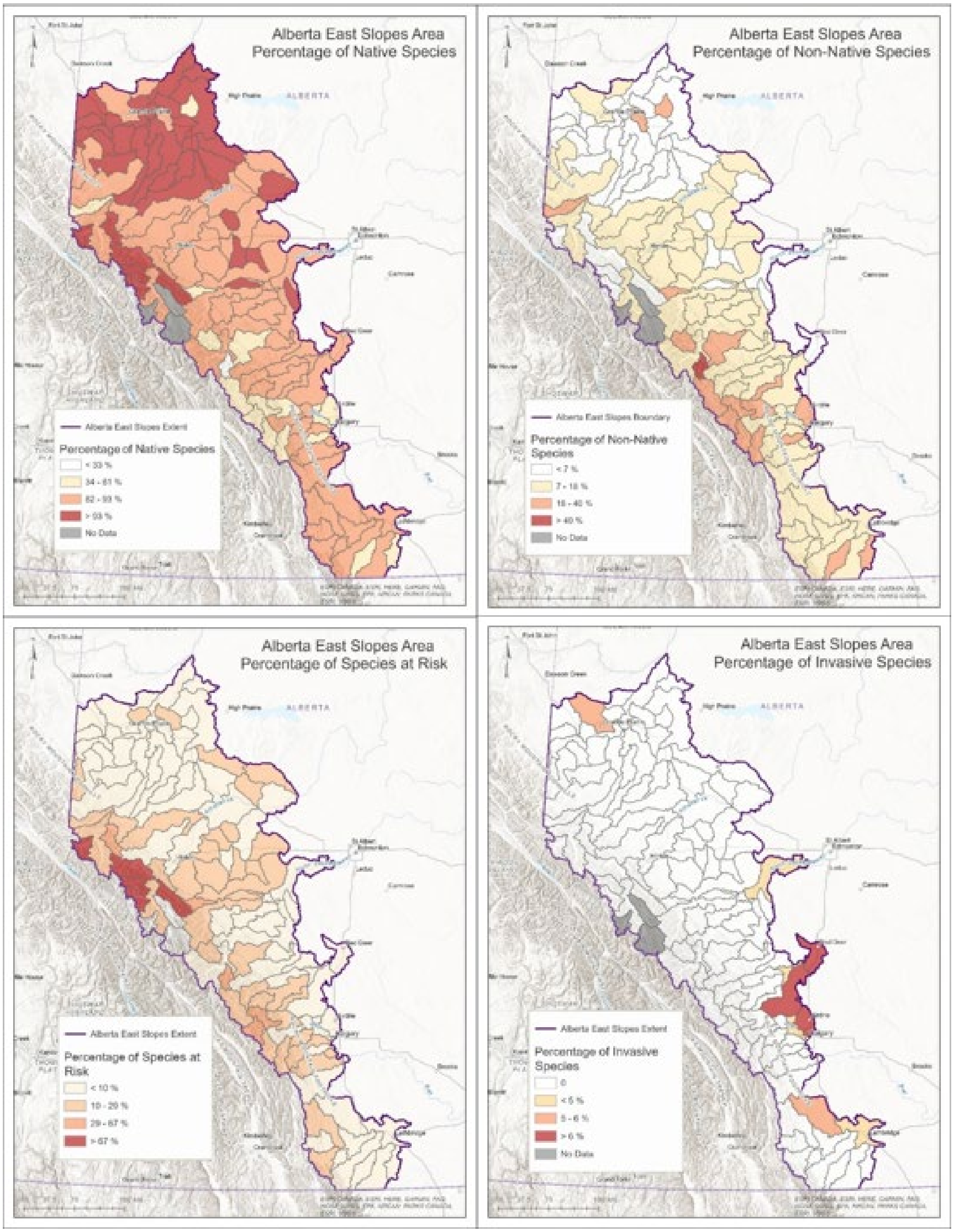

Figure 30. Percentage of the fish community within each assessment unit that is composed of native species (top left), non-native species (top right), invasive species (bottom left) and species at risk (bottom right).

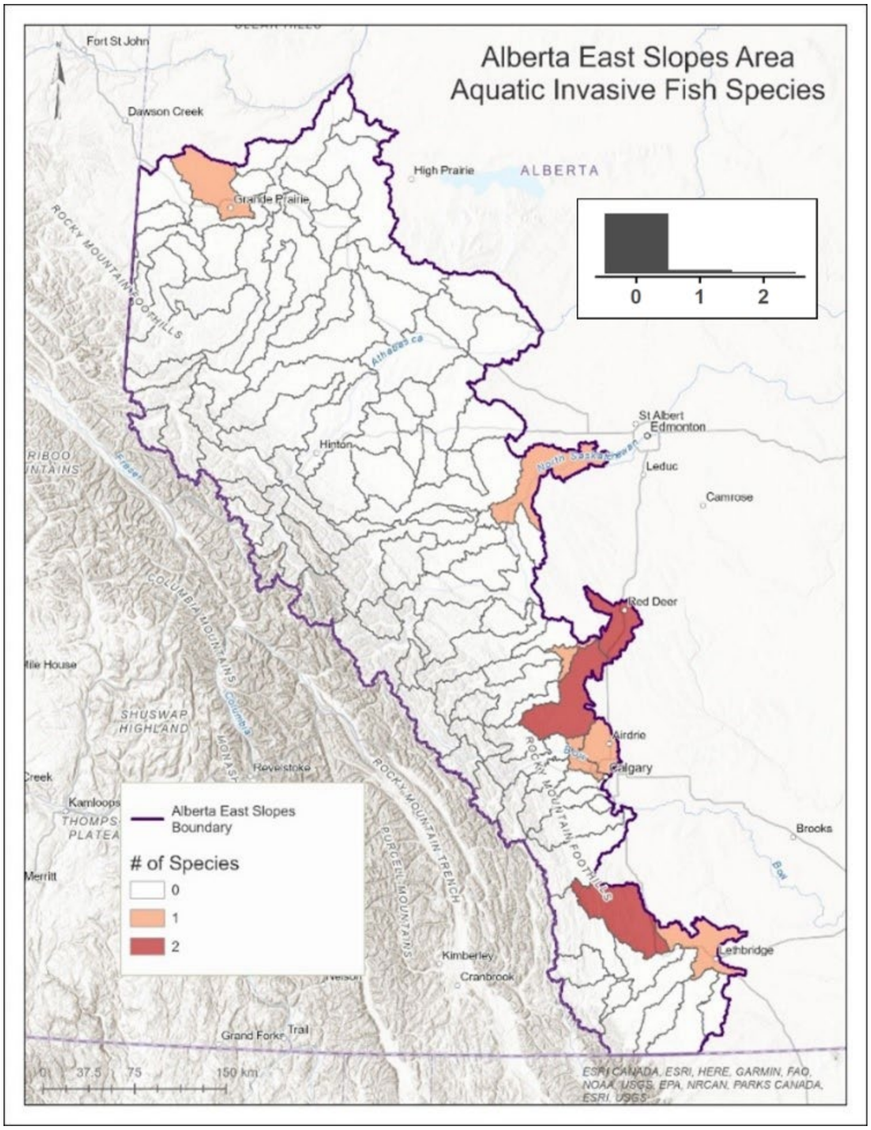

Figure 31. Number of aquatic invasive species within each assessment unit in the AESA.

Across assessment units, the median percentage of native fish species was 88.4%, with higher values found in northern parts of the reporting area (Figure 30). Non-native species (predominantly brook, brown and rainbow trout; Appendix C) composed a median of 11% of the fish community, while invasive species (Prussian carp and goldfish) were generally rare (Figure 30).

Indicator: Water Quality

Chloride concentrations for 21 sites sampled in the AESA ranged from 1.15 to 12 mg·L^{-1} (average; 2.75 mg·L^{-1}) (Figure 32). Concentrations were highest near the urban centres of Calgary and Lethbridge. However, none of the sites had concentrations that exceeded the 120 mg·L^{-1} threshold for protection of aquatic life (Figure 33).

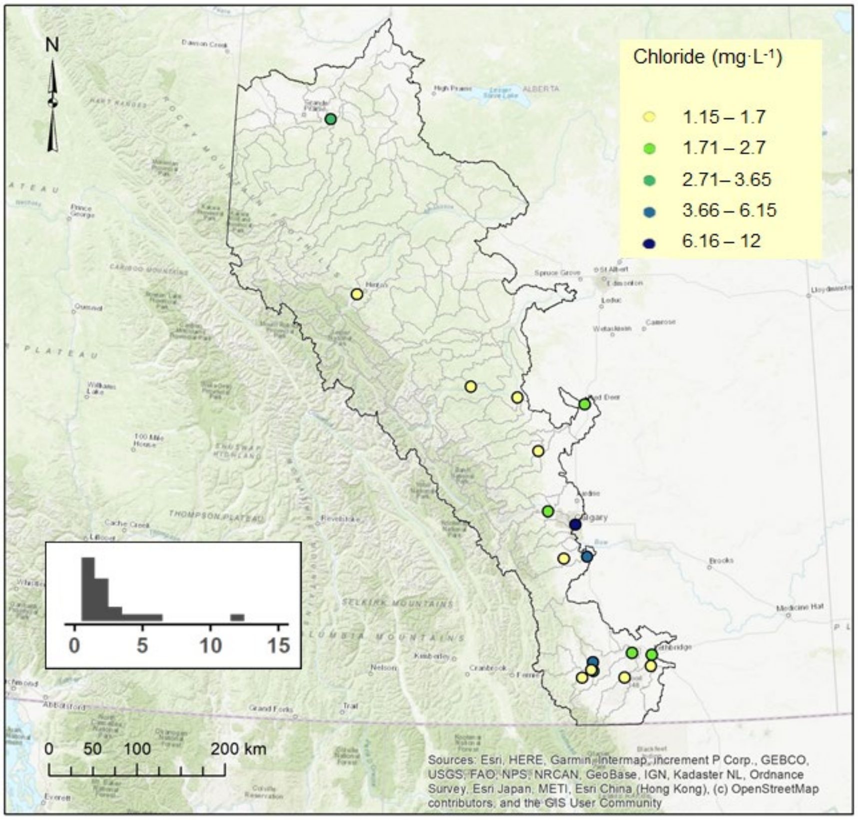

Figure 32. Median chloride concentrations (mg·L^{-1}) at water sampling sites in the AESA.

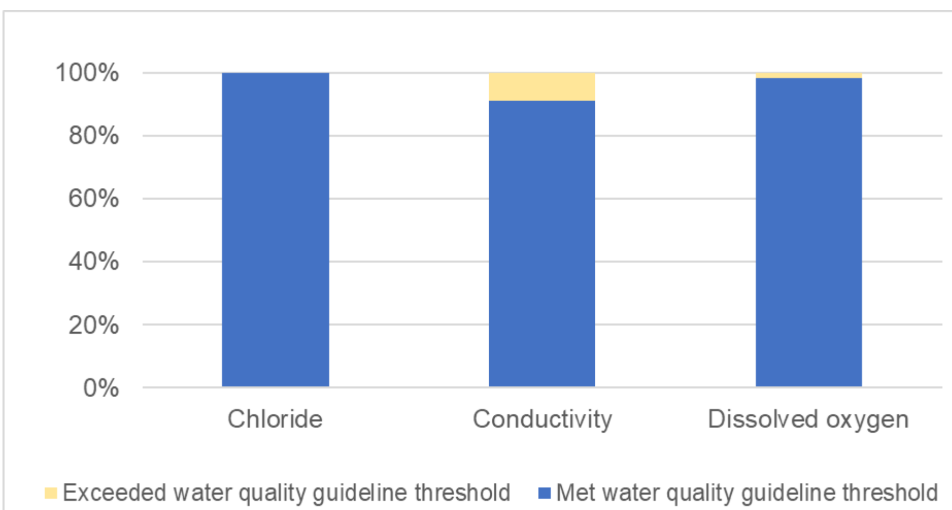

Figure 33. Percentage of water sampling sites in the AESA that met or exceeded water quality guidelines.

There were 55 sites throughout the AES reporting area where conductivity and dissolved oxygen were measured. Conductivity at those sites ranged from 145.85 to 1252 µS·cm^{-1} (average; 379.28 µS·cm^{-1}) and increased from west to east (Figure 34). Five sites near urban centres had conductivity concentrations that exceeded the threshold of 500 µS·cm^{-1}. Dissolved oxygen in AESA ranged from 4.94 to 11.42 mg ·L^{-1} (average; 10.18 mg ·L^{-1}) (Figure 35). Only one site in the centre of the reporting area had a DO value below the 6 mg ·L^{-1} limit. Mean July-

August temperatures in AESA ranged from 10.06 to 20.02 °C with an average of 16.04 °C (Figure 36). Temperatures were warmer in the lower elevation streams and rivers on the east side of the reporting area.

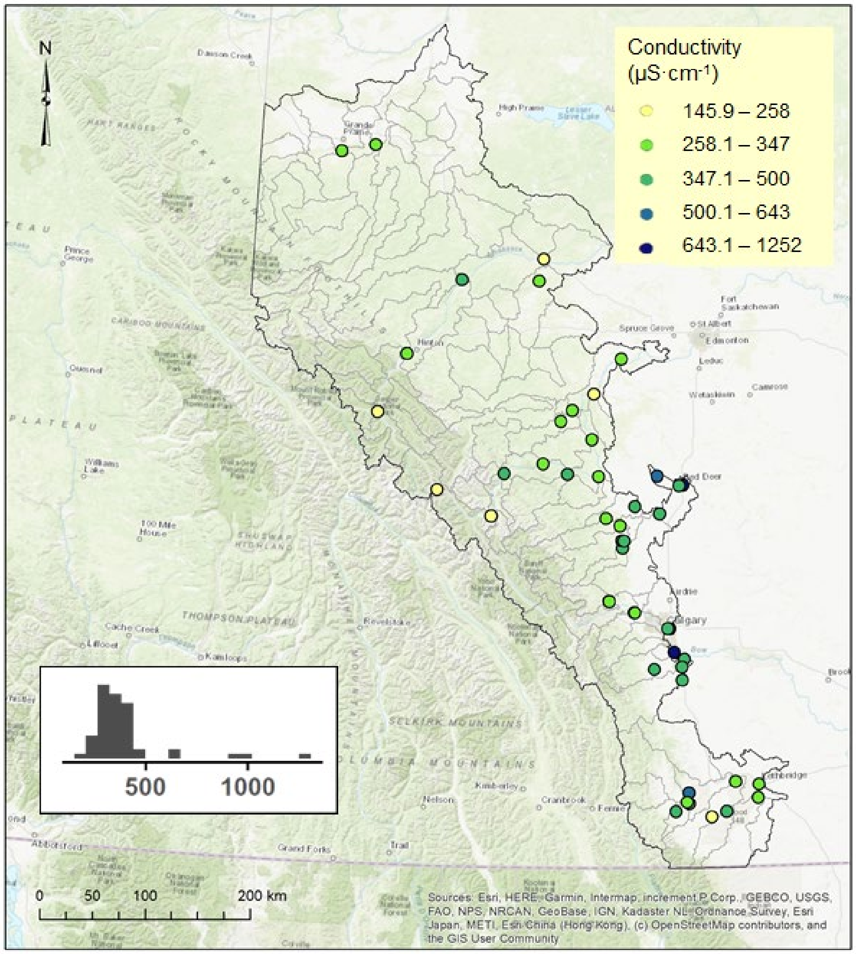

Figure 34. Median conductivity (μS·cm-1) measured in water sampling sites in the AESA.

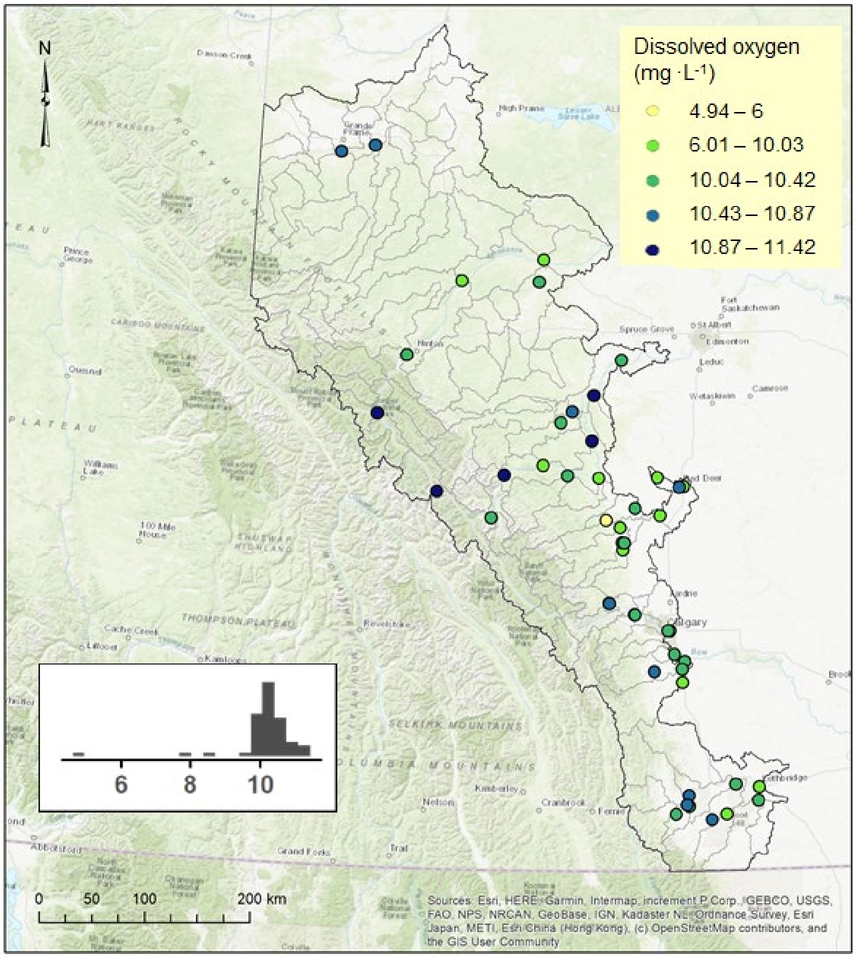

Figure 35. Median dissolved oxygen concentrations (mg·L^{-1}) measured in water sampling sites in the AESA.

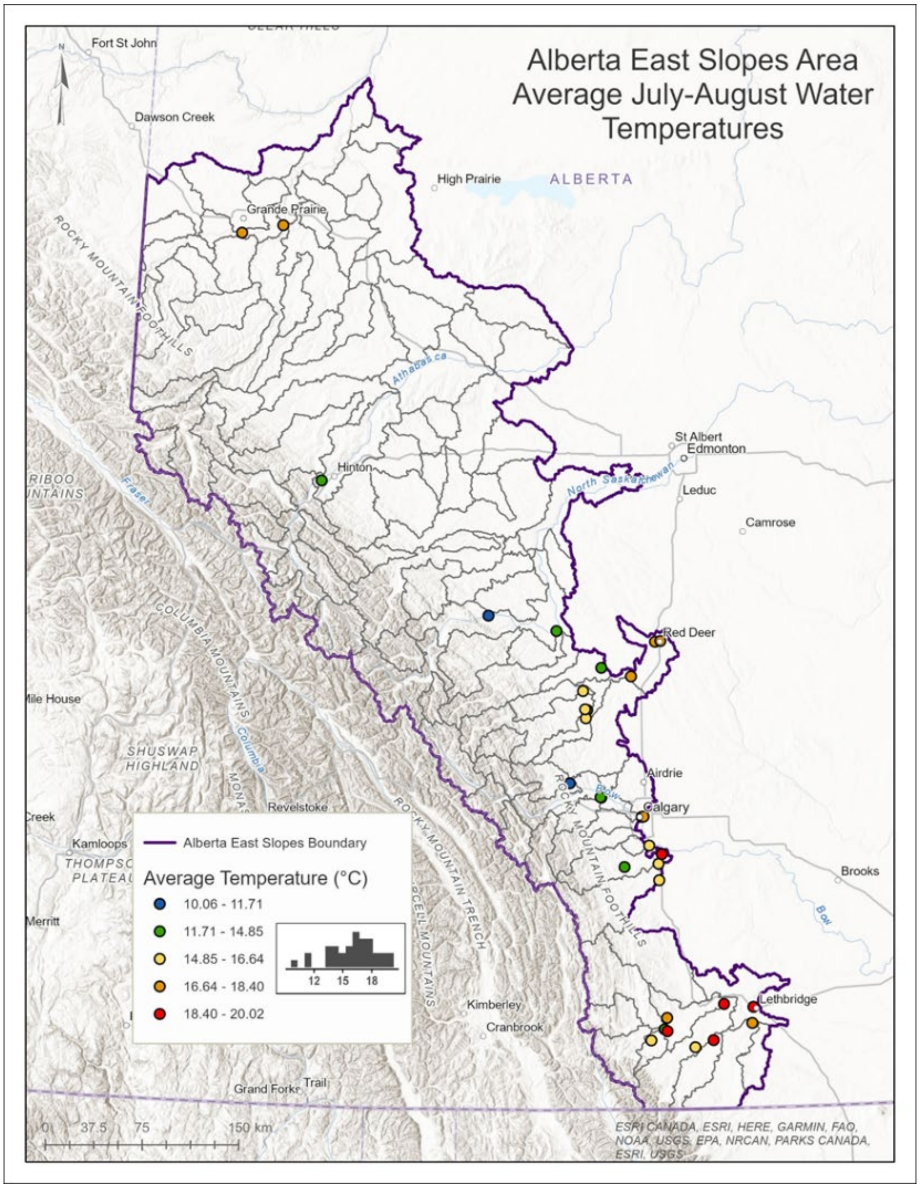

Figure 36. Average July-August water temperatures (°C) measured in rivers and lakes of the AESA.

Indicator: Connectivity

In the western part of the AESA, aquatic connectivity was impacted by waterfalls, with up to 0.22 waterfalls per 10 km stream length found in some assessment units (Figure 37), most of which had unknown passability (Figure 38). Conversely, eastern (and especially southeastern) assessment units had higher densities of dams, with up to 1.1 dams per 10 km stream length (Figure 39). Only two fishways were present within the AESA, each within a separate assessment unit in the middle and the northern part of the reporting area (Figure 40). Twenty six percent of the assessment units had no dams, waterfalls or fishways, according to the Canadian Aquatic Barrier Database.

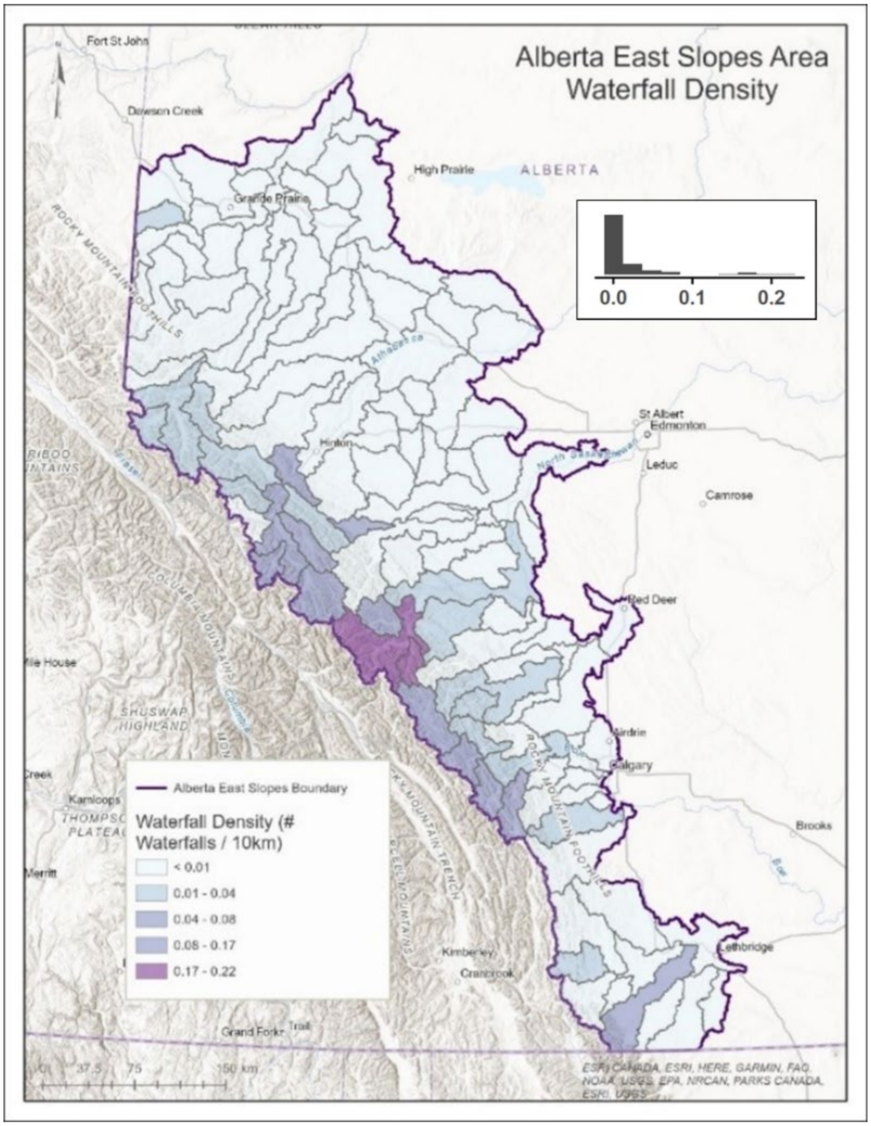

Figure 37. Density of waterfalls (number·10 km^{-1}) within the AESA.

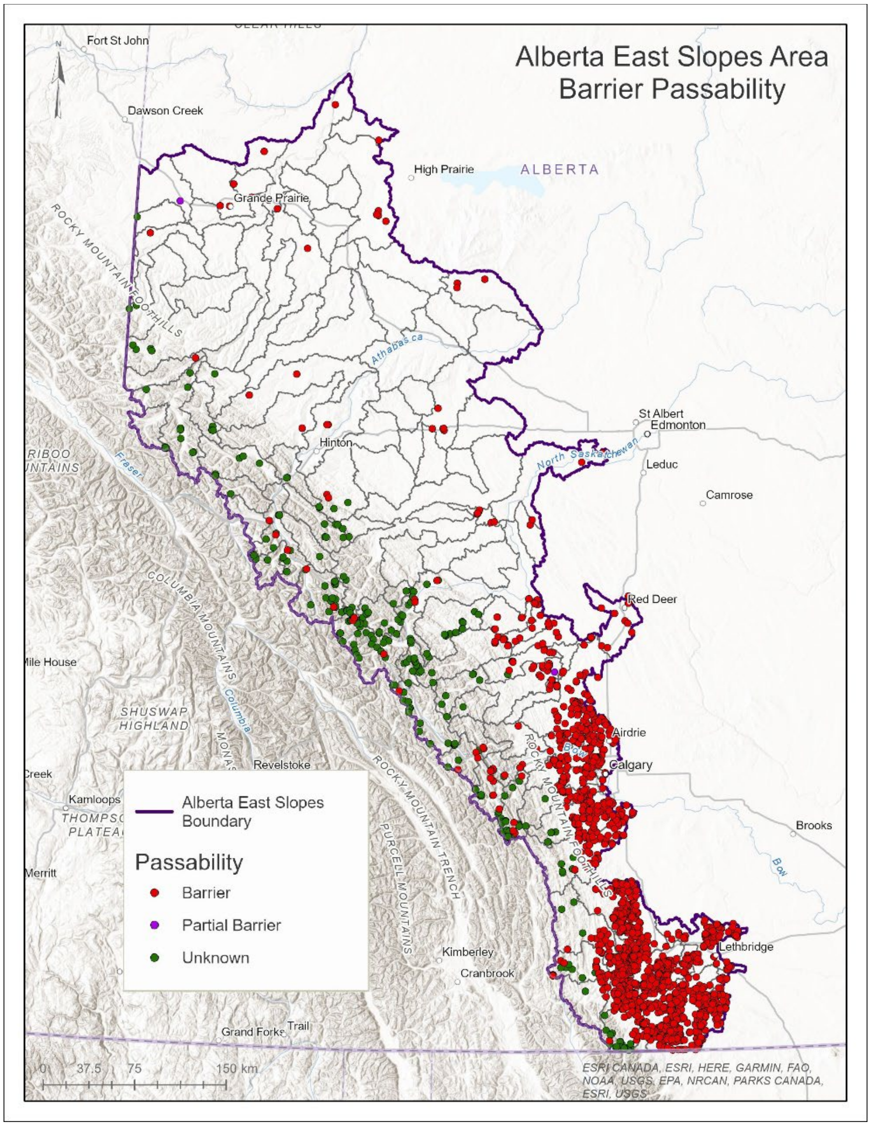

Figure 38. Passability of barriers in the AESA.

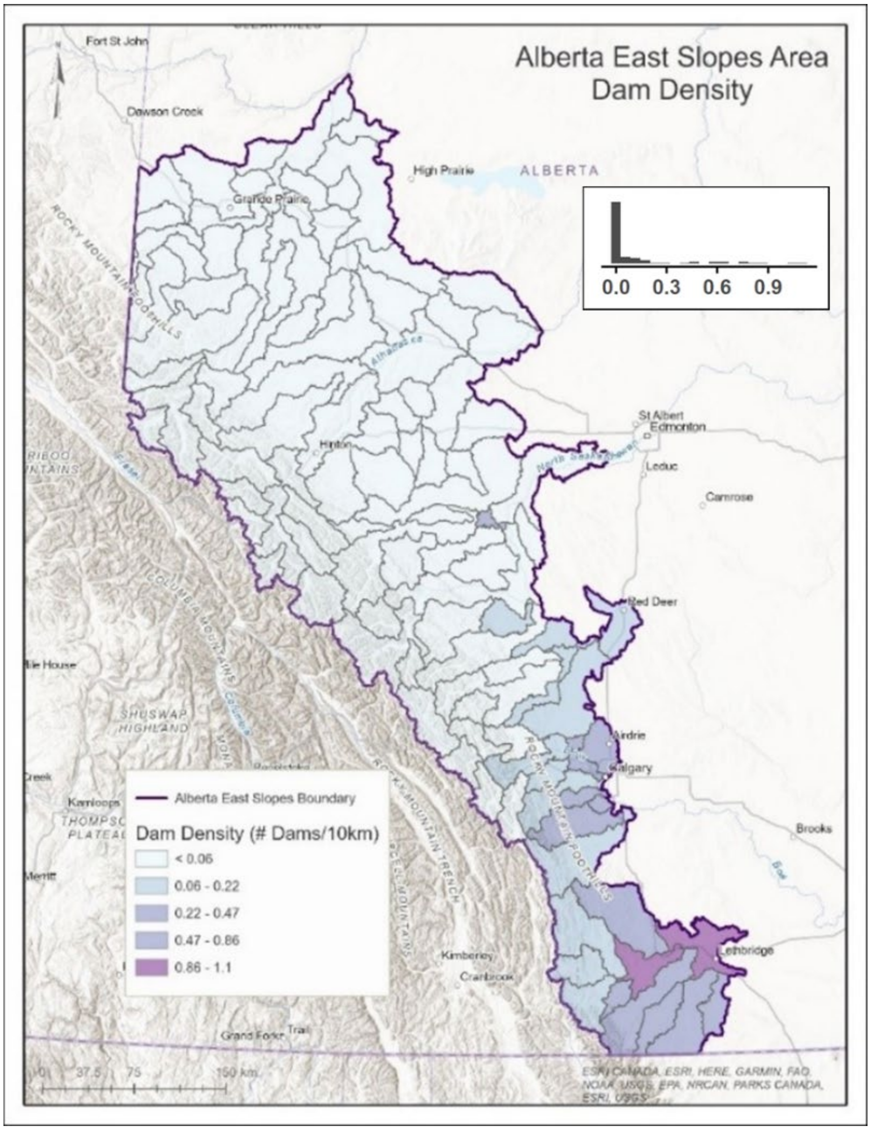

Figure 39. Density of dams (number·10 km^{-1}) within the AESA.

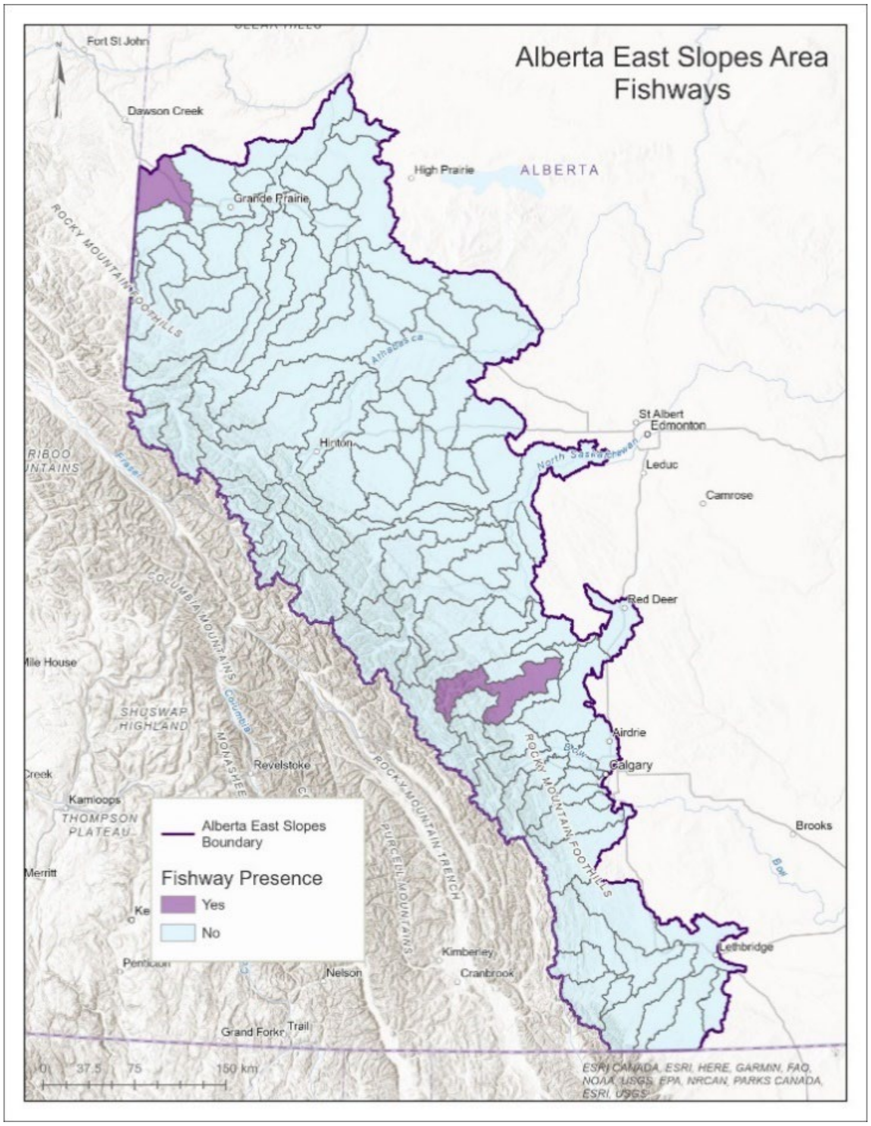

Figure 40. Presence of fishways within the AESA.

Of the 2013 dams, waterfalls and fishways in the AESA, 1727 are known to be barriers to fish movement, 2 are partial barriers, and 284 have unknown passability (Figure 38).

Stream crossing density in AESA varied between 0 and 15.4 (road or rail) crossings per 10 km stream length, with a median value of 1.2 (Figure 41). Assessment units with the highest density of stream crossings were found near large urban centers within the reporting area.

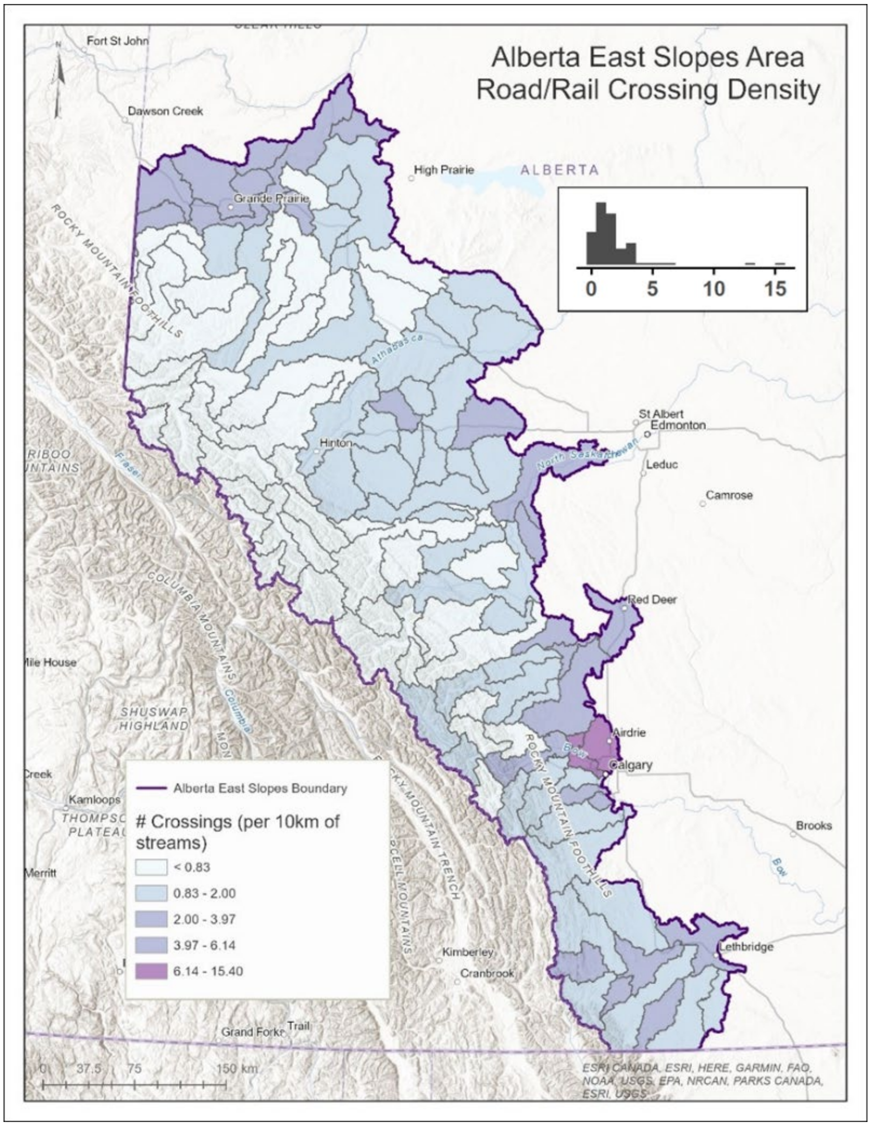

Figure 41. Density of road and rail crossings of watercourses within the AESA.

Stream connectivity metric values were highest in north and western parts of the reporting area (Figure 42), with lower values found in some foothill regions in the Bow and Athabasca River watersheds. Median stream connectivity across assessment units was 44.9%, with a low value of 14.9% and a high value of 99.9%.

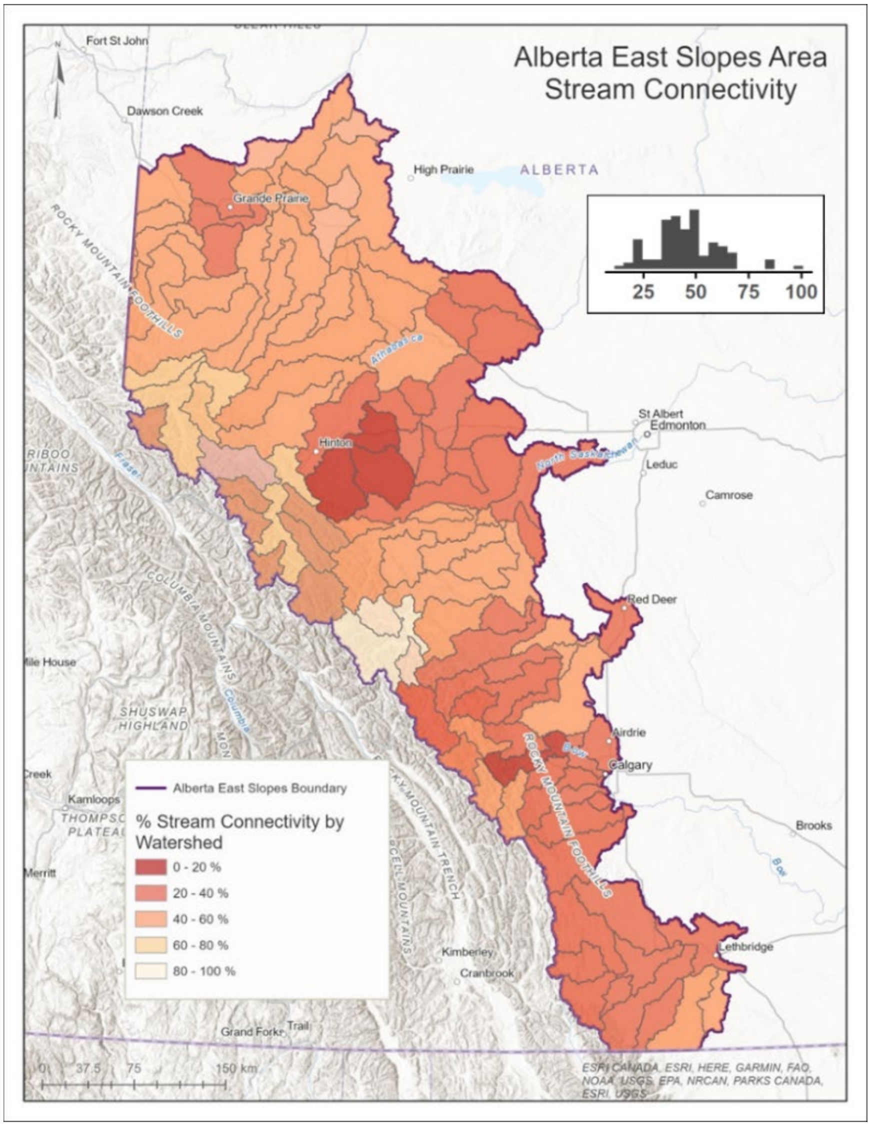

Figure 42. Stream connectivity values for each assessment unit with the AESA.

Indicator: Land Use and Land Cover

Land use and land cover in the AESA shows high spatial variation, with rangeland and crops being predominant land uses in the southeastern part of the reporting area, whereas trees and snow/ice are the predominant land cover in the western and northeastern parts of the reporting areas (Figure 43). High concentrations of built areas were associated with the cities of Grand Prairie, Red Deer, Calgary and Lethbridge.

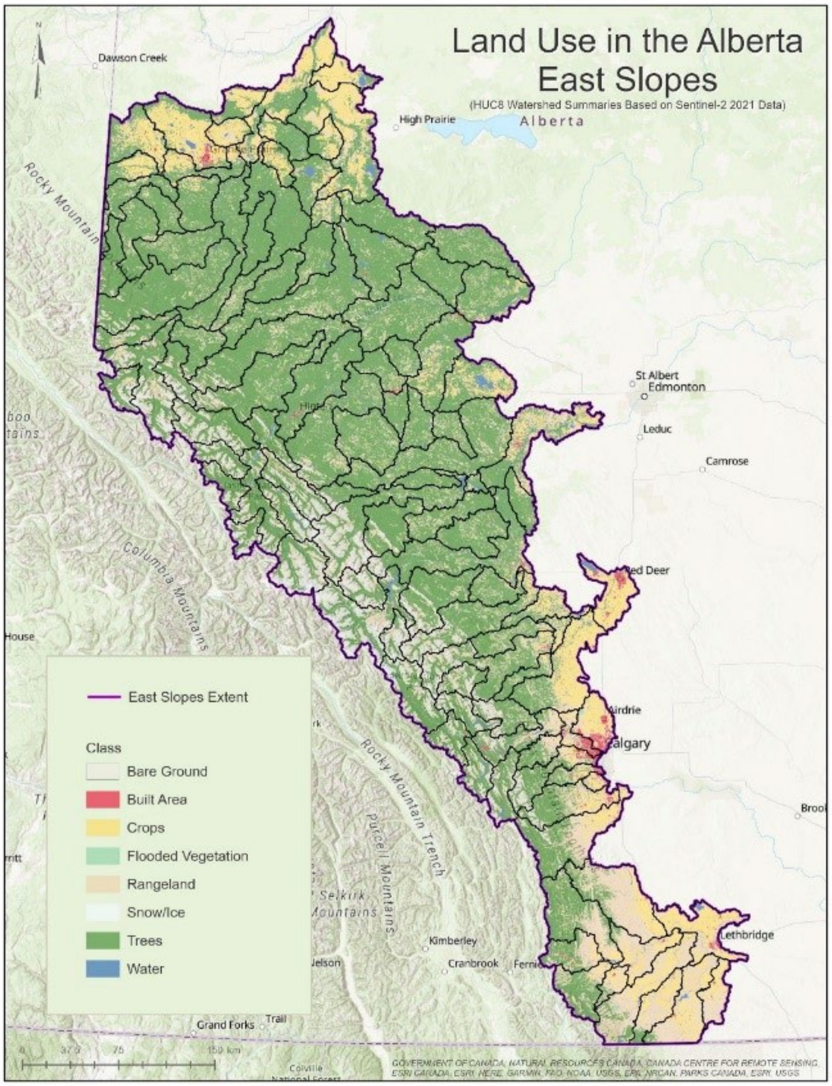

Figure 43. Land use and land cover in the AESA.

Road density in AESA varied between 0 km/km^2 and 4.24 km/km^2, with a median value of 0.37 km/km^2 (Figure 44). Higher road densities were found near major urban centers. Only 1.9% of assessment units within the AESA contained no roads.

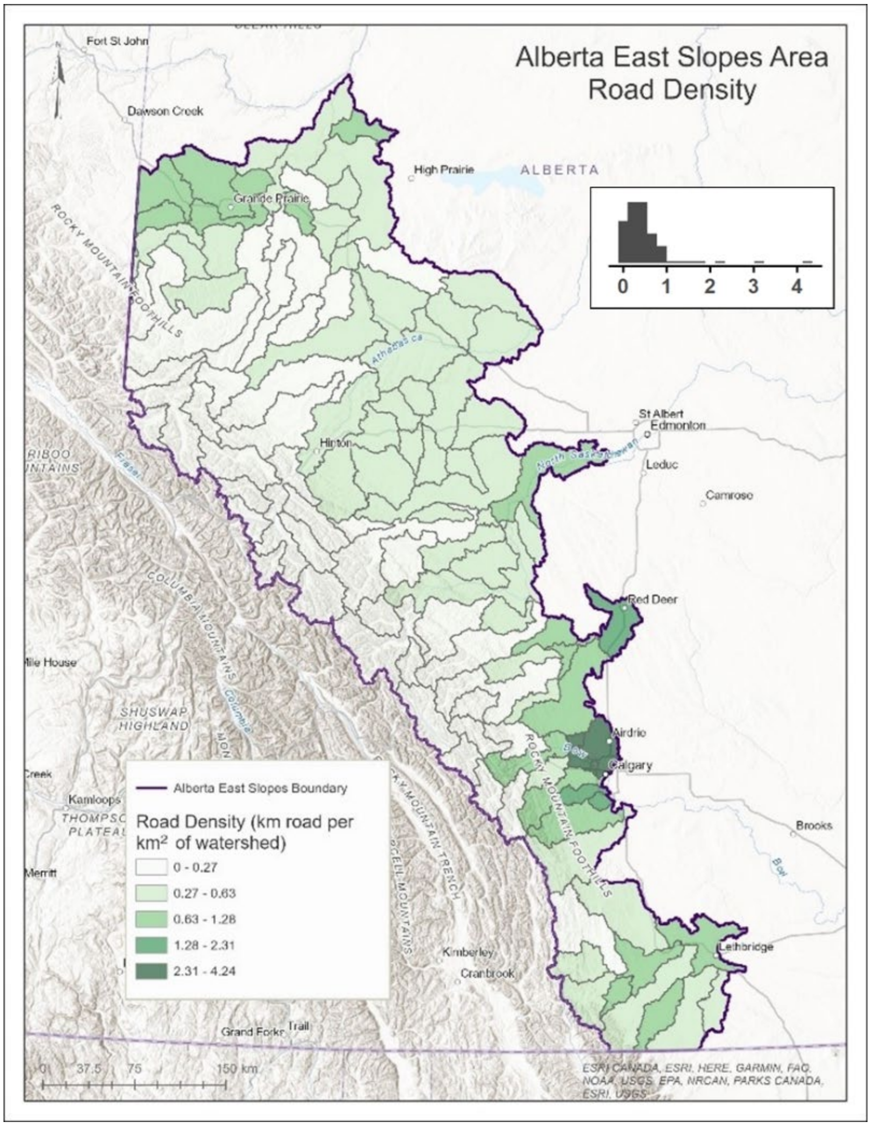

Figure 44. Road density (km road length/km^2 area of the assessment unit) in the AESA.

Riparian areas had a high percentage of natural land cover in the AESA, with 83% of assessment units exceeding the 75% natural land cover threshold (Figure 45). Indeed, the median value of riparian natural cover across assessment units was 99.4%, with assessment units having lower amounts of natural cover being found near large cities in the eastern portion of the reporting area.

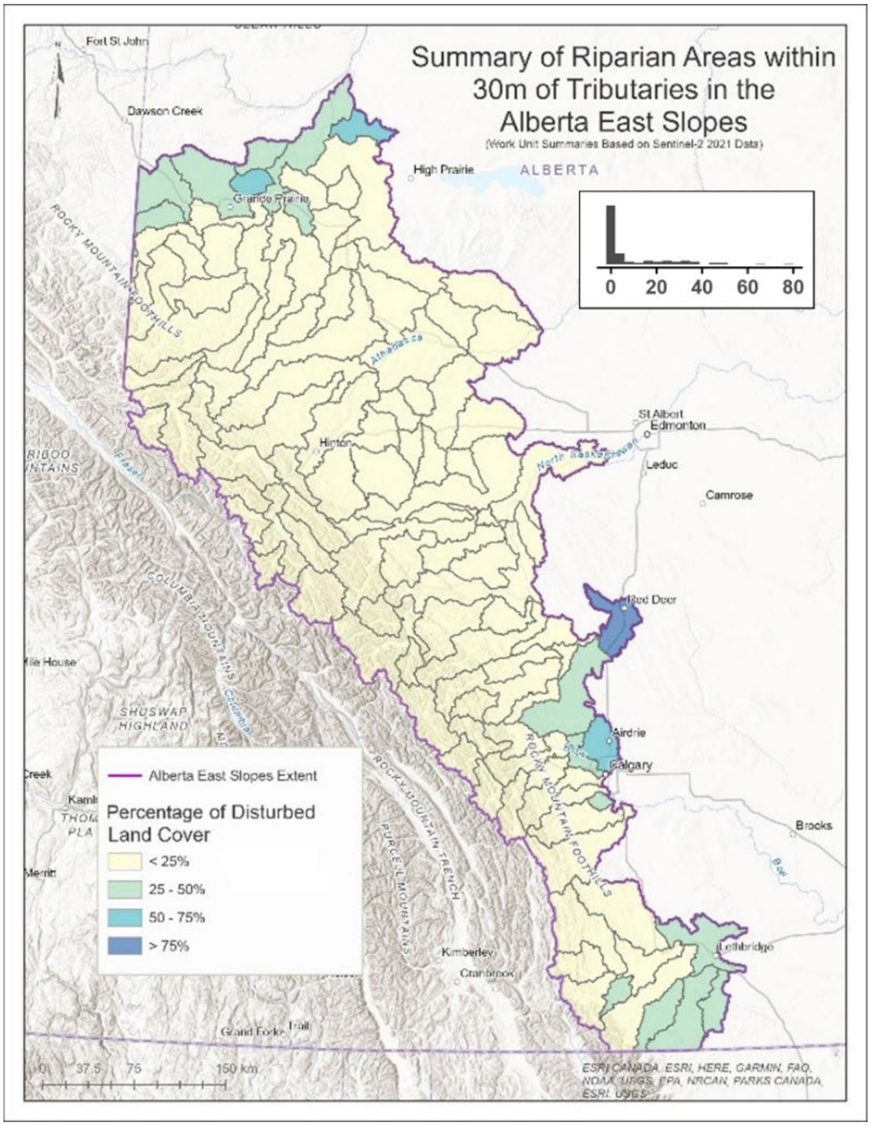

Figure 45. Percentage of riparian areas with disturbed land cover within each assessment unit in the AESA.

Protected area coverage within the AESA varied from 0 to 100% among assessment units (Figure 46; Table 8). High values of protected area coverage were associated with national and provincial parks in the mountainous regions of the reporting area, with lower values found in areas in the foothills and boreal areas to the north and east. Thirty-six assessment units contained no protected areas.

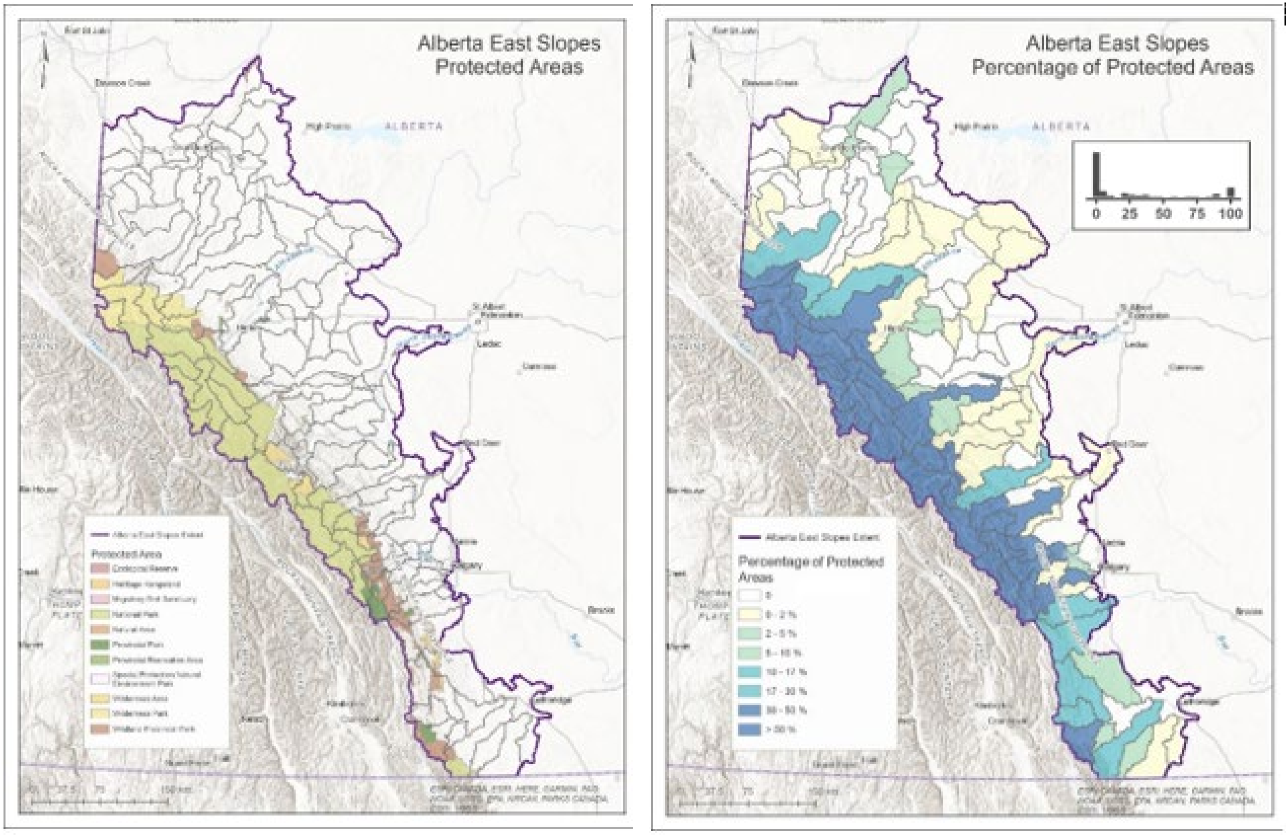

Figure 46. Protected area coverage within the AESA by type of protected area (left), and by percentage of coverage within each assessment unit (right).

Table 8. Total areas (km^2) of different types of protected areas within AESA.

Protected area type	Area (km^2)
Ecological Reserve	102.86
Heritage Rangeland	464.12
Migratory Bird Sanctuary	12.79
National Park	18,591.88
Natural Area	189.59
Provincial Park	1,432.13
Provincial Recreation Area	61.24
Special Protection Natural Environment Park	1.10
Wilderness Area	1,023.91
Wilderness Park	4,602.39
Wildland Provincial Park	4,862.88
Total	31,344.88

Indicator: Climate Change

Forward bioclimatic velocity showed considerable range across the AESA depending on the assessment unit and the emissions scenario, with velocity ranging from 1.2 to 16.6 km•yr^{-1} (Figure 47). In both emissions scenarios, forward bioclimatic velocities were fastest in the assessment units near, and immediately downstream of Banff and Jasper national parks, with slow values found in the northern and southern parts of the assessment units. Backward bioclimatic velocities ranged from 0.59 to 7.62 km•yr^{-1} for the two emissions scenarios. These velocities increased from west to east.

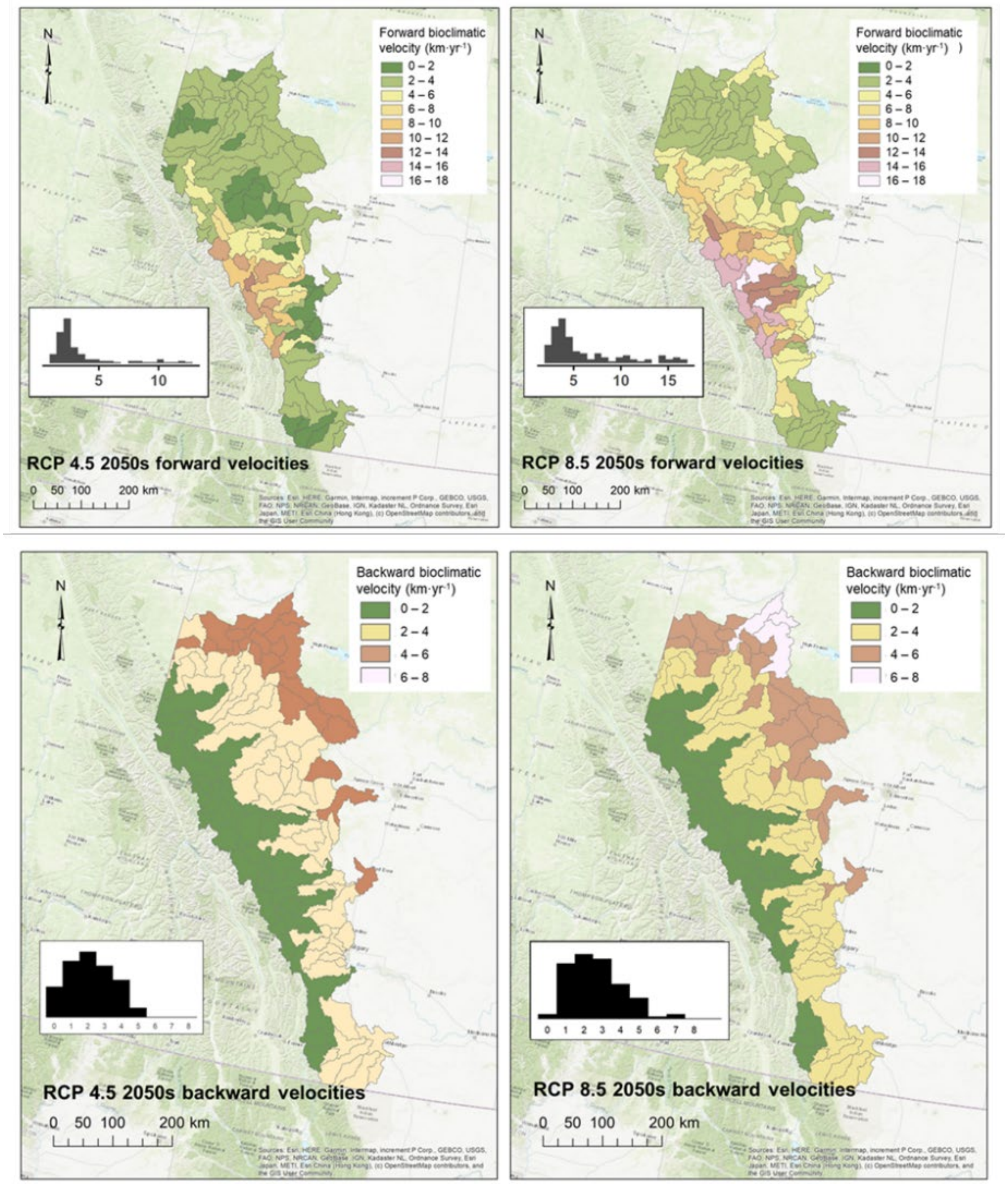

Figure 47. Forward and backward bioclimatic velocities to 2050s for each assessment unit in the AESA under RCP 4.5 and RCP 8.5 emissions scenarios.

Across the reporting area, climate change had limited impacts on a projected 100-year flood (Figure 48; Figure 49). Under RCP 4.5 flood height is predicted to decrease in more northern parts of the reporting area and increase in some center and southern watersheds. Predicted 100-year flooding under RCP 8.5 had less systematic geographical variation, with a mix of higher and lower predicted flood heights through the reporting area. Total flood volume was predicted to slightly decrease from 65.0 cubic kilometers to 64.6 cubic kilometers under the RCP 4.5 emission scenario, and further decrease to 56.1 cubic kilometres under RCP 8.5.

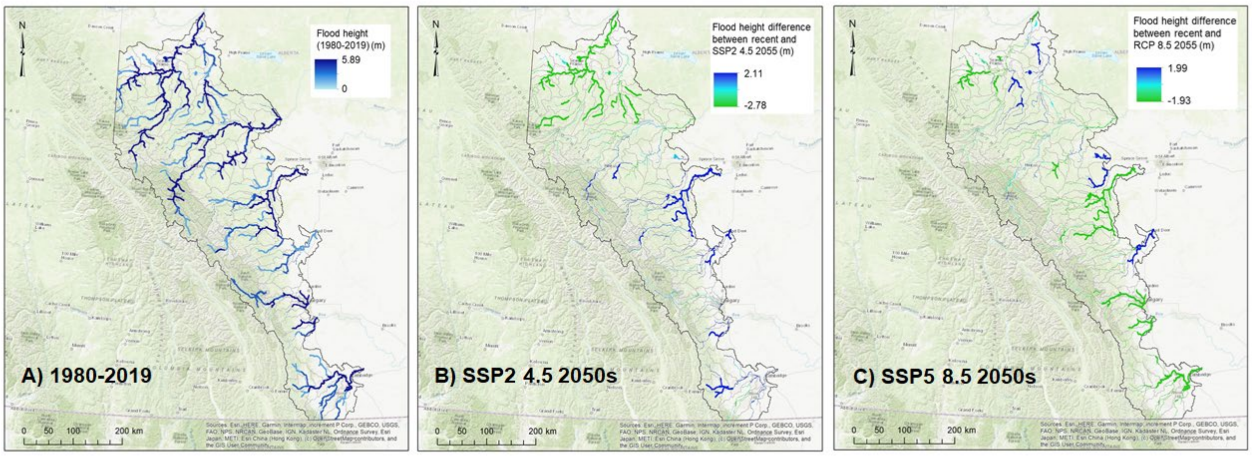

Figure 48. Change in flood height from current (A) to future climate scenario (B, C) for a 100-year flood. Panel A shows flood heights for a 100-year flood between 1980 and 2019, while panel B and C show the change in flood height (green = decrease in height, blue = increase in height) under low (SSP2 4.5) and high (SSP5 8.5) emission scenarios by 2050s.

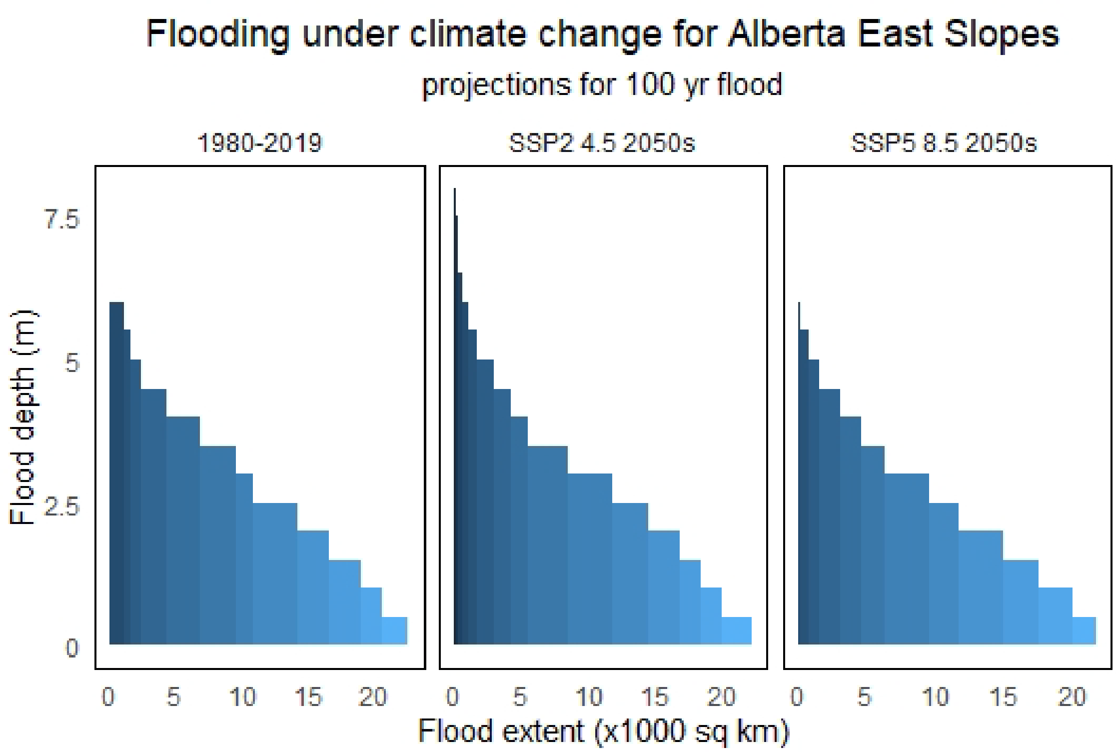

FIGURE 49. PROJECT FLOOD HEIGHTS AND EXTENTS FOR A 100-YEAR FLOOD UNDER CURRENT (1980-2019), SSP2 4.5 AND SSP5 8.5 CLIMATE SCENARIOS FOR THE AESA.

DISCUSSION

With the modernization of the *Fisheries Act*, DFO committed to producing 'State of Fish and Fish Habitat' (SOFFH) reports for Canada's freshwater ecosystems. The data compiled in this report provided information related to the SOFFH for the Ontario and Prairie Region. This document focuses on assessing the SOFFH in two focal reporting areas (the LGLA and AESA) and provides insight into the state of biodiversity, water quality, land use and land cover, connectivity and climate change. These factors are closely related to aquatic ecosystem health including the ability of habitats to support the life processes of fishes.

In general, the SOFFH in the LGLA and AESA reflect geographical patterns in species richness and physical habitat, and the impacts of agriculture and urbanization on watersheds. The LGLA has naturally high species richness associated with the Laurentian Great Lakes freshwater ecoregion but is heavily impacted by land cover change and disruption of aquatic connectivity associated with the dense human population. The human footprint has resulted in degraded water quality in some areas, the presence of multiple aquatic invasive species, and declines in fish and mussel populations resulting in 33 of 155 fish species (21%) having at-risk status. The AESA has much lower natural levels of species richness with correspondingly lower number of SAR however, a similar percentage (7 of 32 fish species, 21%) are also at risk. Urban centers within this reporting area are generally smaller and found in more downstream regions, resulting in lesser impact on water quality and intact natural land cover types in much of the reporting area. However, the AESA is at risk from climate impacts, with high bioclimatic velocities and altered flood dynamics associated with different watersheds and other factors such as introduced species and introgression.

To support the evaluation of the SOFFH in the LGLA and AESA, existing environmental thresholds were applied to the water quality metrics and riparian cover to describe not only the variation in the metrics across the reporting areas, but also to classify the values as "good" or "poor". Establishing thresholds for other metrics included in this report will require further research but could be based on the general approaches outlined in Dey and Chu (2023). For example, thresholds could be developed based on functional relationships between SOFFH metrics and management objectives, existing thresholds, relative ranking or expert opinion, and could be absolute, self-referent, or control referent in nature (see Dey and Chu 2023 for details). Promising metrics for threshold development within LGLA and AESA include thresholds for land use and land cover, which has been previously related to aquatic habitat quality and fish assemblages (Stanfield and Kilgour 2006, Sciera et al. 2008), protected area coverage, which has national and international goals (UN-CBD 2010, ECCC 2021), and change in fish biodiversity, which has been extensively researched in relation to ecosystem health (e.g., Chu et al. 2016, Anas and Mandrak 2022).

Overall scores of the SOFFH for each assessment unit or reporting area were not produced for this report. This decision was made because combining different metrics and indicators requires (implicit or explicit) decisions related to the relative weighting of different metrics to generate the overall score. Because different indicators and metrics may be differentially important to different species, life stages, and habitat features, such weightings are challenging to develop. Furthermore, defining an overall state is also challenged by reconciling the different spatial and temporal scales, and uncertainties related to the different data sources included in this document. For example, some data analyzed above were presented as point data (e.g., water quality measurements) but inferring the overall water quality of an entire assessment unit or reporting area requires assumptions about how the available data generalize across different environmental gradients.

Synthesis of the data for each metric indicated that there are data gaps related to the SOFFH in the focal reporting areas. Many assessment units in the AESA were data deficient for measures of macroinvertebrate community structure (EPT index). While macroinvertebrate community data were more widely available within the LGLA, there were still some geographic areas with poor coverage, either because data did not exist, or were not provided in a timely fashion for this report. Beyond biodiversity metrics, water quality data were also sparse across the AESA, most significantly for nutrient metrics (i.e., nitrate and total phosphorus), but also for chloride, conductivity, water temperature and dissolved oxygen. This scarcity is in contrast to the LGLA, where water quality data were readily available across most of the reporting area.

The indicators and metrics used to evaluate SOFFH in this report were based on recommendations from CSAS participants (i.e., in DFO 2022a), on access to readily available datasets, and on the spatial coverage of the data. Through this synthesis it became obvious that it was not possible to report on some of the recommended metrics such as e.g., physical habitat (e.g., substrate or macrophyte coverage) and spatial extent of water (e.g., width of rivers). This challenge existed for a few reasons. First, a general lack of data for many metrics e.g., substrates are not measured or classified in the majority of aquatic ecosystems in either reporting area. Second, the resolution and incompleteness of the data that are available e.g., rivers are often mapped and processed on provincial and national spatial platforms at a 30 m resolution. This resolution means that a 5 m wide stream is mapped the same as a 30 m wide stream, which can make it difficult to quantify the lateral extent of rivers in the reporting areas. In addition to the lateral limitations of hydrological data, depth data are also not readily available to understand the vertical dimension. Therefore, the actual volume of habitat that may be available for fishes within the reporting areas cannot be quantified, however, lake volumes are more straightforward to determine. Third, some of the analyses require research that is beyond the scope of the 2023 reporting of SOFFH. For example, a future iteration of SOFFH could explicitly quantify connectivity in LGLA using methods such as the Dendritic Connectivity Index (Cote et al. 2009), the hydrological network, and the existing barrier location and passability data to determine how much habitat is connected or fragmented. Finally, alternative metrics for some of the indicators may better reflect the state of fish and fish habitat. For example, although fish species richness as described in this report can identify areas of high versus low biodiversity, and many studies have related species richness to habitat conditions (e.g., Harding et al. 1998), species richness as measured with presence-absence data, may not be sensitive to some changes in fish and fish habitat. For example, Chu et al. (2018) found that other properties of communities such as relative abundance and community size distributions better reflected differences in fish communities inside and outside of protected areas in Ontario. Similarly, metrics related to abundance (or relative abundance) have been suggested to be better indicators of environmental degradation and contamination when compared to species richness in other freshwater and marine systems (Fausch et al. 1990, McKinley and Johnston 2010). More comprehensive monitoring of e.g., relative abundance could provide data that may be useful to explore and report on other metrics.

Identification of data gaps, and the limitations of selected metrics and indicators, is an important goal of the SOFFH reporting initiative. Evidence-based decision making related to the conservation and protection of freshwater ecosystems cannot be conducted in the absence of evidence, and scientific data on freshwater biodiversity and water quality are important components of this evidence base. As such, data gaps identified through the SOFFH reports could serve as priority areas for research and monitoring projects. Overcoming these deficiencies will require increasing the spatial and temporal coverage of sampled sites and monitoring programs throughout each reporting area, as well as adjusting monitoring programs towards measurement of metrics that are sensitive to changes in aquatic ecosystem health. For example, in the AESA, sites could be added in the northern and western regions where the terrain permits access. In the LGLA, more temporal sampling in winter may contribute to a better understanding of water chemistry dynamics. These types of synthesis efforts would also benefit from standardized timelines for data releases among the data sources that are coordinated with periodic updates of SOFFH and other types of assessment reports.

In addition to the uncertainties mentioned for different metrics in the Methods, the compilation of different datasets, analyses, and thresholds for this type of synthesis comes with several additional uncertainties. Measured data such as the water quality variables reflect habitat conditions at the locations and times of sampling but may not accurately represent the condition of habitat at other sites within the same waterway/waterbody/assessment unit or the same site at other time periods (e.g., other times of day or year). In addition to the spatial and temporal data gaps, there could be uncertainties associated with the natural variation of the metrics and ecosystems and the methods used for collection (e.g., differences in sensitivity of sampling instrumentation, measurement error, and the design of monitoring programs). Many existing thresholds, such as the CCME guidelines applied to water quality metrics herein, represent the upper limits (lower limit for dissolved oxygen) for the protection of aquatic life. Knowledge and inclusion of lower limits (e.g., minimum conductivity levels; Knaepkens et al. 2002, Zhang et al. 2019), would further support the development of habitat suitability indices for fishes in each reporting area in the future. Most of the spatial information analyzed for this report also have uncertainties; for example, meta-data from the original sources often include estimates of the accuracy of the data (e.g., within 30 cm or 1 m, or classification accuracy), which may have complex interactions with spatial and temporal data uncertainties described above.

The implications of these inaccuracies, from an ecological perspective, represent an information gap. These informational gaps are present both in the original data analyses conducted in this report, as well as in modelled data (e.g., bioclimatic velocities and flood projections) which include assumptions about the relationships among input parameters, the values of those input parameters, and overall model complexity. Furthermore, some of the classifications used in our analysis (e.g., Jenks natural breaks), describe the variation in the data but may not necessarily represent meaningful ecological classes. These uncertainties can be addressed with further research, standardized and extensive monitoring, and the development of methods to account for, or accurately communicate information about, uncertainties.

Despite these widespread uncertainties, the data compiled and presented in this report provide insight into the SOFFH in the Ontario and Prairie region and demonstrate how a quantitative approach to reporting on the SOFFH could be used by DFO in other regions. In addition to supporting immediate reporting needs, this document should also support future work to develop a consistent national approach to SOFFH reporting, which could be implemented in subsequent iterations of SOFFH reporting.

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APPENDIX A

Table A1. Data sources for State of Fish and Fish Habitat reporting within the Lower Great Lakes Area and Alberta East Slopes Area.

Indicator	Metric	Reporting area	Data source
Biodiversity	Fish species richness, SAR richness, AIS richness	LGLA	• Unpublished DFO fish inventories • NDMNRF Aquatic Resource Area layer • Smith et al. 2023 • Anas and Mandrak 2022 • Canadian species at risk distributions: Fisheries and Oceans Canada Species at Risk Distribution (Range)
-	Fish species richness, SAR richness, AIS richness	AESA	• Fish and Wildlife Management Information System (FWMIS), Alberta Environment and Parks
-	EPT index	LGLA	• Ontario Benthos Biomonitoring Network (OBBN) • NDMNRF Provincial Integrated Hydrology layer
-	-	AESA	• Canadian Aquatic Biomonitoring Network • Alberta FWMIS Hydrology
Water quality	Chloride, Conductivity, Dissolved oxygen, Nitrates, Total phosphorus, Temperature	LGLA	• Great Lakes DatsStream • Nutrients in Great Lakes Priority Tributaries Data • Ontario Provincial Water Quality Monitoring Network
-	Chloride, Conductivity, Dissolved oxygen, Temperature	AESA	• Long Term River Station Data • Lake Water Quality Data • Tributary Monitoring Network
Connectivity	Barrier inventory	LGLA and AESA	• Canadian Aquatic Barrier Database
-	Stream connectivity	AESA	• Stream connectivity layer, Alberta Environment and Parks
-	Watercourse crossings	AESA and LGLA	See road density data below, plus: • Ontario Rail Network • Ontario Integrated Hydrology data • National Rail Network • Alberta FWMIS Hydrology
Land use and land cover	Land use and land cover types, riparian vegetation	LGLA and AESA	• ESA Sentinel-2 imagery • Used hydrology layers above to generate 30 m riparian buffers
-	Protected areas	LGLA	• Canadian Protected and Conserved Area Database (CPCAD) • Ontario NGO Nature Reserves
-	-	AESA	• Canadian Protected and Conserved Area Database (CPCAD) • Parks and protected areas of Alberta

Indicator	Metric	Reporting area	Data source
-	Road density	LGLA and AESA	• Ontario Road and Rail Network • National Road Network
Climate change	Bioclimatic velocities	LGLA and AESA	• Adaptwest
-	Floods	LGLA and AESA	• Floodplain projections

APPENDIX B

Table B1. Native, non-native or listed invasive fish species found in LGLA. Non-native species are introduced either outside their native range in North America or native to another continent but introduced and established with LGLA. Invasive species are those listed federally or provincially as an invasive species because they have negative impacts on invaded ecosystems. Values indicate the total number of assessment units where the species was found.

Species	Scientific name	Native	Non-native	Invasive
Alewife	*Alosa pseudoharengus*	0	62	0
American Brook Lamprey	*Lampetra appendix*	48	0	0
American Eel	*Anguilla rostrata*	47	5	0
American Shad	*Alosa sapidissima*	1	0	0
Amur pike	*Esox reichertii*	0	1	0
Atlantic Salmon	*Salmo salar*	16	0	0
Aurora trout	*Salvelinus fontinalis timagamiensis*	1	0	0
Banded Killifish	*Fundulus diaphanus*	82	0	0
Bigmouth Buffalo	*Ictiobus cyprinellus*	17	20	0
Black Buffalo	*Ictiobus niger*	0	6	0
Black Bullhead	*Ameiurus melas*	79	0	0
Black Crappie	*Pomoxis nigromaculatus*	108	0	0
Black Redhorse	*Moxostoma duquesnei*	24	0	0
Blackchin Shiner	*Notropis heterodon*	74	0	0
Blackfin Cisco	*Coregonus nigripinnis*	3	0	0
Blacknose Dace	*Rhinichthys atratulus*	15	0	0
Blacknose Shiner	*Notropis heterolepis*	136	0	0
Blackside Darter	*Percina maculata*	84	0	0
Blackstripe Topminnow	*Fundulus notatus*	10	0	0
Bloater	*Coregonus hoyi*	5	0	0
Bluegill	*Lepomis macrochirus*	150	0	0
Bluntnose Minnow	*Pimephales notatus*	185	0	0
Bowfin	*Amia calva*	60	0	0
Brassy Minnow	*Hybognathus hankinsoni*	124	0	0
Bridle Shiner	*Notropis bifrenatus*	10	0	0
Brindled Madtom	*Noturus miurus*	21	0	0
Brook Silverside	*Labidesthes sicculus*	70	0	0
Brook Stickleback	*Culaea inconstans*	174	0	0
Brook Trout	*Salvelinus fontinalis*	100	0	0
Brown Bullhead	*Ameiurus nebulosus*	171	0	0
Brown Trout	*Salmo trutta*	0	69	0
Burbot	*Lota lota*	40	0	0
Central Mudminnow	*Umbra limi*	164	0	0
Central Stoneroller	*Campostoma anomalum*	70	0	0
Chain Pickerel	*Esox niger*	0	3	0
Channel Catfish	*Ictalurus punctatus*	67	0	0

Species	Scientific name	Native	Non-native	Invasive
Channel Darter	*Percina copelandi*	23	0	0
Chinook Salmon	*Oncorhynchus tshawytscha*	0	33	0
Chum Salmon	*Oncorhynchus keta*	0	1	0
Cisco	*Coregonus artedi*	51	0	0
Coho Salmon	*Oncorhynchus kisutch*	0	24	0
Common Carp	*Cyprinus carpio*	0	134	0
Common Shiner	*Luxilus cornutus*	181	0	0
Creek Chub	*Semotilus atromaculatus*	175	0	0
Deepwater Cisco	*Coregonus johannae*	1	0	0
Deepwater Sculpin	*Myoxocephalus thompsonii*	5	0	0
Eastern Blacknose Dace	*Rhinichthys atratulus*	112	0	0
Eastern Sand Darter	*Ammocrypta pellucida*	29	0	0
Eastern Silvery Minnow	*Hybognathus regius*	6	0	0
Emerald Shiner	*Notropis atherinoides*	119	0	0
European Flounder	*Platichthys flesus*	0	3	0
Fallfish	*Semotilus corporalis*	54	0	0
Fantail Darter	*Etheostoma flabellare*	90	0	0
Fathead Minnow	*Pimephales promelas*	178	0	0
Finescale Dace	*Chrosomus neogaeus*	71	0	0
Flathead Catfish	*Pylodictis olivaris*	0	6	0
Florida Gar	*Lepisosteus platyrhincus*	0	1	0
Fourspine Stickleback	*Apeltes quadracus*	0	3	0
Freshwater Drum	*Aplodinotus grunniens*	67	0	0
Ghost Shiner	*Notropis buchanani*	26	0	0
Gizzard Shad	*Dorosoma cepedianum*	70	12	0
Golden Redhorse	*Moxostoma erythrurum*	76	0	0
Golden Shiner	*Notemigonus crysoleucas*	167	0	0
Goldfish	*Carassius auratus*	0	0	91
Grass Carp	*Ctenopharyngodon idella*	0	0	5
Grass Pickerel	*Esox americanus vermiculatus*	27	0	0
Greater Redhorse	*Moxostoma valenciennesi*	60	0	0
Green Sunfish	*Lepomis cyanellus*	84	0	0
Greenside Darter	*Etheostoma blennioides*	61	0	0
Hornyhead Chub	*Nocomis biguttatus*	100	0	0
Iowa Darter	*Etheostoma exile*	118	0	0
Johnny Darter	*Etheostoma nigrum*	142	0	0
Lake Chub	*Couesius plumbeus*	27	1	0
Lake Chubsucker	*Erimyzon sucetta*	13	0	0
Lake Sturgeon	*Acipenser fulvescens*	39	0	0
Lake Trout	*Salvelinus namaycush*	39	0	0
Lake Whitefish	*Coregonus clupeaformis*	34	0	0
Largemouth Bass	*Micropterus salmoides*	183	0	0

Species	Scientific name	Native	Non-native	Invasive
Least Darter	*Etheostoma microperca*	71	0	0
Logperch	*Percina caprodes*	129	0	0
Longear Sunfish	*Lepomis megalotis*	38	0	0
Longnose Dace	*Rhinichthys cataractae*	117	0	0
Longnose Gar	*Lepisosteus osseus*	68	0	0
Longnose Sucker	*Catostomus catostomus*	31	0	0
Margined Madtom	*Noturus insignis*	4	0	0
Mimic Shiner	*Notropis volucellus*	107	0	0
Mooneye	*Hiodon tergisus*	27	0	0
Mottled Sculpin	*Cottus bairdii*	105	0	0
Muskellunge	*Esox masquinongy*	61	0	0
Ninespine Stickleback	*Pungitius pungitius*	17	0	0
Northern Brook Lamprey	*Ichthyomyzon fossor*	19	0	0
Northern Hog Sucker	*Hypentelium nigricans*	95	0	0
Northern Madtom	*Noturus stigmosus*	10	0	0
Northern Pearl Dace	*Margariscus nachtriebi*	113	0	0
Northern Pike	*Esox lucius*	144	0	0
Northern Redbelly Dace	*Chrosomus eos*	150	0	0
Northern Sunfish	*Lepomis peltastes*	56	0	0
Orangespotted Sunfish	*Lepomis humilis*	0	10	0
Oscar	*Astronotus ocellatus*	0	1	0
Pink Salmon	*Oncorhynchus gorbuscha*	0	6	0
Pugnose Minnow	*Opsopoeodus emiliae*	11	0	0
Pugnose Shiner	*Notropis anogenus*	16	0	0
Pumpkinseed	*Lepomis gibbosus*	189	0	0
Quillback	*Carpiodes cyprinus*	57	0	0
Rainbow Darter	*Etheostoma caeruleum*	86	0	0
Rainbow Smelt	*Osmerus mordax*	0	0	52
Rainbow Trout	*Oncorhynchus mykiss*	0	105	0
Redfin Shiner	*Lythrurus umbratilis*	46	0	0
Redside Dace	*Clinostomus elongatus*	22	0	0
River Chub	*Nocomis micropogon*	75	0	0
River Darter	*Percina shumardi*	8	0	0
River Redhorse	*Moxostoma carinatum*	14	0	0
Rock Bass	*Ambloplites rupestris*	192	0	0
Rosyface Shiner	*Notropis rubellus*	100	0	0
Round Goby	*Neogobius melanostomus*	0	0	83
Round Whitefish	*Prosopium cylindraceum*	11	0	0
Rudd	*Scardinius erythrophthalmus*	0	0	22
Sand Shiner	*Notropis stramineus*	50	0	0
Sauger	*Sander canadensis*	13	0	0
Sea Lamprey	*Petromyzon marinus*	0	0	49

Species	Scientific name	Native	Non-native	Invasive
Shorthead Redhorse	*Moxostoma macrolepidotum*	81	0	0
Shortjaw Cisco	*Coregonus zenithicus*	4	0	0
Shortnose Cisco	*Coregonus reighardi*	3	0	0
Silver Chub	*Macrhybopsis storeriana*	17	0	0
Silver Lamprey	*Ichthyomyzon unicuspis*	29	0	0
Silver Redhorse	*Moxostoma anisurum*	65	0	0
Silver Shiner	*Notropis photogenis*	31	0	0
Slimy Sculpin	*Cottus cognatus*	46	0	0
Smallmouth Bass	*Micropterus dolomieu*	181	0	0
Smallmouth Buffalo	*Ictiobus bubalus*	5	0	0
Spoonhead Sculpin	*Cottus ricei*	2	0	0
Spotfin Shiner	*Cyprinella spiloptera*	101	0	0
Spottail Shiner	*Notropis hudsonius*	126	0	0
Spotted Gar	*Lepisosteus oculatus*	10	0	0
Spotted Sucker	*Minytrema melanops*	26	0	0
Stonecat	*Noturus flavus*	96	0	0
Striped Shiner	*Luxilus chrysocephalus*	84	0	0
Tadpole Madtom	*Noturus gyrinus*	59	0	0
Tessellated Darter	*Etheostoma olmstedi*	19	0	0
Threespine Stickleback	*Gasterosteus aculeatus*	29	8	0
Trout-Perch	*Percopsis omiscomaycus*	63	0	0
Tubenose Goby	*Proterorhinus semilunaris*	0	0	15
Walleye	*Sander vitreus*	115	0	0
Warmouth	*Lepomis gulosus*	7	0	0
Western Blacknose Dace	*Rhinichthys obtusus*	123	0	0
White Bass	*Morone chrysops*	69	0	0
White Crappie	*Pomoxis annularis*	60	0	0
White Perch	*Morone americana*	0	69	0
White Sucker	*Catostomus commersonii*	193	0	0
Yellow Bullhead	*Ameiurus natalis*	89	0	0
Yellow Perch	*Perca flavescens*	184	0	0

APPENDIX C

Table C1. Fish species found in AESA and whether they are native, non-native or invasive. Non-native species are either introduced outside their native range in North America or native to another continent but introduced and established with either reporting area. Invasive species are those listed federally or provincially as an invasive species because they have negative impacts on invaded ecosystems. Values indicate the total number of assessment units where the species was found.

Common name	Scientific name	Native	Non-native	Invasive
Arctic Char	*Salvelinus alpinus*	1	0	0
Arctic Grayling	*Thymallus arcticus*	39	1	0
Athabasca Rainbow Trout	*Oncorhynchus mykiss*	3	0	0
Brassy Minnow	*Hybognathus hankinsoni*	1	0	0
Brook Stickleback	*Culaea inconstans*	74	0	0
Brook Trout	*Salvelinus fontinalis*	0	55	0
Brown Trout	*Salmo trutta*	0	45	0
Bull Trout	*Salvelinus confluentus*	72	0	0
Burbot	*Lota lota*	77	0	0
Cutthroat Trout	*Oncorhynchus clarki*	32	0	0
Dolly Varden	*Salvelinus malma*	3	0	0
Emerald Shiner	*Notropis atherinoides*	27	0	0
Fathead Minnow	*Pimephales promelas*	44	0	0
Finescale Dace	*Chrosomus neogaeus*	51	0	0
Flathead Chub	*Platygobio gracilis*	23	0	0
Golden Trout	*Oncorhynchus aquabonita*	2	0	0
Goldeye	*Hiodon alosoides*	15	0	0
Goldfish	*Carassius auratus*	0	0	6
Iowa Darter	*Etheostoma exile*	14	0	0
Kokanee	*Oncorhynchus nerka*	1	0	0
Lake Chub	*Couesius plumbeus*	84	2	0
Lake Sturgeon	*Acipenser fulvescens*	6	0	0
Lake Trout	*Salvelinus namaycush*	19	0	0
Lake Whitefish	*Coregonus clupeaformis*	17	3	0
Largescale Sucker	*Catostomus macrocheilus*	10	0	0
Longnose Dace	*Rhinichthys cataractae*	85	0	0
Longnose Sucker	*Catostomus catostomus*	88	0	0
Mooneye	*Hiodon tergisus*	9	0	0
Mountain Sucker	*Catostomus platyrhynchus*	30	0	0
Mountain Whitefish	*Prosopium williamsoni*	88	0	0
Ninespine Stickleback	*Pungitius pungitius*	2	0	0
Northern Pike	*Esox lucius*	62	0	0
Northern Pikeminnow	*Ptychocheilus oregonensis*	4	0	0
Northern Redbelly Dace	*Chrosomus eos*	42	0	0
Peamouth Chub	*Mylocheilus caurinus*	1	0	0
Pearl Dace	*Margariscus nachtriebi*	72	0	0

Common name	Scientific name	Native	Non-native	Invasive
Prickly Sculpin	*Cottus asper*	1	0	0
Prussian Carp	*Carassius gibelio*	0	0	6
Pygmy Whitefish	*Prosopium coulterii*	3	0	0
Quillback	*Carpiodes cyprinus*	2	0	0
Rainbow Trout	*Oncorhynchus mykiss*	0	66	0
Redside Shiner	*Richardsonius balteatus*	21	0	0
River Shiner	*Notropis blennius*	8	0	0
Rocky Mountain Sculpin	*Cottus bondi*	1	0	0
Round Whitefish	*Prosopium cylindraceum*	1	0	0
Sauger	*Sander canadense*	4	0	0
Shorthead Redhorse	*Moxostoma macrolepidotum*	13	0	0
Silver Redhorse	*Moxostoma anisurum*	5	0	0
Slimy Sculpin	*Cottus cognatus*	38	0	0
Spoonhead Sculpin	*Cottus ricei*	63	0	0
Spottail Shiner	*Notropis hudsonius*	34	2	0
Threespine Stickleback	*Gasterosteus aculeatus*	1	0	0
Trout-perch	*Percopsis omiscomaycus*	67	0	0
Tullibee (Cisco)	*Coregonus artedii*	3	0	0
Walleye	*Sander vitreus*	43	0	0
Westslope Cutthroat Trout	*Oncorhynchus clarkii lewisi*	7	0	0
White Sucker	*Catostomus commersonii*	89	0	0
Yellow Perch	*Perca flavescens*	25	0	0

APPENDIX D

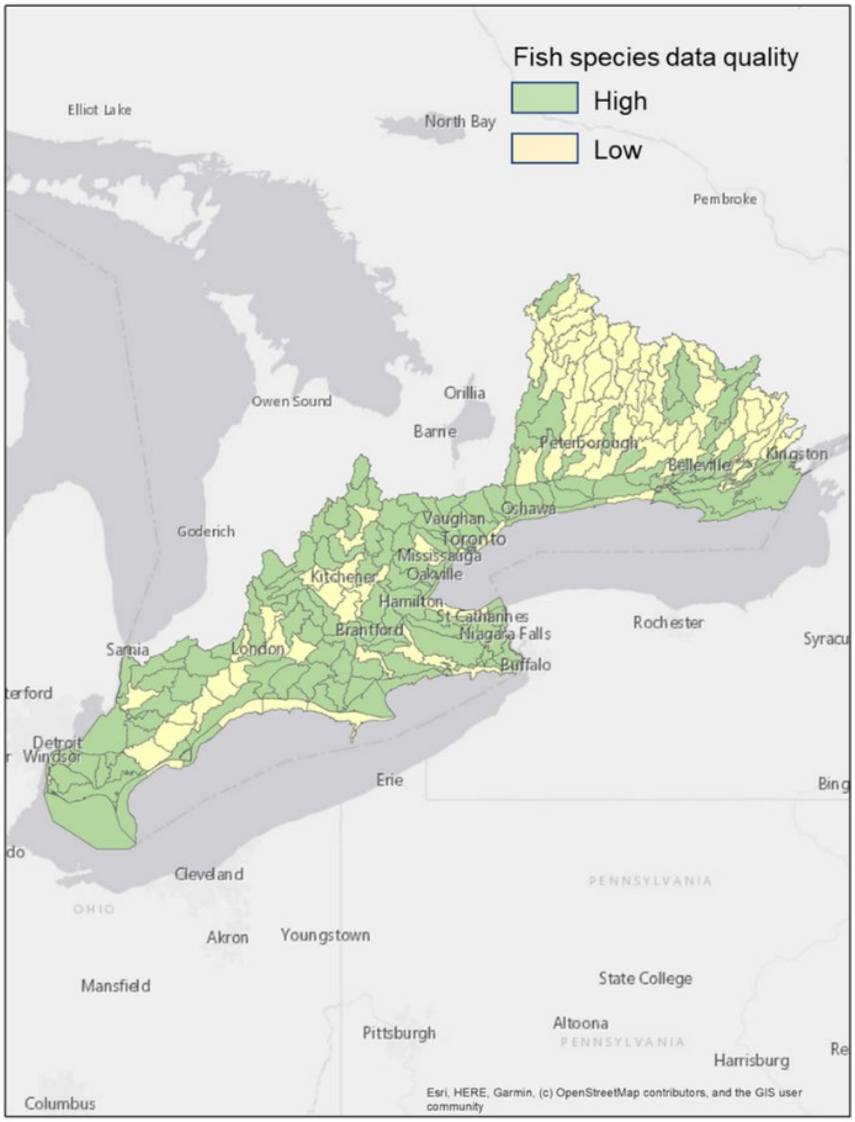

Figure D1. Quality of the fish species data in the assessment units of the LGLA. Data quality was determined using species accumulation curves. Assessment units with high data quality had curves that reached an asymptote (i.e., sampling was sufficient to be confident that all species in the community were captured). Species accumulation curves that did not asymptote were assigned low data quality, which suggests that the sampling was insufficient to reflect the whole fish community.

APPENDIX E

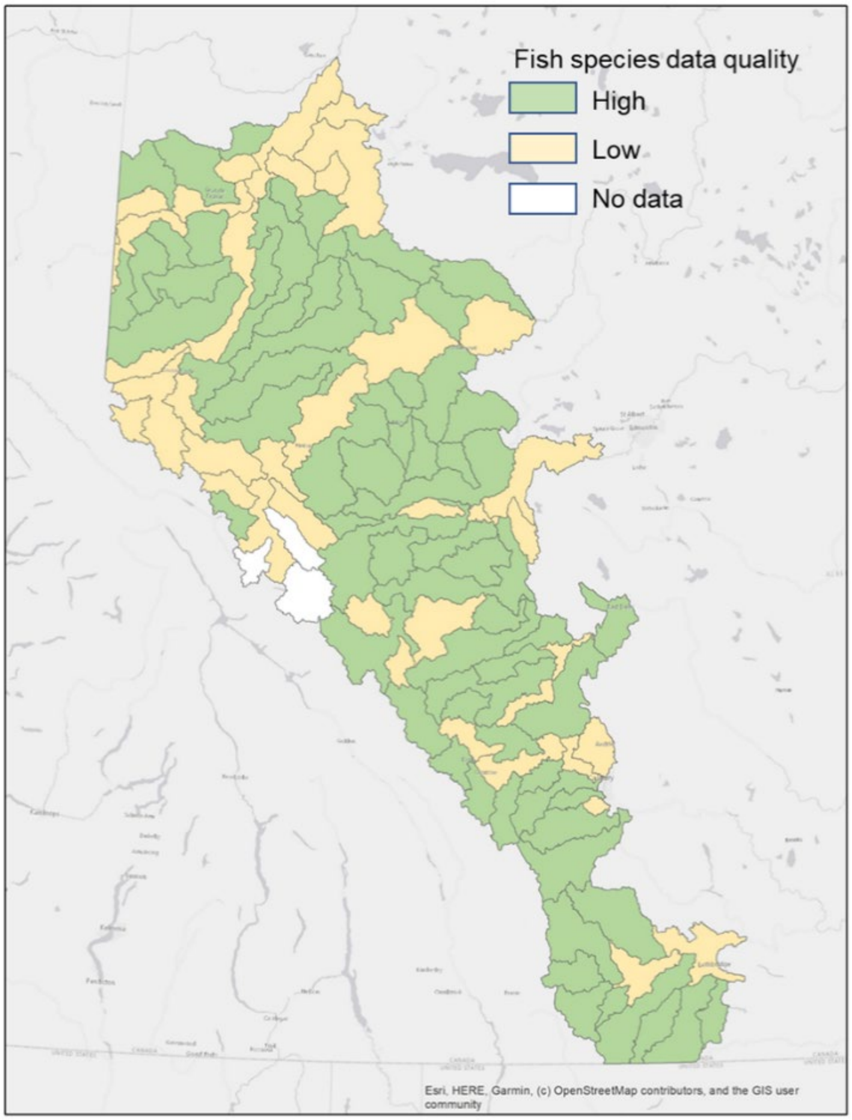

Figure E1. Quality of the fish species data in the assessment units of the AESA. Data quality was determined using species accumulation curves. Assessment units with high data quality had curves that reached an asymptote (i.e., sampling was sufficient to be confident that all species in the community were captured). Species accumulation curves that did not asymptote were assigned low data quality, which suggests that the sampling was insufficient to reflect the whole fish community.