Conservation of Lakeshore Zones in the Northern Boreal Mountains:

State of Knowledge, and Principles and Guidelines for Planning and Management

JOËL POTIÉ AND DONALD REID

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Front cover: Mountains of the Coast Range are reflected in still water (Lindeman Lake, Donald Reid). Back cover: A thunderstorm builds over the Horseranch Range (Boya Lake, Donald Reid).

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DEDICATION – GERRY WHITLEY

We dedicate this Report to the memory of the late Gerry Whitley.

Gerry was a scientist with a passion for water and a strong desire to see it used wisely. Among other accomplishments, he was Study Director for the Yukon River Basin Study, published in 1984. This was a bold initiative to survey the attributes and resources of the drainage and improve the planning and stewardship of its water resources in the context of economic development.

Gerry also had a passion for conservation and natural history. He realised that aerial imagery can be an excellent tool for telling a story and getting a better perspective on our valuable lands and waters. Along with his wife, Mary, who has a similar passion, he flew many hours with an array of cameras attached to his aircraft, capturing video footage that he made available to conservation organizations.

We hope that this document will help to keep Gerry's vision of better water stewardship alive into the future.

ACKNOWLEDGEMENTS

We are indebted to three passionate fish and fish habitat biologists, each with extensive experience in the northern boreal mountains and/or other boreal drainages, for their advice and guidance on this work and for their reviews of an earlier draft of the manuscript. They are Don Toews, Al von Finster, and Paul Blanchfield. Despite their input and efforts, any remaining errors in fact or interpretation remain ours, as authors.

Gerry Whitley generously flew his aircraft to capture many aerial images of Yukon landscapes for use by those interested in conservation and the future of our water. Some of those are featured here.

Maria Leung prepared the line drawings and provided images for illustration. Piia Kortsalo prepared the maps. Hilary Cooke and Lila Tauzer shared images of Yukon lakes. All of these figures substantially enhance the presentation of information.

This project was supported by generous funding from the Yukon Fish and Wildlife Enhancement Trust, and from The Weston Family Foundation.

Yukon Fish & Wildlife Enhancement Trust

Weston Family Foundation

SUMMARY

Lakes and their shorelines are profoundly valuable to human beings and a wide range of other species with whom we share the world. We are drawn to lakes because they provide us with food and travel routes. Long vistas over water enhance our safety through reading weather and other risks, and open our imaginations to esthetic and spiritual exploration. The particularly high diversity of species associated with lakes, and the relatively high productivity of their shore and associated littoral and riparian zones, clearly show that these habitats have high ecological value.

The goal of this document is to illustrate the high ecological and social value of lakeshore zones for humans and wildlife, and to lay out possible approaches for better recognition of lakeshore values in ongoing planning and stewardship for these ecosystems in the northern boreal mountains. Our geographic focus is the Boreal Cordillera ecozone of northern British Columbia and south Yukon. We provide summaries of the ecological and social values of lakeshore zones and their associated near-shore and tributary water bodies. We also outline a set of knowledge gaps that have emerged from this review. Finally, we lay out a series of suggested principles and associated guidelines for proactive and improved planning and management of lakeshore zones in the future. These are presented as reference for planners, managers, and assessors as they implement their land-planning and management mandates at scales varying from the strategic to the operational.

Although the distinction between land and water is thought to be obvious, with lake edges often being clearly defined as a "shoreline," the ecosystem actually straddles this edge with a remarkably diverse set of interactions between land and water and their associated species including humans. This is the lakeshore zone or ecosystem. We provide an overview of the species of fish, amphibians, birds, and mammals that occupy the lakeshore ecosystem in the Boreal Cordillera and their intricate linkages and mutual effects through the food web.

Each lake or pond is the product of an ongoing set of interactions with the surrounding land, largely through surface and groundwater flows and inputs. The interactions are strongly influenced by climate and by how the whole drainage basin captures water and other materials from the atmosphere and processes them through soils and bedrock on the way downslope. The fish

The goal of this document is to illustrate the high ecological and social value of lakeshore zones for humans and wildlife, and to lay out possible approaches for better recognition of lakeshore values in ongoing planning and stewardship for these ecosystems in the northern boreal mountains.

living in a particular lake have colonized through complicated patterns of post-glacial drainage. Other organisms have arrived by fascinating but often poorly understood patterns of range expansion since glaciers covered the region. All now interact in a food web driven by the summer pulse of nutrient inflow from the land, photosynthesis, and warming water, largely concentrated in shallow water (the littoral zone) close to the shore.

This food web is partly contained within the lake, but is closely linked to land. Aquatic insects and fish often dominate the diet of terrestrial birds and various mammals consume fish, transferring nutrients back to the land. The terrestrial part of the ecosystem (the riparian zone) generally supports the highest diversity of species and the widest variety of plant communities of any forested landscape in this region. In summary, lakes and lakeshore ecosystems are remarkably diverse, with aquatic and terrestrial components closely interlinked in a complete ecosystem that supports the needs of numerous species including humans.

Lakeshores and associated habitats in the northern boreal mountains have been crucial habitats for humans since Indigenous peoples moved into the interior of the continent. Lakes, rivers and valley bottom shorelines are relatively straightforward travel corridors through rugged terrain. Their waters support substantial populations of fish that can be caught quite readily in certain habitats. Their shorelines and associated wetlands provide home to other harvestable species, such as beaver, moose and waterfowl. Indigenous peoples found particular sites on lakeshores to have high value for shelter as camps, for access to food, for safety as places of lookout and perspective, and for esthetic and spiritual meaning as places of great beauty or high flows of energy. These values persist today for many people.

The value of lakeshore ecosystems has tended to be overlooked by land-use and land-management decision processes in the north. Although substantial information is available from other boreal regions, new information from lakes in the Boreal Cordillera would be valuable. In particular, we often lack lake and drainage-specific information on fish movements and spawning sites, along with information on high-value habitats and cultural sites. New information and approaches to management can and are being acquired through Land Claims Agreements and through processes that combine scientific and technical information with local and traditional knowledge from Indigenous communities and people frequently using lakes. Ongoing field investigations are also contributing new insights.

We lay out a proposed set of Principles and Guidelines, based mainly on scientific and technical considerations, that appear to be essential for good planning and management of lakeshore zones. We view Principles as general statements of desired future condition. Some pertain to the regional (strategic) scale and others to the individual lake (local or operational) scale. Principles should lead to Actions, which need to be implemented in planning and management processes and by agencies, and Actions ideally result in Outcomes. The Guidelines are methods and directions for implementing Actions as a way to achieve Outcomes – they lay out how a Principle might be achieved.

We lay out a proposed set of Principles and Guidelines, based mainly on scientific and technical considerations, that appear to be essential for good planning and management of lakeshore zones.

We suggest the following Principles and *Guidelines* (in italics) for a planning region scale:

- Ascertain the full set of ecological and socio-cultural values associated with lakes in the planning region.
- Apply a whole hydrological system (watershed) approach to subsequent planning and management considerations.
- Protect a set of lakes that well represents the range of different types of lake ecosystems found regionally and in the Boreal Cordillera, including rare and unique lake types. *Lake Classification system.*
- Lay out allowed ranges of human influence on individual lakes and/or lakeshores with a lakeshore zoning system. *Lake and Lakeshore Zoning system.*

We suggest the following Principles and *Guidelines* (in italics) for planning and management at the individual lake scale:

- Maintain the variety of riparian and littoral habitats a lakeshore zone would have within its typical range of natural variability at spatial scales that function well ecologically. *Mapping of littoral and riparian zone habitats and application of Riparian Management Area standards based on pertinent field data for key species and ecological processes.*
- Maintain high levels of terrestrial (riparian) and hydrological (littoral & stream) connectivity at the individual lake scale. *Lake and lakeshore zoning system.*
- Protect key and critical habitats for focal species whose scale of habitat needs is easily impacted by the scale of new human developments and activities. *Management of key habitats with spatial buffers and timing windows.*
- Minimize negative impacts of development in the riparian zone. *Riparian Stewardship actions.*
- Minimize risk of introduction of invasive species to lakes. *Boat and equipment cleaning and maintenance actions.*

1.0 INTRODUCTION

The goal of this document is to illustrate the high ecological and social value of lakeshore zones for humans and wildlife, and to lay out possible approaches for better consideration of lakeshore values in ongoing planning and stewardship for these ecosystems in the northern boreal mountains.

Lakes and their shorelines are profoundly valuable to human beings and a wide range of other species with which we share the world. We are drawn to lakes largely because they provide us with food and travel routes, and because freshwater is essential for the survival of all life. Along their shores we also benefit from long-distance perspectives that enhance our safety through reading weather and other risks and that open our imaginations to esthetic and spiritual exploration. In addition, it is clear, from the particularly high diversity of species associated with lakes and the relatively high productivity of their shore zones (Nilsson and Svedmark 2002, Strayer and Findlay 2010), that these habitats have high ecological value.

The early scientific view often considered aquatic and terrestrial environments as separate and rather isolated systems (Forbes 1887). That view has changed considerably as geographers, naturalists, and ecologists have developed a greater understanding of the remarkably diverse set of interactions between land and water and their associated species, including humans, in this "lakeshore zone" or ecosystem (Likens 1984, Wetzel 2001, Strayer and Findlay 2010). However, the clear distinction between land and water defined by a "shoreline" still leads us to structure and organize our management agencies, policy approaches, and environmental assessment processes into these two realms. More needs to be done to integrate the ways that humans manage and steward both the water bodies themselves and the lands of their drainage basins by thinking more of ecosystem processes that span these realms. Our intention is that this document will stimulate some more of this thinking and action for this region.

As with many ecosystems, the edges of the lakeshore ecosystem are not obvious and defining the bounds of the shore zone is difficult (Strayer and Findlay 2010). However, we follow the general definition provided by Strayer and Findlay (2010): "the shore zone is the region closely adjoining the shoreline in which strong and direct interactions tightly link the terrestrial ecosystem to the aquatic ecosystem, and vice versa." These linkages are primarily underground water supporting growth of trees on land (the riparian zone), and mate-

The riparian, shoreline, and littoral components of shore zone ecosystems vary substantially in width and composition depending on topography and extent of fluctuations in lake levels.

(Top left) The riparian and littoral zones are very narrow where steep ground inclines directly to the shoreline and into the lake and the shoreline varies in position due to extensive fluctuations in water level (Kluane Lake, August 2019) (Donald Reid).

(Top right) Steep slopes (near shore) leave only a narrow ribbon of riparian spruce forest, whereas more level ground supports a wider riparian forest (far shore) and the littoral zone of variable width shows as lighter colours in the water (Middle Snafu Lake, September 2019) (Donald Reid).

(Bottom left) With relatively stable water levels and flat ground, the entire lake is in the littoral zone and the wide riparian zone supports a mix of mature trees, shrubs, and water-dependent ground cover (M'Clintock Oxbow Lake, May 2020) (Donald Reid).

(Bottom right) Beavers changed the water level, flooding some riparian spruce forest that died (foreground), and leaving a margin of open grass and sedge vegetation around this shallow bay that is entirely in the littoral zone (Loon Lake, June 2014) (Donald Reid).

rials from land supporting growth of organisms in the shallow waters of the lake (the littoral zone). The tight linkages, in effect, make this one ecosystem unto itself: the shore zone ecosystem.

The body of water and its underlying structure and substrates are the dominant elements defining habitats for many of the organisms in this shore zone ecosystem. They can be termed "aquatic" species. However, many characteristics of the water and its substrates are strongly influenced by the adjacent land, which supplies, at varying rates, much of the water, organic matter, sediments and minerals found in the water body. Each lake or pond is therefore the product of an ongoing set of interactions with the surrounding land. The nature and speed of these interactions is strongly influenced by climate and by how the upslope drainage basin captures water and other materials from the atmosphere and then processes these materials through bedrock and soils to plants and animals, ultimately depositing some of them into the water (Likens 1984).

Similarly, materials flow from the aquatic world to the land. Many aquatic species, especially insects, emerge from the water for portions of their lives, living in air and on vegetation growing on land. Here they become food for land-based species, especially birds and bats (Schindler and Smits 2017). Fish captured by birds and mammals are often consumed on or over land and contribute nutrients to the terrestrial environment (Gende et al. 2002). Many fish species move into or through shallow water in lakes and associated streams where they are preyed on and eaten by carnivores that live mostly on the land. These are examples of flows of organic material and nutrients that the lake provides mainly to adjacent lands, significantly enhancing the diversity and abundance of terrestrial species and even the productivity of the vegetation (Wetzel 2001).

In addition, many species requiring air to breathe and terrestrial habitats for shelter have evolved to gather large amounts of their food from the aquatic part of the ecosystem. They can be called "semi-aquatic" species, and include numerous birds and mammals

In summary, lakeshore ecosystems, including substantial portions of the lakes themselves along with the shoreline and adjacent land, are remarkably diverse with components closely interlinked and supporting the needs of numerous species of which humans are only one.

Lakeshores and associated habitats in the northern boreal mountains of northwest North America have been crucial habitats for humans since Indigenous peoples moved into the interior of the continent following the last glacial maximum (McClellan 1987, Gotthardt 1992, Thomas 2003, Heffner 2008). Lakes and rivers and their valley bottom shorelines were relatively straightforward travel corridors, by boat or foot, through rugged terrain. Their waters supported substantial populations of resident and migratory fish, such as whitefish (*Coregonus* spp) and salmon *(Oncorhynchus* spp), that could be caught quite readily in certain habitats, and led to seasonal camps and settlements that were used over hundreds or thousands of years (Gotthardt 1992, Gotthardt and Hare 1994, Gotthardt 2000, Charlie and Clark 2003). Their shorelines and associated wetlands were home to other species, such as beaver (*Castor canadensis*), moose (*Alces alces*), and waterfowl (Anatidae), that humans could use for food and other purposes (McClellan 1987, Norman 1990, Charlie and Clark 2003).

Indigenous peoples found particular sites on lakeshores to have high value for access to freshwater, fish and game, for shelter as camps, for safety as places of lookout and perspective, and for esthetic and spiritual meaning as places of great beauty or high flows of energy (McClellan 1987, Gotthardt 2000). Humans also influenced the lakeshore ecosystems, by changing vegetation patterns (sometimes with fire) and by harvesting, and they would have influenced local abundances of many species (Gottesfeld 1994, Turner et al. 2000, Berkes and Davidson-Hunt 2006). However, the relatively small size of the Indigenous population, peoples' frequent movements among seasons and years, and their lack of modern-day technologies, reduced the scope and intensity of changes. These Indigenous peoples were therefore well integrated into the ecosystem and their actions contributed to its structure and functioning. Quite often they established stewardship systems or habitat manipulations targeted at sustaining populations of desired species such as salmon or beaver (Berkes 1998, Turner et al. 2000). These can be summarized as rules-of-thumb that were transmitted through numerous generations (Gadgil et al. 1993).

Following contact and the colonial settler influx that started in the nineteenth century, human impacts on lakeshores and associated aquatic and terrestrial habitats have increased, accelerating the rates of change to structure and functioning of lakeshore ecosystems (Wetzel 2001, Strayer and Findlay 2010). Many lakes in the Canadian boreal region have already suffered large impacts because of the cumulative effects of numerous human activities (Schindler 1998). These activities are diverse in type and scale, but in the lakeshore zone include increasing numbers of people using lakes, permanent human occupation of larger proportions of lakeshore zones, vegetation clearing and surface hardening on land that increases run-off, vegetation clearing and removal of debris that destroys habitat quality in shallow water and contaminant releases (Schindler 1998, Schindler and Lee 2010).

At whole lake and watershed scales, fish populations have frequently declined, and water quality has deteriorated with pollution from local and remote industrial effluents and impacts of extensive deforestation in watersheds (Schindler 1998). The effects of various stressors are not necessarily additive, but may include synergistic and antagonistic effects on different parts of the ecosystem in ways that are difficult to project (Christensen et al. 2006). Intensive development within the lakeshore zone along many Canadian lakes has left few options for maintaining connectivity for all migrating animals and for sustaining populations of potentially impacted species. Adequate planning in advance of development can avoid numerous problems when options are more limited (e.g., the Okanagan to Kalamalka Lake corridor, Parrott 2017).

The northern boreal mountains of Yukon, northern British Columbia and interior Alaska are still rich with relatively intact lakeshore ecosystems. Human population density is still relatively low and people put high value on lakes. The opportunity for proactive conservation of lakes and their shore zones is high and needs to be recognized and taken advantage of before poorly planned and unregulated developments continue to unfold.

The risks are real and current. Lakeshores have been impacted and these impacts are expected to increase as the human population expands and occupies more land and water. Yukon's human population has shown almost continuous growth from less than 5,000 in the 1920s to over 42,000 by 2020, with one of the highest population growth rates of Canadian jurisdictions in 2016 (Statistics Canada 2018, Whitehorse Star 2020). Human activities associated with lakeshores have diversified over the decades to include recreational boating, residential developments, commercial timber harvesting, wildfire suppression and agricultural developments, so an increasing proportion of lakeshores have high likelihood of permanent or long-lasting vegetation change. Modern technologies, such as motorized vehicles, means of clearing vegetation and more efficient means of harvesting fish and game, have led to impacts that are generally more frequent and often more intense.

Many developments are effectively permanent. They include private land holdings, which occupy significant stretches of shoreline, for homes, recreational cottages and camps, boat launches and agricultural developments. Permanent travel corridors on land, including roads and trails, access the shorelines and often follow along them. Travel on water or ice by boat or snowmobile is unrestricted. Some permanent developments are located at or close to sensitive habitats (e.g., wetlands, estuaries, alluvial fans, creeks with spawning fish runs, permanent open water habitats in winter, migratory bird staging sites and protected bays) where they have increased the risk of displacing fish and wildlife and of reducing habitat quality and quantity.

Past study and management of lakeshore ecosystems has tended to focus on components or sub-sets of the whole, such as individual species or particular processes, such as wave action. Less attention has been given to an integrated understanding and application of all ecological entities and processes that straddle the water-land interface of the shore zone (Strayer and Findlay 2010). This may have resulted in part from the different educational and institutional backgrounds of terrestrial and aquatic managers; from legal and administrative practices; or from the need to break complexity into its component parts. However, it is important that we focus more on the entire lakeshore ecosystem, including its aquatic and terrestrial components, because as an integrated whole, these areas support such high biodiversity, are more productive than most and are important to humans of diverse socio-cultural backgrounds (Strayer and Findlay 2010). The impetus to provide managers and landowners with options to protect lakeshore values stems from a realization of the growing risk that future developments will erode and compromise these values, especially given growing human population densities and the permanence of many developments.

Human activities triggering permanent changes to the shore zone ecosystem have affected some lakes in the Boreal Cordillera.

(Top) Forests bordering wetlands and beaches are often lost when residential development occurs, and homes are built in situations increasingly at risk of flooding in summer (M'Clintock subdivision, Marsh Lake, June 2020) (Donald Reid).

(Bottom) Roads are often built very close to shorelines, changing riparian vegetation and access to water for people and wildlife (Lewes Marsh, Marsh Lake, May 2017) (Gerry Whitley).

With this document we hope to stimulate a more proactive approach to lakeshore planning and stewardship in the northern boreal mountains of western Canada (Fig. 1), so that various values are more explicitly considered before and during processes that make decisions about whether and how changes to lakeshores might be allowed and under what terms. These could include types of land tenure, intensity of developments and constraints around specific sites. Our primary focus is ecological values on public or collectively owned lands, including First Nations' settlement lands. We are primarily interested in the value of lakeshore ecosystems for fish, wildlife, and biodiversity generally, and we recognize that private ownership gives the owner the option to embrace value promotion, including ecological stewardship.

A secondary focus is on values associated with Indigenous cultures, because these are often closely coincident with some ecological values and have often been overlooked. This approach assumes that on public or collectively owned lands, governments will accept their obligation to be good planners and stewards of ecosystems, working to sustain all elements of biodiversity at appropriate scales while recognizing Indigenous cultural values and rights. This assumption stems from the directions given to Land Use Planning Commissions in Chapter 11 of Yukon's Umbrella Final Agreement (UFA 1993). It assumes that on private lands, owners will also see fit to sustain healthy ecosystem functioning wherever possible.

In this document, we first outline the approach we took to address conservation of lakeshore zones in the northern boreal mountains. Next we summarize the biogeographic and jurisdictional scope of investigation. We then provide summaries of the ecological and social values of lakeshore zones and their associated near shore and tributary water bodies. Next, we outline a set of knowledge gaps that we have identified in this review. Finally, we offer a series of suggested principles and associated guidelines for proactive planning and management of lakeshore zones in the future. These are presented as a reference for planners, managers, and assessors as they implement their various planning and management mandates at a range of scales from the regional or strategic planning scale to the more local operational management scale.

2.0 APPROACH

2.1 Goals

Our principal goal in writing this document is *to protect and conserve the ecological integrity, ecosystem functioning, and biodiversity of lakeshore ecosystems in the Boreal Cordillera region*. Our view is through an ecological lens, where the "lakeshore" includes the adjacent aquatic and terrestrial environments and will be referred to as the "lakeshore zone". Habitats and ecological processes are our main focus, often with specific species or groups of species in mind. Components of this principal goal include: (i) to identify the suite of influential ecological processes and high value habitats for fish and wildlife species; (ii) to minimize the scope and severity of human-induced environmental impacts that could compromise ecosystem and human health.

A secondary goal in writing this document is *to protect and conserve the heritage of Indigenous human-use sites associated with lakeshores including the ecological and habitat attributes of these sites*. The need to include this goal has been made to us repeatedly during meetings with First Nations governments and with communities in Yukon where we introduced this project and its objectives. We are not experts in Indigenous societies or past land use patterns, so we have probably addressed this goal incompletely. However, we include it because many of the principles and guidelines we propose can be applied to ecological and socio-cultural values in similar manners, and because ecological and social values need to be addressed concurrently in any conservation vision.

2.2 General Approach

In general, our approach has been to synthesize the existing science dealing with the diverse ecological values associated with lakeshore zones, including lessons from past human actions, so as to put forward a proposed approach for conservation of these values in the future. We have combined peer-reviewed literature (web-based searches), grey literature (Yukon libraries), and interviews (knowledgeable individuals) to compile information for this synthesis of science mediated with local information and expertise. The document addresses lakeshore zones in the Boreal Cordillera ecozone. We found limited information published on this ecozone, so information came from other parts of the North American boreal zone when necessary. We interviewed knowledgeable individuals for their insights to ensure that local ecological knowledge was included.

We have augmented this approach by communicating the project's goals and scope to staff in some First Nations' government departments that have responsibility for land and natural resources, so as to provide a more thorough scoping of values and interests from the perspective of First Nations governments. We have addressed the Carcross Tagish, Kwanlin Dun and Ta'an Kwäch'än First Nations. Similarly, we have talked about the project with Renewable Resources Councils (DanKeyi, Carcross/Tagish, Carmacks, Selkirk, Mayo, and Dawson) across Yukon to better scope the community-based values and interests in lakeshore zones.

The core of this approach has been to identify the ecological *values* associated with lakes and lakeshore zones. Ecological values include conservation of viable populations of the full suite of organisms (biodiversity) in water and on land, protection of key habitats, maintenance of connectivity for dispersal and colonization, and sustenance of hydrological regimes including water quality. Broadly speaking these ecological values have been organized by ecological zone or ecological community, with long-term conservation of these communities being the objective. They range from near-shore and shallow-water zones supporting various life history stages of fish, to wetland zones filtering water and supporting diverse species of birds and insects, to riparian zones providing shelter and reproductive space for semi-aquatic mammals and birds. Ecological values are realized at various scales, from the entire watershed to localized high value habitats.

Interest in lakes is widespread through human societies in northwest Canada, and lakes are highly valued for example as places for subsistence and recreational fishing, for experiencing nature more broadly, for relative ease of travel, and for various recreational experiences. Many sites of human use are easily viewed as specific places, ranging from historic and present-day communities and camps, to homes, to burial areas, and to places of high emotional and spiritual meaning. These sites often deserve conservation and management attention in and of themselves, because components of the ecosystem (such as aggregations of food species and comfortable local climates) have strongly influenced peoples' choices of these sites, and because the sites have heritage value. We attempt to address this need in this document.

At the same time, the diversity and intensity of multiple values, often widespread and integrated across whole lakes, or portions of very large lakes, provide an opportunity to produce a relative rating or rank by which different lakes can be compared. We do not propose a quantitative approach for such comparisons; such valuation is necessarily subjective and depends on who is charged with making the decision. However, we do propose that such an exercise be an important component of future regional, local area, and other planning, so that lakes are explicitly addressed in planning processes.

This document puts forward Principles and Guidelines for consideration in the conservation of lakeshore values in the future. We view Principles as general statements of desired future condition; they are broad and hopefully relatively uncontroversial. The Guidelines are specific statements laying out how a Principle might be achieved. Application of the Guidelines by land managers or owners can vary in the degree to which they prescribe or detail actions. Prescriptive guidelines can be considered useful, even necessary, for certain land management processes, such as mitigating environmental impacts through environmental assessments undertaken by the Yukon Environmental and Socio-economic Assessment Board or environmental assessment bodies in other jurisdictions, and protecting critical or uncommon habitat features such as open water in winter and early spring. Planning processes may choose to be informed by the Guidelines to the extent that their terms of reference or mandates allow. Our Guidelines are often quite detailed; not all details may be pertinent to a particular circumstance. Our aim is to stimulate attention by the appropriate authorities (governments, land owners, resource management agencies, others) to the various interlinked values and issues. We identify if and when the Guidelines are based on published science, and provide references for those who wish to gain a more complete understanding of the science.

Lakeshores are highly valued by people as (top left) places of settlement and intersection of travel routes (Carcross, May 2018) (Donald Reid), (top right) as places to access the water for fishing and recreation (Fox Lake campground, June 2017) (Donald Reid), and (bottom left) as places of high emotional and spiritual value (Little Atlin Lake, October 2012) (Donald Reid).

3.0 SCOPE

3.1 Geographic Scope – the Northern Boreal Mountains

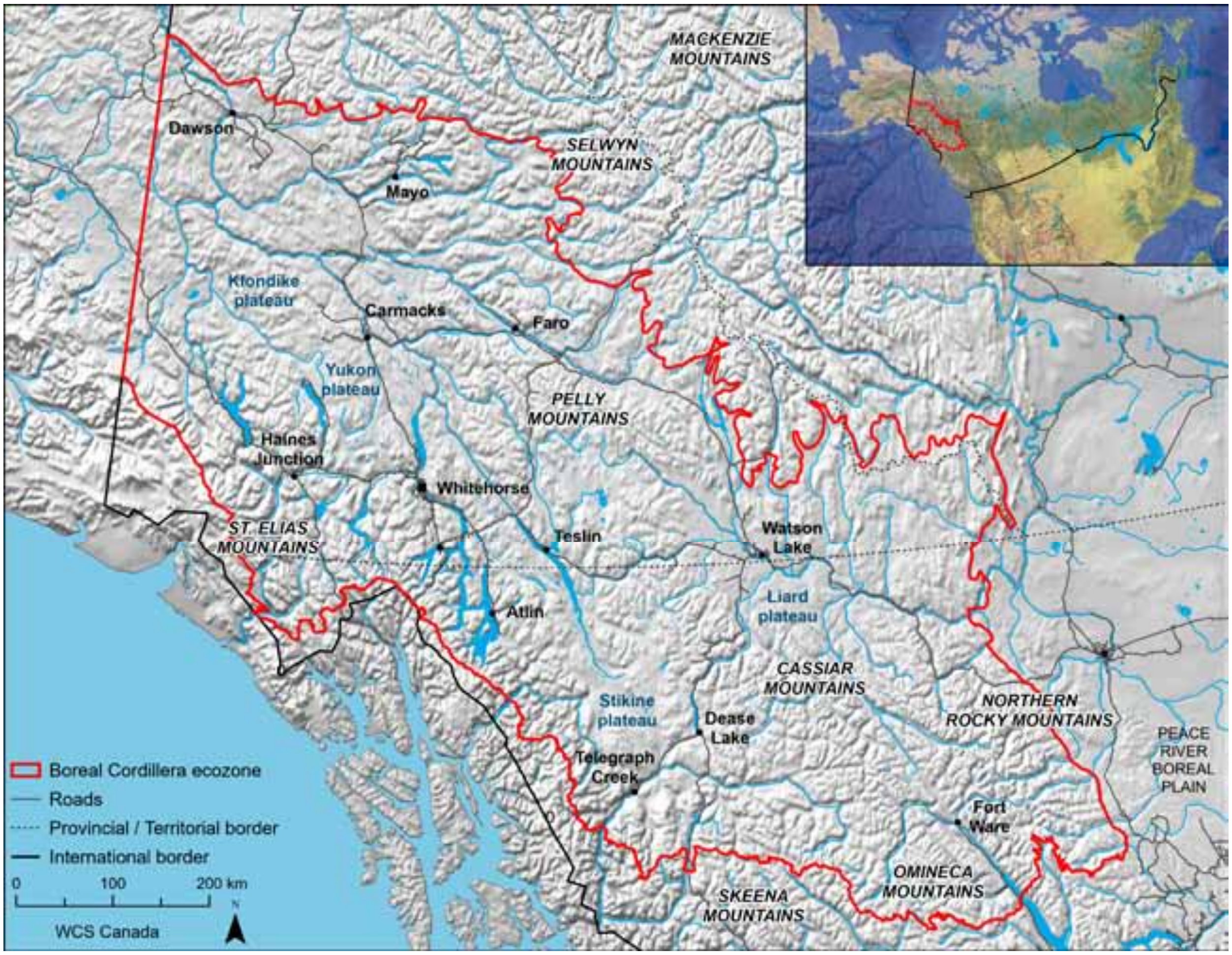
3.1.1 Physical Setting

The boreal forest region of North America is vast, and in the northwest part of the continent coincides with numerous mountain ranges. In these northern boreal mountains, forests are relegated to lower elevations, and alpine tundra, rock, and ice are frequently found at higher elevations. This document pertains to a large portion of this northern boreal mountain region in Canada, best described as the Boreal Cordillera ecozone (Figure 1; Canadian Council of Forest Ministers 2005), and does not deal with similar ecologies in Alaska.

The Boreal Cordillera ecozone covers about 459,864 km^2 of land shared between southern Yukon and northern British Columbia. It is bordered by the Coast Mountains to the west, the Selwyn and Mackenzie Mountains to the north and the Peace River boreal plain to the east. This ecozone encompasses large portions of the St. Elias, Skeena, Cassiar, Omineca and northern Rocky Mountain ranges, as well as the Stikine, Yukon and Klondike plateaus. It is characterised by mountain ranges, some with glaciers and high peaks, and by extensive plateaus separated by wide valleys. There are a few extensive lowland areas, such as the Liard Basin. Landscapes have been heavily influenced by Pleistocene glaciation and peri-glacial drainage patterns, except for large parts of the Klondike Plateau in the northwest that were unglaciated during the last glacial maximum (Duk-Rodkin 2004, Dyke 2004). Other prominent processes that affect landforms include mass wasting, frost fracturing, alluvial depositions in flood plains and fans, permafrost, solifluction, and tephra deposition (Bond et al. 2004).

In this geologically diverse landscape, soils vary a lot in mineral composition, but are generally poorly developed due to recent glaciation and a cold climate which results in extensive permafrost in northern portions and low plant productivity and rates of decomposition throughout. At higher elevations cryosols dominate, and brunisols (associated with glacial deposits) and luvisols (associated with meltwater deposits) dominate at lower elevations. Organic soils (mostly peat) are found in some wetlands (Smith 2004).

Figure 1. Maps showing the situation of the Boreal Cordillera ecozone within North America (inset), and the ecozone's detailed topography, mountain ranges, hydrology, roads and major communities (Map by Piia Kortsalo).



Data sources:

- Base maps: Natural Earth.
- Boreal Cordillera borders: Geomatics Yukon and Agriculture and Agri-Foods Canada (modified).
- Canada borders: Boundary Files, 2011 Census. Statistics Canada Catalogue no. 92-160-X (modified).
- International borders: Natural Earth (modified).
- Populated places: Natural Resources Canada (CanVec Series), licensed under the Open Government Licence - Canada.
- Roads (Canada): Natural Resources Canada (CanVec Series), licensed under the Open Government Licence - Canada.
- Roads (US): Alaska Department of Natural Resources.
- Hydrography: Commission of Environmental Cooperation; Natural Resources Canada (CanVec Series), licensed under the Open Government Licence - Canada (modified).

3.1.2 Drainages and Water

The Boreal Cordillera ecozone encompasses the upstream portions of six major drainage systems: Yukon River draining to the Bering Sea; Alsek, Taku, and Stikine Rivers all draining to the Pacific Ocean; Liard and Peace Rivers draining to the Arctic Ocean via the Mackenzie River.

Freshwater lakes and ponds occur less frequently in this mountainous region than in much of Canada's boreal regions, especially the Boreal Shield ecozone east of the mountains. However, lakes are still abundant, with approximately 3,770 of Yukon's lakes occurring in this ecozone (Yukon Renewable Resources 2001). Lakes can occur at a wide range of elevations, including alpine tarns, but the great majority are at lower elevations. In particular, numerous large lakes (>10,000 ha) dominate the geography of the larger valleys in the southern Yukon and northern British Columbia, giving the upper Yukon River drainage an extraordinary number and surface area of large lakes (Table 1, Figure 2). We do not know of any summary of lake sizes for the ecozone, but the great majority of lakes much are smaller. Mean size of a sample of 69 lakes in one set of drainages in south Yukon was 124 ha (Reid, unpubl. data). This compares to a mean size of 504 ha for a sample of 2,734 boreal lakes typical of those occupied by lake trout, but not all lakes, on the Canadian Shield in Ontario (Gunn and Pitbaldo 2004). However, lakes are uncommon to absent through those portions of Yukon that were unglaciated in the Pleistocene.

Approximately 15.6% (73,320 km^2) of the Boreal Cordillera ecozone is composed of wetlands (CCFM 2005). Furthermore, there are extensive groundwater resources and aquifers, as well as widespread frozen water sources such as glaciers and permafrost (Janowicz 2004).

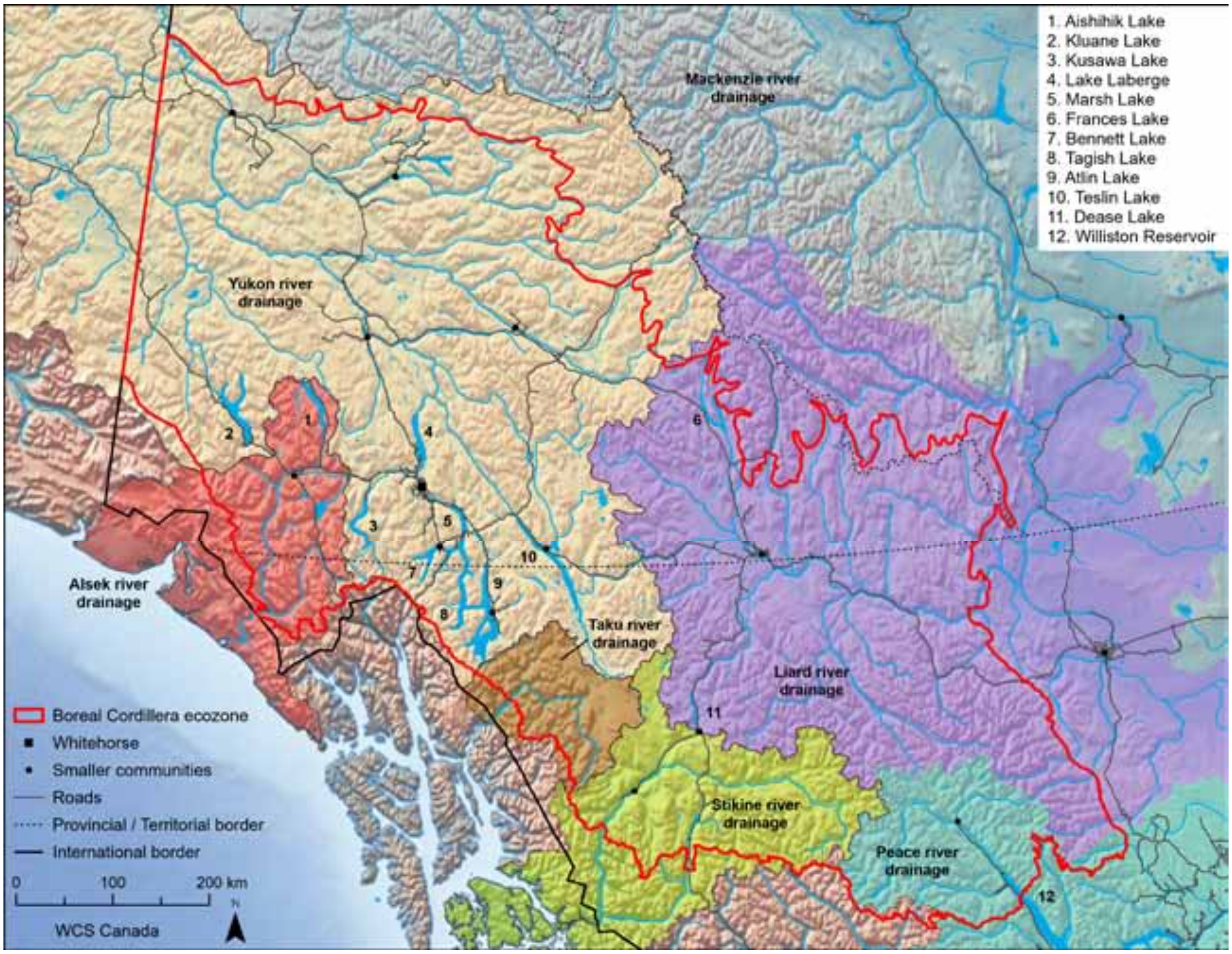
Because of strong seasonality and cold winters with snow accumulation, stream flows tend to peak in early summer following snow melt, and are substantially reduced in winter. In glacier-fed drainages flows remain high throughout summer. Lake levels rise gradually during spring and summer to peak levels sometime during summer, depending on sources of incoming water, position in the drainage, and amount of summer precipitation. Lakes supplied in large part by glacier melt tend to reach peak levels later, even into early autumn, and peak at higher levels in warm, sunny summers (Janowicz 2004).

Table 1. List of the large lakes (>10,000 ha in surface area) in the Boreal Cordillera ecozone of Yukon and northern British Columbia. All lakes fall completely within the ecozone except for the Williston Reservoir, which is mostly outside the ecozone (Figure 2) (Brown et al. 1976, Yukon Renewable Resources 2001)

Lake Name	Drainage Basin	Jurisdiction	Surface Area (ha)
Aishihik	Alsek	Yukon	14,747
Kluane	Yukon	Yukon	40,821
Kusawa	Yukon	Yukon	13,999
Laberge	Yukon	Yukon	20,100
Marsh	Yukon	Yukon	15,100
Bennett	Yukon	Yukon and British Columbia	16,317
Tagish	Yukon	Yukon and British Columbia	35,235
Atlin	Yukon	Yukon and British Columbia	63,455
Teslin	Yukon	Yukon and British Columbia	36,240
Frances	Liard	Yukon	10,227
Dease	Liard	British Columbia	5,230
Williston Reservoir	Peace	British Columbia	177,300

(Left) Large deep lakes store the greatest volumes of fresh water in the region (Tagish Lake, September 2018) (Donald Reid), but (right) smaller, shallower lakes are much more common and generally more ecologically productive (Unnamed Lake, September 2018) (Donald Reid).

Figure 2. Map showing the major drainage basins that intersect the Boreal Cordillera ecozone, and highlighting the larger lakes (> 10,000 ha) mentioned in Table 1 (Map by Piia Kortsalo).



Data Sources:

- Base map: Natural Earth.
- Boreal Cordillera borders: Geomatics Yukon and Agriculture and Agri-Foods Canada (modified).
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3.1.3 Climate

The Boreal Cordillera ecozone experiences a continental, subarctic, climate characterised by long, cold winters (mean January daily temperature of -15° to -25°C) and short, warm summers (mean July daily temperature of 5° to 15°C) (Wahl 2004). The major air masses flow either from the Pacific Ocean into the interior, or from the continental northwest in Alaska. Those from the Pacific are relatively warm and wet, dropping considerable precipitation on windward slopes of the Coast, Pelly-Cassiar, and Mackenzie-Rocky Mountain chains. Those from the continental interior are drier and colder in winter, but warmer in summer, compared to the Pacific air masses. Local climates vary considerably depending on position with respect to air flow, elevation, and aspect. There is often a strong gradient of precipitation over short distances, with an annual average of 400 mm (range 300 – 1000 mm), 30 to 60% of which falls as snow (Wahl 2004). Plant hardiness ranges from zone 2b in the south to 0a in the north and at higher elevations (NRCan 2020).

3.1.4 Land Cover

Approximately 51% of this ecozone is forested (CCFM 2005). These forests often have closed canopies at lower elevations, in the boreal low bioclimate zone, but have open canopies trending to scattered trees at higher elevations, in the boreal high bioclimate zone (Environment Yukon 2016). Unforested shrub communities are extensive, and found on recently disturbed sites (e.g. after forest fires), on periodically flooded alluvial fans and floodplains, in some wetlands, on many valley floors subject to cold air pooling and thermal inversions in winter, and mixed with open canopy forests in higher elevation forests and in the subalpine (McKenna et al. 2004, CCFM 2005). The great majority (c.78.6%) of forests are dominated by softwood species, including white spruce (*Picea glauca*), black spruce (*Picea mariana*), subalpine fir (*Abies lasiocarpa*), and lodgepole pine (*Pinus contorta*). Mixedwood forests are fairly abundant (c. 17.8%), and hardwood forests of trembling aspen (*Populus tremuloides*), white birch (*Betula neoalaskana*), and balsam poplar (*Populus balsamifera*) are uncommon (c. 3.6%) (CCFM 2005 Table 1.1.a).

Apart from forest cover, the region has substantial areas of grassland on south-facing slopes at lower elevations, open wetlands (fens, marshes, swamps, and bogs), alpine tundra, and expanses of unvegetated rock, snow and ice (McKenna et al. 2004). Many of the wetlands are directly associated with lakes, forming part of the lakeshore itself. Many are interspersed among neighbouring lakes and ponds in wetland complexes.

 

Many lakes are associated with wetlands. (Left) Marshes commonly develop in shallow standing water around the edges of lakes, sometimes in a complex of wetland types (Unnamed Lakes, September 2019) (Donald Reid). (Right) Marsh vegetation bordering lakes is particularly productive (Tatchun Lake, June 2017) (Donald Reid).

3.1.5 Wildlife and Fish

The Boreal Cordillera ecozone does not support a high diversity of terrestrial species by global standards, largely because of the long, cold winters and low productivity (O'Donoghue and Staniforth 2004). However, species richness is relatively high for such a northern latitude (Currie 1991). This reflects the wide range of elevations and habitats found in mountainous terrain compared to the flatter terrain of much of the boreal biome, plus the diverse biogeographic origins for the current species that colonized the region from the Pleistocene glacial refugia of Beringia, the west coast of North America, and the continental regions south of the Laurentide icecap (Slough and Jung 2007).

A small proportion of Boreal Cordilleran mammal species are strongly or periodically reliant on the lakeshore zone. Of the 61 mammal species found in the region, only 5 (8%) are strongly reliant or dependent on the shore zone, being semi-aquatic animals that feed in water and use water as a primary route for travel (Table 2). Beaver and river otter (*Lontra canadensis*) are good examples of this group. Another 5 (8%), including moose, rely periodically on the shore zones, generally because they feed in or above the water, or because their valley bottom movements bring them along lakeshores. Roughly half (51%, 31 species) of the mammal species do not rely on the shore zone of water bodies but frequently use these habitats, often in preference over other habitats. All mammals are resident year-round, except perhaps for bats that are believed to migrate to warmer winter climates. This year-round residency adds to the importance of shore zone habitats because winter is often the most limiting season to survival of semi-aquatic mammals (Reid et al. 1994b, Baker and Hill 2003).

Beavers are the most influential mammal in the shore zone ecosystem, and depend on it.

(Top left) They often feed in the shallow water adjacent to the shoreline (Lower Snafu Lake, September 2019) (Donald Reid).

(Top right) They build their lodges in shallow water or along the shoreline (Tern Lake, September 2012) (Donald Reid).

(Bottom left) They regularly harvest woody vegetation within 60 m of water (Tarfu Lake, May 2010) (Donald Reid).

(Bottom right) They create ponds, small lakes and wetlands by damming streams (Haunka Lake 2, February 2014) (Donald Reid).

None of the mammals strongly reliant on lakeshore zones has a conservation problem in the Boreal Cordillera at present. However, 2 of the 5 species that are periodically reliant are of conservation concern: Grizzly bear (S3/Special concern in British Columbia; S3/Vulnerable in Yukon; Special concern nationally); Fisher (S3/Special concern in British Columbia; S2S4/Uncertain in Yukon; Unranked nationally) due to vulnerability to habitat loss, mortality, and disturbance (BC CDC 2017, Government Canada 2017, Environment Yukon 2017a)

Many more bird species, than mammals, are reliant on lakeshore zones. In Table 3 we list those birds, from the complete list of 211 species regularly occurring in the Canadian portion of Bird Conservation Region 4 (BCR4) (Environment Canada 2013 – Appendix 1), that have strong reliance on the lakeshore zone, and we classify that reliance as occurring only during migration (not breeding) or in at least one season if the species nests in the Boreal Cordillera. BCR4 covers much the same area as the Boreal Cordillera ecozone in Canada, but also extends north into parts of the Taiga Cordillera (Environment Canada 2013). We classify a few species that, within BCR4, nest only in the Taiga Cordillera portion (e.g., Greater White-fronted Goose, Tundra Swan, Baird's sandpiper) as migrants in Table 3 (based on nesting records in Sinclair et al. 2003). Table 3 also includes 6 species that migrate semi-regularly through the Boreal Cordillera (Sinclair et al. 2003) but are not in the BCR4 listings (Yellow-billed Loon, Eurasian Wigeon, Ruddy Turnstone, Sanderling, Western Sandpiper, and Dunlin). This gives a total of 217 species with which to assess reliance on the lakeshore zone.

Seventy-two species (33%) nest in the ecozone and are strongly reliant on the lakeshore zone in at least one season (Table 3), normally the nesting season. A further 21 species (10%) are reliant on the lakeshore zone during migration, but do not nest in the ecozone. In total, 93 of the 217 species (43%) that commonly occur in the Boreal Cordillera are strongly reliant on lakeshore zones. For most of these species, this reliance is seasonal. A small proportion of the populations of Trumpeter Swan, Mallard, Common Goldeneye, Common Merganser and Bald Eagle are winter residents, along with a substantial number of American Dipper.

The importance of lakeshore zones to many birds is clear, but is further emphasized by the conservation status of these birds. Environment Canada (2013 – Table 1) classifies 4 of the species in Table 3 (American Wigeon, Lesser Scaup, Lesser Yellowlegs and Rusty Blackbird) as having regional conservation concern due to declining population trends, and another 26 being of national or continental conservation concern (see Table 3). Gulls and terns (5 of 8 species), loons (2 of 4 species), and shorebirds (9 of 25 species) particularly show up as needing conservation attention. These figures further emphasize the high value of lakeshore habitats for conservation.

Table 2. Mammals of the Boreal Cordillera, ranked by relative degree of reliance on shore zone habitats (N = No reliance; NF = No reliance but frequent use; P = Periodic or seasonal reliance; S = strong reliance). Information in this Table is derived from Nagorsen and Brigham 1995, Nagorsen 1996, Shackleton 1999, Nagorsen 2005, Slough and Jung 2007, and Slough et al. 2014).

Common Name	Latin Name	Reliance On Shore Zone Habitats
Shrews		
Arctic Shrew	Sorex arcticus	NF
Cinereus Shrew	Sorex cinereus	NF
American Pygmy Shrew	Sorex hoyi	N
Dusky Shrew	Sorex monticolus	N
American Water Shrew	Sorex palustris	S
Tundra Shrew	Sorex tundrensis	N
Bats		
Big Brown Bat	Eptesicus fuscus	NF
Little Brown Myotis	Myotis lucifugus	P
Northern Myotis	Myotis septentrionalis	P
Keen`s Long-eared Myotis	Myotis keenii	NF
Long-legged Myotis	Myotis volans	NF
Silver Haired Bat	Lasionycteris noctivagans	P
Hoary Bat	Lasiurus cinereus	N
Lagomorphs		
Snowshoe Hare	Lepus americanus	NF
Collared Pika	Ochotona collaris	N
Rodents		
Northern Flying Squirrel	Glaucomys sabrinus	NF
Hoary Marmot	Marmota caligata	N
Woodchuck	Marmota monax	N
Arctic Ground Squirrel	Urocitellus parryii	N
Least Chipmunk	Tamias minimus	N
Red Squirrel	Tamiasciurus hudsonicus	NF
Beaver	Castor canadensis	S
Nearctic Brown Lemming	Lemmus trimucronatus	N
Long-tailed Vole	Microtus longicaudus	N
Singing Vole	Microtus miurus	N
Root Vole	Microtus oeconomus	NF
Meadow Vole	Microtus pennsylvanicus	NF
Taiga Vole	Microtus xanthognathus	NF
Southern Red-backed Vole	Myodes gapperi	NF
Northern Red-backed Vole	Myodes rutilus	NF
Bushy-tailed Woodrat	Neotoma cinerea	N
Common Muskrat	Ondatra zibethicus	S

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Common Name	Latin Name	Reliance On Shore Zone Habitats
Northwestern Deermouse	Peromyscus keeni	NF
North America Deermouse	Peromyscus maniculatus	NF
Western Heather Vole	Phenacomys intermedius	NF
Eastern Heather Vole	Phenacomys ungava	NF
Northern Bog Lemming	Synaptomys borealis	NF
Meadow Jumping Mouse	Zapus hudsonius	NF
Western Jumping Mouse	Zapus princeps	NF
North American Porcupine	Erethizon dorsatum	NF
Carnivores		
Coyote	Canis latrans	NF
Wolf	Canis lupus	NF
Red Fox	Vulpes vulpes	NF
American Black Bear	Ursus americanus	NF
Grizzly Bear	Ursus arctos	P
Wolverine	Gulo gulo	NF
North American River Otter	Lontra canadensis	S
American Marten	Martes americana	NF
Fisher	Martes pennanti	P
Ermine	Mustela erminea	NF
Least Weasel	Mustela nivalis	NF
American Mink	Neovison vison	S
Canadian Lynx	Lynx canadensis	N
Cougar	Puma concolor	N
Ungulates		
Moose	Alces alces	P
Elk	Cervus elaphus	N
Mule Deer	Odocoileus hemionus	N
White-tailed Deer	Odocoileus virginianus	N
Caribou	Rangifer tarandus	NF
American Bison	Bison bison	N
Mountain Goat	Oreamnos americanus	N
Thinhorn Sheep (Dall`s and Stone`s)	Ovis dalli	N




A wide variety of birds rely on the shore zone ecosystem for nesting and feeding, including (top left) Bald Eagle (Upper Tarfu Lake, October 2012) (Donald Reid), (top right) Lesser Yellowlegs (Unnamed Lake, May 2019) (Donald Reid), (bottom left) Common Loon (on nest, Loon Lake, June 2014) (Donald Reid), and (bottom right) American Wigeon (Nettle Lake, July 2011) (Donald Reid).

Table 3. The 72 bird species of the Boreal Cordillera with a strong reliance on the lake shore zone, including wetland habitats that often comprise or are associated with shore zones. The list differentiates species that nest in the ecozone (and may or may not be resident) (code S) from those that migrate through the ecozone but do not nest (code M). The Table does not include species that may use shore zone habitats but do not strongly rely on these habitats in any one season. Species of regional, national or continental conservation concern are highlighted in bold font. Information in this Table comes from Sinclair et al. 2003, and Environment Canada 2013 – Appendix 1.

Common Name	Latin Name	Reliance On Shore Zone Habitats
Loons		
Red-throated Loon	Gavia stellata	M
Pacific Loon	**Gavia pacifica**	**S**
Common Loon	**Gavia immer**	**S**
Yellow-billed Loon	Gavia adamsii	M
Grebes		
Pied-billed Grebe	Podilymbus podiceps	S
Horned Grebe	**Podiceps auritus**	**S**
Red-necked Grebe	Podiceps grisegena	S
Cormorants and Herons		
Double-crested Cormorant	Phalacrocorax auritus	S
Waterfowl		
Greater White-fronted Goose	Anser albifrons	M
Snow Goose	Chen caerulescens	M
Canada Goose	Branta canadensis	S
Cackling Goose	Branta hutchinsii	M
Brant	Branta bernicla	M
Trumpeter Swan	Cygnus buccinator	S
Tundra Swan	Cygnus columbianus	M
Gadwall	Anas strepera	S
Eurasian Wigeon	Anas penelope	M
American Wigeon	**Anas americana**	**S**
Mallard	Anas platyrhynchos	S
Blue-winged Teal	**Anas discors**	**S**
Cinnamon Teal	Anas cyanoptera	S
Northern Shoveler	Anas clypeata	S
Northern Pintail	**Anas acuta**	**S**
Green-winged Teal	Anas crecca	S
Canvasback	**Aythya valisineria**	**S**
Redhead	Aythya americana	S
Ring-necked Duck	Aythya collaris	S
Greater Scaup	Aythya marila	S
Lesser Scaup	**Aythya affinis**	**S**
Harlequin Duck	Histrionicus histrionicus	S

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Common Name	Latin Name	Reliance On Shore Zone Habitats
Surf Scoter	**Melanitta perspicillata**	**S**
White-winged Scoter	**Melanitta fusca**	**S**
Long-tailed Duck	**Clangula hyemalis**	**S**
Bufflehead	Bucephala albeola	S
Common Goldeneye	**Bucephala clangula**	**S**
Barrow`s Goldeneye	Bucephala islandica	S
Hooded Merganser	Lophodytes cucullatus	S
Common Merganser	Mergus merganser	S
Red-breasted Merganser	Mergus serrator	S
Ruddy Duck	Oxyura jamaicensis	S
Birds of Prey		
Osprey	Pandion haliaetus	S
Bald Eagle	Haliaeetus leucocephalus	S
Peregrine Falcon	**Falco peregrinus**	**S**
Rails, Coots and Cranes		
Sora	**Porzana carolina**	**S**
American Coot	Fulica americana	S
Shorebirds		
Black-bellied Plover	Pluvialis squatarola	M
American Golden-Plover	**Pluvialis dominica**	**S**
Semipalmated Plover	Charadrius semipalmatus	S
Killdeer	**Charadrius vociferus**	**S**
Greater Yellowlegs	Tringa melanoleuca	S
Lesser Yellowlegs	**Tringa flavipes**	**S**
Solitary Sandpiper	**Tringa solitaria**	**S**
Wandering Tattler	Heteroscelus incanus	S
Spotted Sandpiper	Actitis macularia	S
Whimbrel	**Numenius phaeopus**	**S**
Hudsonian Godwit	Limosa haemastica	S
Ruddy Turnstone	Arenaria interpres	M
Sanderling	Calidris alba	M
Semipalmated Sandpiper	**Calidris pusilla**	**M**
Western Sandpiper	Calidris mauri	M
Least Sandpiper	Calidris minutilla	S
Baird`s Sandpiper	Calidris bairdii	M
Pectoral Sandpiper	Calidris melanotus	M
Dunlin	Calidris alpina	M

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Common Name	Latin Name	Reliance On Shore Zone Habitats
Stilt Sandpiper	Calidris himantopus	M
Short-billed Dowitcher	**Limnodromus griseus**	**S**
Long-billed Dowitcher	Limnodormus scolopaceus	M
Wilson`s Snipe	**Gallinago delicata**	**S**
Wilson`s Phalarope	Phalaropus tricolor	S
Red-necked Phalarope	**Phalaropus lobatus**	**S**
Gulls and Terns		
Bonaparte's Gull	**Larus philadelphia**	**S**
Mew Gull	Larus canus	S
Herring Gull	**Larus argentatus**	**S**
Thayer's Gull	**Larus thayeri**	**M**
Glaucous-winged Gull	Larus glaucescens	M
Glaucous Gull	Larus hyperboreus	M
Arctic Tern	**Sterna paradisaea**	**S**
Black Tern	**Chlidonias niger**	**S**
Kingfishers		
Belted Kingfisher	Ceryle alcyon	S
Swallows		
Tree Swallow	Tachycineta bicolor	S
Violet-Green Swallow	Tachycineta thalassina	S
Northern Rough-winged Swallow	Stelgidopteryx serripennis	S
Bank Swallow	Riparia riparia	S
Cliff Swallow	Petrochelidon pyrrhonota	S
Barn Swallow	**Hirundo rustica**	**S**
Dippers		
American Dipper	Cinclus mexicanus	S
Warblers		
Yellow Warbler	Dendroica petechia	S
Northern Waterthrush	Parkesia noveboracensis	S
Common Yellowthroat	Geothlypis trichas	S
Sparrows		
Lincoln's Sparrow	Melospiza lincolnii	S
Swamp Sparrow	Melospiza georgiana	S
Blackbirds		
Red-winged Blackbird	Agelaius phoeniceus	S
Rusty Blackbird	**Euphagus carolinus**	**S**

Five species of amphibians are found in this ecozone: the wood frog (*Rana sylvatica*); Columbia spotted frog (*Rana luteiventris*); boreal chorus frog (*Pseudacris maculata*); western toad (*Anaxyrus boreas*, formerly *Bufo boreas*); long-toed salamander (*Ambystoma macrodactylum*) (Matsuda et al. 2006, Slough and Mennell 2006, Slough 2013). All these species require standing water for portions of their life cycle, and are closely associated with wetlands, ponds and small lakes. The northwestern salamander (*Ambystoma gracile*) and the roughskin newt (*Taricha granulosa*) are found in nearby southeast Alaska, but have yet to be recorded in the Boreal Cordillera (Slough and Menell 2006).

The freshwater drainages of the Boreal Cordillera ecozone (see 2.1.2 above) provide habitats for about 29 species of fish, including 1 species of lamprey (von Finster 2004, McPhail 2007) (Table 4 and Appendix 1). However, many lakes and rivers have not been adequately surveyed, so the species list could change a bit, and, in particular, the distributions of some species within the region could change. For example, the list in Table 4 does not include a number of species that are known from the Liard River system just downstream of the Boreal Cordillera and might be found further upstream and in the ecozone (von Finster 2004). Also, some species that are cryptic or have disjunct distributions, such as the pygmy whitefish (*Prosopium coulterii*), may yet be found in lakes not yet sufficiently sampled (e.g., Blanchfield et al. 2014).

Ten fish species (Arctic lamprey, 4 salmon species, steelhead, dolly varden, 3 cisco species, inconnu) have at least some populations that are anadromous, migrating to ocean or estuarine habitats for part of the annual cycle. These anadromous species and populations tend not to use lake habitats as much as rivers. However, juvenile age classes of some anadromous species rely on lakes for part of their development (Table 4). Sockeye salmon (Kokanee form), inconnu, Dolly Varden, and perhaps Arctic lamprey have at least some populations that are not anadromous, but reside in lakes for their entire life cycle. Apart from the anadromous species, two others (flathead chub and longnose dace) are largely confined to streams and rivers. At least 21 fish species are strongly dependent on lakes.

The six major watersheds (Alsek, Liard, Peace, Stikine, Taku, and Yukon) of the Boreal Cordillera have many fish species in common (Table 4). However, their shared history of Pleistocene glaciation, and intermittent capture of one drainage by another in the Holocene, have resulted in complex patterns of isolation and overlap at the population level as fish recolonized the region from peripheral refugia (Lindsey 1975, McPhail and Lindsey 1970, Lindsey et al. 1981). The Alsek River basin, for example, is one of a few Pacific drainages in North America to contain northern pike, round whitefish, and Arctic grayling, testimony to at least one earlier connection to the Yukon River system (Lindsey et al. 1981, McPhail 2007). However, inconnu, broad whitefish, least cisco, and lake chub are present in the Yukon River system but not the Alsek (Lindsey et al. 1981). Furthermore, lake whitefish, which occurs widely across North America, is absent from the Stikine and Taku River drainages (McPhail 2007). The pygmy whitefish has a broad distribution in British Columbia, but a disjunct distribution within the Boreal Cordillera, being well documented only in widely separated locations in Alsek and Yukon drainages (McPhail 2007, Witt et al. 2011). More careful sampling might uncover further populations (see Blanchfield et al. 2014). Genetically distinct lineages of Arctic grayling are linked to disjunct Pleistocene refugia (Stamford and Taylor 2004).

The fact that some lakes have been colonized by relatively few species seems to have resulted in the use of different niches within the same lake by different populations of the same species. These populations may take on different ecological roles (e.g., predators in pelagic versus benthic habitats), and differ in body shape and structure, and in genetics, perhaps to the species level. For example, divergence of limnetic and benthic morphs of lake whitefish has been observed in four Yukon lakes (Bodaly et al. 1988) and appears to have resulted from one population separating into two populations after retreat of glaciers (Bodaly et al. 2011). Three morphs of pygmy whitefish are found in the same lake in southwest Alaska (Gowel et al. 2012). Two different body types of least cisco are found in some portions of the upper Yukon River drainage, and there appear to be anadromous and lake-resident populations in other portions of their range (McCart and Mann 1981, McPhail 2007). The degree of genetic differentiation resulting from isolation in unconnected lakes, or from evolution of new genetic lineages of the same species in the same drainage is an expanding area of interest. It will be important for determining the units of biological diversity for conservation purposes (Witt et al. 2011, Rogers et al. 2013).

3.1.6 Protected Areas

Approximately 19.3% of the surface area of the Boreal Cordillera ecozone is designated as land and water areas whose primary purpose is conservation of ecosystems and species (e.g., territorial parks, ecological reserves, and habitat protection areas) (Figure 3) (Woodley 2015). However, the Kluane Wildlife Sanctuary (3.423 km^2) is effectively useless as a protected area because it does not preclude natural resource extraction other than harvest of large game animals.

This designated protection is disproportionately assigned to certain ecoregions within the ecozone. One ecoregion, the St. Elias Mountains, has about 97% of its area protected (in Yukon by Kluane National Park, Asi Keyi Territorial Park, and Kluane Wildlife Sanctuary, and in British Columbia by Tatsenshini Provincial Park) so is very well represented (data from Ecological Stratification Working Group 1996, Cooke 2017). A number of other ecoregions, notably Klondike Plateau and Pelly Mountains, have no representation (Cooke 2017). Most ecoregions lie somewhere in between these extremes of representation. The British Columbia portion of the ecozone has more complete coverage of constituent ecoregions within the existing network of protected areas than does Yukon (Figure 3).

There are opportunities for First Nations', federal, provincial, and territorial governments to identify and protect additional areas in this ecozone. Under the International Convention on Biological Diversity, Canada has committed to reaching the target of protecting at least 17% of its land (including internal waters) by 2020, in conservation designations that are representative of its eco-

Table 4. Native fishes of the Boreal Cordillera ecozone, with summaries of the drainages they occupy and the types of water body within the Boreal Cordillera that they commonly occupy seasonally. Drainage codes are: A = Alsek, L = Liard, P = Peace, S = Stikine, T = Taku, Y = Yukon. Information in this Table comes from von Finster 2004, McPhail 2007, and NatureServe 2013. See footnote for definitions.

Common Name	Latin Name	Drainages Occupied	Types Of Water Body Occupied By Season*		
			Open Water	**Ice Cover**	**Spawn**
Lampreys					
Arctic Lamprey	Lethenteron camtschaticum	Y	Ocean; lakes (shallows); rivers	Ocean; lakes; large rivers; streams	Streams/ rivers (riffles)
Minnows					
Lake Chub	Couesius plumbeus	L, P, S, T, Y	Lakes (littoral); rivers; streams	Lakes and large rivers	Streams; lakes (littoral)
Peamouth	Mylocheilus caurinus	P	Lakes (benthic and pelagic)	Lakes (benthic, deep)	Lakes (littoral); inlet/ outlet streams
Flathead Chub	Platygobio gracilis	L	Rivers / streams	Rivers / streams	Rivers / streams
Longnose Dace	Rhinichthys cataractae	L, P	Streams/rivers	Streams/rivers	Streams (riffles)
Redside Shiner	Richardsonius balteatus	P	Lakes (littoral & limnetic); rivers	Lakes; rivers	Inlet/outlet streams; lakes
Suckers					
Longnose Sucker	Catostomus catostomus	A, L, P, S, T, Y	Lakes (limnetic & littoral); large rivers; streams	Lakes; large rivers	Rivers/streams; Lakes (littoral)
White Sucker	Catastomus commersoni	L, P	Lakes (littoral, benthic); large rivers	Lakes; large rivers	Inlet/outlet streams (riffles); lakes (shallows, stream mouths)
Pikes					
Northern Pike	Esox lucius	A, L, Y	Lakes (shallows, littoral); rivers; streams	Lakes	Inlet/outlet streams; lakes (shallows); rivers
Salmon & Chars					
Chum Salmon	Oncorhynchus keta	A, L, S, T, Y	As returning adults in large rivers; streams; lake margins	Incubate only, then direct migration to ocean	Discharging ground-water areas in rivers, streams
Coho Salmon	Oncorhynchus kisutch	A, S, T, Y	As returning adults in large rivers; streams	At least one winter in streams or rivers; migrate to ocean	Rivers; streams
Rainbow Trout (Steelhead)	Oncorhynchus mykiss	A, S, T	Complex – lakes; rivers; streams	Residents in lakes, streams; Anadromous at least one winter in freshwater	Streams; rivers
Sockeye Salmon (Kokanee)	Oncorhynchus nerka	A, S, T	As returning adult (sockeye) or non-anadromous (Kokanee) in lakes; rivers; streams	Sockeye at least one winter in lakes, rivers, streams; As Kokanee entire life in lakes, rivers, streams	Streams; rivers; lakes
Chinook Salmon	Oncorhynchus tshawytscha	A, S, T, Y	As returning adults in lakes, rivers, streams	Spend one winter in streams, rivers	Streams; rivers

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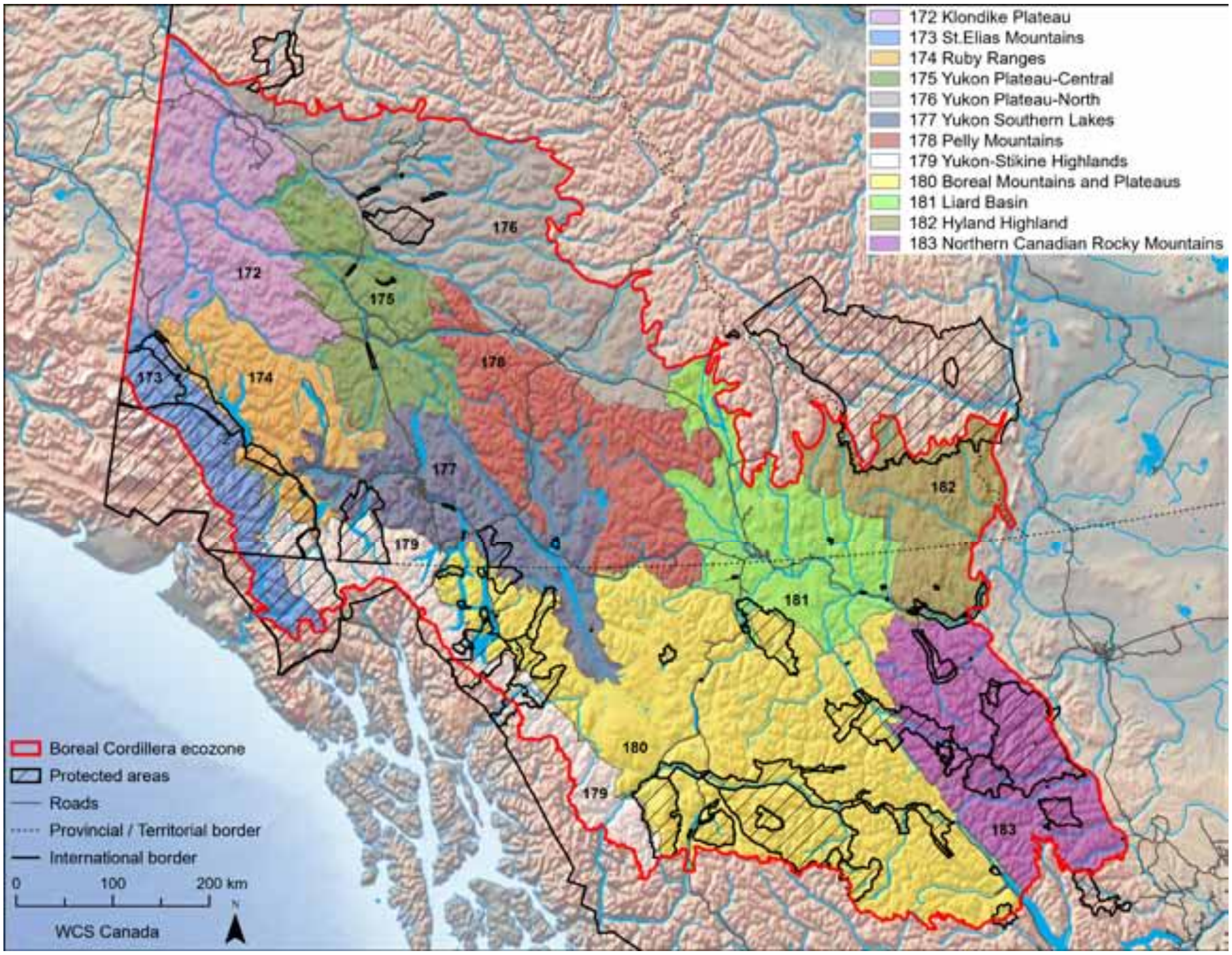
Common Name	Latin Name	Drainages Occupied	Types Of Water Body Occupied By Season*		
			Open Water	**Ice Cover**	**Spawn**
Bull Trout	Salvelinus confluentus	L, P, S, T, Y	Rivers; streams; lakes (limnetic)	Lakes; large rivers	Inlet/outlet streams; rivers
Dolly Varden	Salvelinus malma	A, L, S, T	Anadromous and non-anadromous in rivers; lakes; streams	Anadromous and non-anadromous in rivers; lakes; streams	Streams; rivers
Lake Trout	Salvelinus namaycush	A, L, P, T, Y	Lakes; rivers; streams (benthic & pelagic)	Lakes	Lakes (shallows); wind-swept rocky shores and islands; outlet streams
Whitefishes					
Arctic Cisco	Coregonus autumnalis	L	Rivers; streams	Not present	Streams
Bering Cisco	Coregonus laurettae	Y	Rivers; streams	Not present	Streams
Least Cisco	Coregonus sardinella	Y	Lakes (pelagic & benthic); rivers	Lakes	Lakes; Inlet/outlet streams & rivers
Lake Whitefish	Coregonus clupeaformis	A, L, P, Y	Lakes; large rivers; streams	Lakes; large rivers	Lakes (shallows); Inlet/outlet streams
Broad Whitefish	Coregonus nasus	Y	Rivers / streams; lakes	Large rivers; lakes	Rivers;/ streams
Pygmy whitefish	Prosopium coulterii	A, Y	Lakes (often profundal); rivers	Lakes	Inlet streams; lakes (shallows)
Round Whitefish	Prosopium cylindraceum	A, L, T, Y	Lakes; rivers/streams	Lakes; large rivers	Streams – often inlet/outlet; lakes (shallows)
Mountain Whitefish	Prosopium williamsoni	L, P, S	Rivers; lakes (often littoral)	Large rivers; lakes	Streams); lakes (shallows)
Inconnu	Stenodus leucichthys	L, Y	Rivers; lakes	Lakes; rivers; estuaries	Streams (often inlet) & rivers
Graylings					
Arctic Grayling	Thymallus arcticus	A, L, P, S, T, Y	Rivers, streams, lakes	Lakes; large rivers	Streams (often inlet)
Cods					
Burbot	Lota lota	L, P, S, Y	Lakes (benthic & profundal); rivers	Lakes; rivers; streams	Lakes; rivers
Sculpins					
Slimy Sculpin	Cottus cognatus	A, L, P, S, T, Y	Rivers/streams; lakes (littoral)	Rivers; lakes; streams	Streams; rivers; lakes

* Definitions of some habitat terms (see also section 4.12): Littoral = shallow waters that receive enough light to support growth of rooted plants; Benthic = the lake bottom where sediments build up; Limnetic = open water area receiving enough light for photosynthesis; Profundal = open water too deep to support photosynthesis; Pelagic = open water at all depths (i.e. limnetic plus profundal).

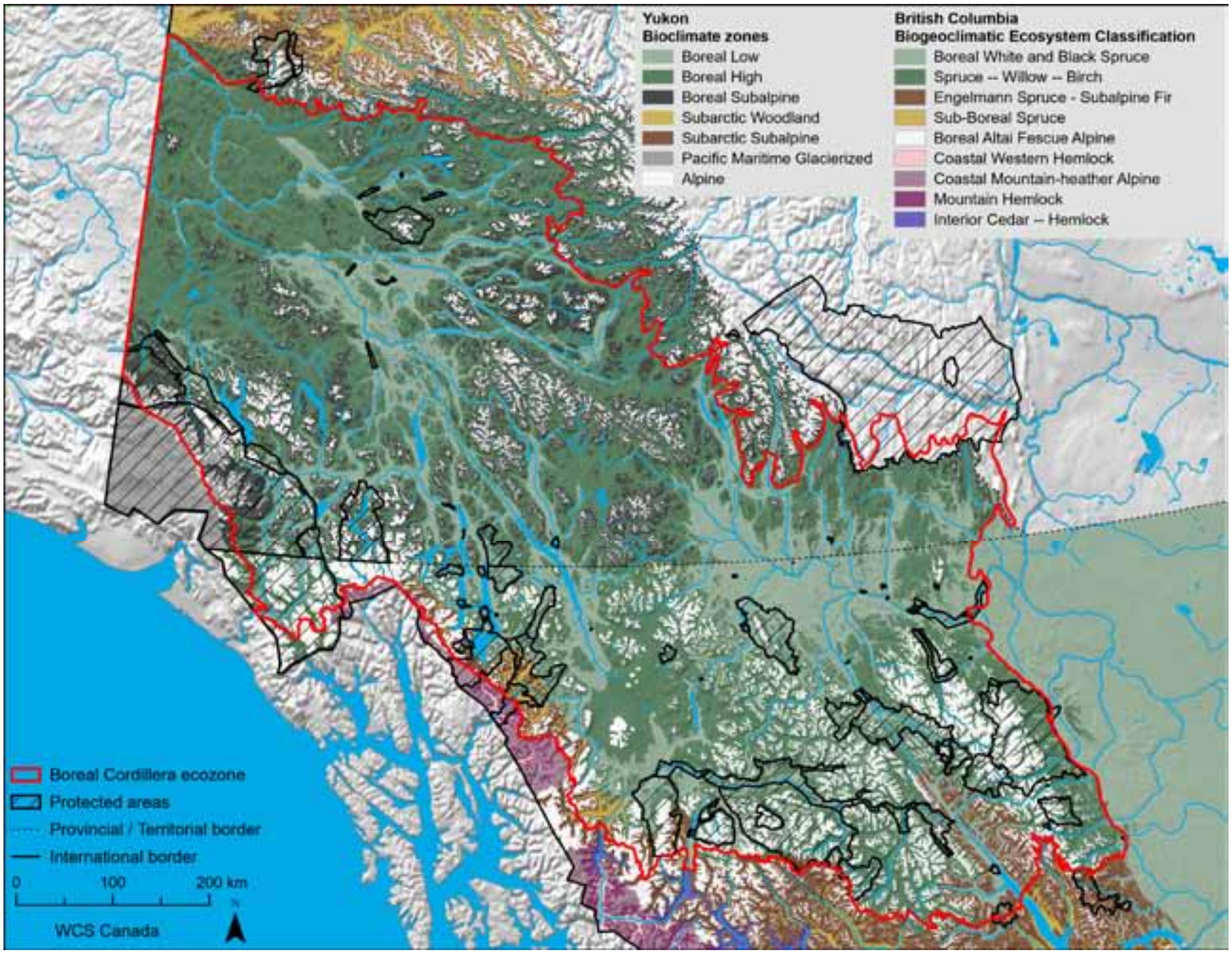
Figure 3. Map showing the ecoregions that comprise the Boreal Cordillera ecozone, and the distribution of protected areas that at least partly overlap one or more of the ecoregions (Map by Piia Kortsalo).



Data Sources:

- Base map: Natural Earth.
- Boreal Cordillera borders: Geomatics Yukon and Agriculture and Agri-Foods Canada (modified).
- Canada borders: Boundary Files, 2011 Census. Statistics Canada Catalogue no. 92-160-X (modified).
- International borders: Natural Earth (modified).
- Roads (Canada): Natural Resources Canada (CanVec Series), licensed under the Open Government Licence - Canada.
- Roads (US): Alaska Department of Natural Resources
- Hydrography: Commission of Environmental Cooperation; Natural Resources Canada (CanVec Series), licensed under the Open Government Licence - Canada (modified).
- Protected areas: Canadian Council on Ecological Areas, Geomatics Yukon, Ministry of Environment and Climate Change Strategy - Parks Planning and Management (modified)
- Ecological areas: Geomatics Yukon and Agriculture and Agri-Foods Canada.

Figure 4: Map showing the distribution of the major bioclimate zones in Yukon and biogeoclimatic zones in British Columbia, along with the protected areas. The map extends the coverage of the bioclimate zones within Yukon, and biogeoclimatic zones within British Columbia, beyond the borders of the Boreal Cordillera to illustrate how the Boreal Cordillera ecozone is representative of a particular suite of ecological conditions that change quickly outside the ecozone (Map by Piia Kortsalo).



Data Sources :

- Base map: Natural Earth.
- Boreal Cordillera borders: Geomatics Yukon and Agriculture and Agri-Foods Canada (modified).
- Canada borders: Boundary Files, 2011 Census. Statistics Canada Catalogue no. 92-160-X (modified).
- International borders: Natural Earth (modified).
- Protected areas: Canadian Council on Ecological Areas, Geomatics Yukon, GeoBC (modified)
- Hydrography: Commission of Environmental Cooperation; Natural Resources Canada (CanVec Series), licensed under the Open Government Licence - Canada (modified).
- Yukon Bioclimate zones: Environment Yukon
- British Columbia Biogeoclimatic Ecosystem Classification: Ministry of Forests, Lands, Natural Resource Operations and Rural Development - Forest Analysis and Inventory

logical diversity (SCBD 2010, MacKinnon et al. 2015). Much still needs to be done to achieve representation of the Boreal Cordillera's ecological diversity in its network of conservation lands. For example, the conservation lands within the St. Elias Mountains ecoregion are comprised largely of rock, ice, and snow-covered terrain, that amounts to 5.2% of the ecozone area, yet accounts for 26.8% of all the conservation lands in the ecozone. The remaining 14.1% of the ecozone that has status as conservation lands is therefore spread over 94.8% of the ecozone, which means these lands fall short of adequately representing the diversity of wildlife and fish habitats in the ecozone (Woodley 2015).

There are other opportunities for the protection of land and water. Under the Canadian National Parks system, a representative Park Reserve has yet to be chosen for region 7 (Northern Interior Plateaus and Mountains) (Parks Canada 2017). This region closely aligns with the Boreal Cordillera ecozone. Under the Final Umbrella Agreement that guides land claims settlements in Yukon, regional land use planning is mandated (chapter 11 in UFA 1993). Such planning processes can result in establishment of new conservation lands (e.g., NYLUPC 2009).

Lakes naturally occur in valley bottoms. The great majority of lakes, and especially the larger ones, are found at lower elevations, in the wide glaciated valleys that are characteristic of much of the ecozone (Figure 4). Lakes are not well represented in the current network of conservation areas. In general, this is because a relatively small proportion of the total area in conservation lands and freshwater is at lower elevations (i.e. in the boreal low bioclimate zone) (Figure 4). Considering larger lakes in British Columbia, parts of Atlin Lake are protected in Atlin Lake Provincial Park, and Coldfish Lake is protected in Spatsizi Provincial Park. In Yukon, Kusawa Lake is covered by Kusawa Lake Territorial Park, and Agay Mene Territorial Park protects a network of lower elevation lakes of small to moderate size. There is a real need to design new protected areas to include more lakes and lakeshore zones at lower elevations where the productivity of ecosystems and the diversity of species are highest, and where human activities are most likely to expand and occupy shore zones in the near future.

3.1.7 Human Population and Footprint

The Boreal Cordillera ecozone has a low human population density (c. 0.09 persons / km^2) compared to many other ecozones in North America. Nearly the entire human population of Yukon lives within the ecozone, amounting to approximately 42,000 people, 33,119 of whom (79 %) live in a single municipality – Whitehorse (YBS 2020). Other smaller communities include Dawson City, Watson Lake, Haines Junction, Mayo, Faro, Ross River, Pelly Crossing, Carmacks, Burwash Landing, Destruction Bay, and Beaver Creek. In British Columbia there is no large urban centre in the ecozone. Data from the 2016 census, taken from portions of the Stikine, Kitimat-Stikine and Peace River regional districts that overlap the ecozone, give a total human population of about 3,275 spread amongst small communities such as Kwadacha, Ingenika Point, Good Hope Lake, Atlin, Dease Lake, Iskut, and Telegraph Creek (BC Stats 2016).

Although the human population is low overall, two issues drive a growing need to focus on lakeshore conservation. First, the Whitehorse urban area and associated rural subdivisions include shorelines of a number of Yukon's most prominent lakes (Figures 1 and 2). The extent and variety of transportation infrastructure, along with residential, recreational, forestry, and agricultural land uses, often directly associated with lakeshores, are increasing because of the relatively high and growing density of people in this urban and suburban area. Second, the human population of the ecozone in summer increases substantially compared to the permanent resident population, because of extensive tourism (Yukon Tourism 2018) and also mineral exploration and development. These activities bring more people into the ecozone, especially in summer, both as employees and clients of the business activities. For example, Yukon government estimated 323,000 person-nights of visitation to the Territory in 2018, the last year with published data (Yukon Tourism 2018). These activities are frequently focussed on lakeshores and lakes which are particularly attractive for temporary and seasonal camps, for easy access to remote areas with float planes, and for many tourist activities including campgrounds and other accommodations.

3.2 Legal and Jurisdictional Scope

The options and processes for planning and management of lakeshore zones are directly dependent on the laws and regulations that pertain to the water itself and to the earth (including bedrock, unconsolidated rock, sediments, etc.) that lie under the water and make up the land adjacent to the water, because these together comprise the ecosystem. In the Boreal Cordillera region, the governments of Canada, British Columbia and Yukon, all have immediate influence. In addition, land claims settlements in Yukon allow signatory First Nations governments to enact legislation and regulations for their own Settlement Lands.

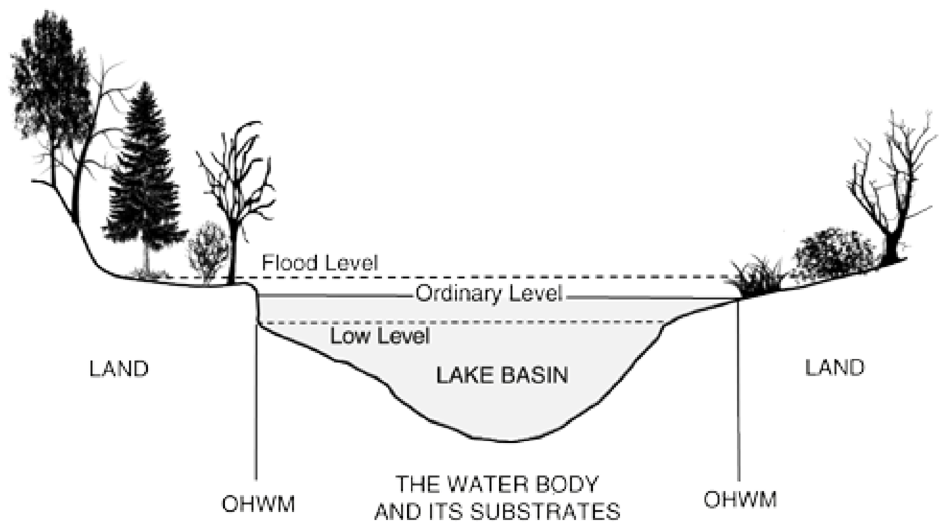
3.2.1 The Border Between Water and Land

A key piece of information is the definition of where water ends and land begins. This boundary is important because it defines where land owners have rights (Figure 5) (Haekel 2002, Ballantyne 2015). The boundary line between land and water is often referred to as the Ordinary High Water Mark (OHWM), but also the water's edge, high water mark, present natural boundary, or bank (Ballantyne 2015) (Figure 5).

Clearly the water level in a pond, lake, stream or river varies during the year, and with greater variation in some years than others, for example with floods and droughts. Also, the substrates close to the water's edge can be taken away (eroded) or added to (accreted) by the natural actions of water, independent of human activities. So, the boundary of water and land is open to interpretation, and its definition varies across jurisdictions to some extent. In Yukon, OHWM is used, whereas British Columbia refers to the line as "present natural boundary", which is effectively the same concept (Ballantyne 2015). Various biophysical signs are used to provide legal definition to these terms at the time of a land survey. These include the existence of a clear bank (physical break in the gradient of the substrate from under water to land), the lower limit on land of permanent vegetation that cannot persist with perpetual water covering above-ground growth, and discolouration on rocks, wood and other substrates as a result of long-term or repeated water cover (Ballantyne 2015).

Important results of the definition of OHWM are: (i) that intermittently flooded areas higher than the OHWM are not part of the water body; (ii) that many substrates exposed to air during seasonally low water levels, but covered by water in other seasons, remain part of the water body and subject to ownership pertaining to the substrates under the water (though riparian land owners have right of access across those seasonally exposed substrates); (iii) wetlands with lake water covering substrates in all seasons, but with emergent vegetation, are also part of the water body. These points are illustrated in Figure 5, and apply to British Columbia and Yukon (Ballantyne 2015).

Figure 5: Schematic cross section of a lake and different shoreline slopes (drop-off. Left side; gradual slope, right side) illustrating how the Ordinary High Water Mark (OHWM) is defined by ordinary maximum water levels, and how flooding or droughts can change this level but not the legal boundary (Diagram by Maria Leung).



3.2.2 Jurisdiction Over Land

Jurisdiction over land above the OHWM rests with the governments of Canada, British Columbia, Yukon, or individual First Nations. The federal government maintains statutory ownership of lands identified as Indian Reserves (Indian Act), National Parks and Reserves (National Parks Act), and National Wildlife Areas (National Wildlife Area Act). Indian Reserves exist in portions of the Boreal Cordillera where Indigenous land claims settlements are not finalized. The federal government has devolved varying degrees of ongoing control and management of Indian Reserves to individual Bands (INAC 2017). In most of Yukon, Final Agreements negotiated in accordance the Umbrella Final Agreement (UFA) have generally replaced Indian Reserves with Settlement Lands, which are owned, administered and managed by individual First Nation governments. Self-government Agreements enable First Nations to enact legislation in a number of areas that deal directly or indirectly with lands. Apart from federal and First Nations lands, British Columbia and Yukon have jurisdiction over the remainder of the lands. However, British Columbia is a province and is, constitutionally, a Crown in respect of provincial-type powers. Yukon is not a province. Provincial type responsibilities have been devolved to the Yukon Government but lands and waters remains vested in the Federal Crown. Each jurisdiction has the right to alienate, lease, or allow the use of lands for private or other interests. The rights may include those typical of fee simple land holdings, forest harvesting, the construction of access routes, or a multitude of other purposes. However, any transfer must be done in accordance with the current understanding of the need to consult with First Nations and the form that such consultation is expected to follow.

The majority of lands in the Boreal Cordillera remain vested in the Crown as public lands (whether federal, provincial, or territorial). Indigenous land holdings (Indian Reserves and Settlement Lands) and private land ownership have tended to be disproportionately associated with lakeshores. This reflects past land use and settlement patterns and the high social, economic, and aesthetic values associated with these lands. This pattern is likely to continue with intermittent but ongoing sales or allocations of public lands to private owners, and future resolution of Indigenous land claims.

Private ownership may be influential for fish and wildlife management because certain provincial or territorial statutes, regulations and land management guidelines do not apply to private lands in the same manner as on public lands. Generally speaking, control of wildlife habitats on private land are at the discretion of the land owner. Private lands are permanently removed from public control, with their habitat values being dependent on the interests of the private land holder(s). In Yukon, private land does not always extend all the way to the shore or OHWM of navigable waters, which include the majority of lakes addressed in this document. The Territorial Lands (Yukon) Act (clause 11.b) states that a 100-foot strip of public land must remain between the Ordinary High Water Mark and a private land holding that is adjacent to "…any navigable water or an inlet to it; …". In practice, however, private land owners close to lakes effectively occupy this 100-foot (30 m) strip, and frequently clear vegetation in the strip to improve views and provide access to lakeshore docks and boat launches. In many cases the land owners are unaware of the existence of the public land adjacent to water, and Yukon Government may re-write deeds to remove the strip of public land (CBC 2019). Overall, the existence of this public land is often seen as a "defect", and in effect it offers little or no conservation value. In British Columbia, private land can extend right to the Ordinary High Water Mark, though permitting processes, often at the Regional District level, can mandate maintenance of natural features in the riparian zone (e.g., a buffer strip of 15 m width within which natural vegetation is to remain largely undisturbed, RDFFG 2004).

Private land ownership is likely to influence lakeshore vegetation and use of the shore zone by wildlife and people. Much of the original forest or other vegetation can be kept in place, sometimes satisfying the 30-m strip of public land above the high-water mark (Little Atlin Lake, June 2020) (Donald Reid).

Given the influence of private land holdings on the lakeshore zone, it is therefore fair for government, and members of the public who are granted or assume standing in the land disposal process, to explicitly consider where private ownership of lakeshores can and cannot occur, so as to minimize impacts from a proposed private use and also from potential future uses. This consideration needs to occur at various scales from the strategic (whole lakes or groupings of lakes) to the operational or specific (individual habitat values or portions of lakeshores). It should also deal with existing access to the lakes, because a new private land holding could cut off existing access by the public. This document is intended, in part, to help address this need for careful consideration of the location of private land holdings adjacent to lakes.

The main focus of this document is the conservation of government-owned lands (public or Crown lands) along lakeshores. A large variety of provincial and territorial pieces of legislation, regulations and policies apply to these lands. We do not provide an exhaustive compilation of these here. In the proposed Principles and Guidelines (section 9.0), we address the legislation and policies that can be influential, pointing out where there are gaps, specific needs, and opportunities to use the legislation and regulations to good effect.

3.2.3 Jurisdiction Over Water and Underlying Substrates

Jurisdiction over water is primarily a provincial or territorial responsibility. However, certain federal piecesof legislation apply to many or most water bodies and courses. Additionally, First Nations with Self Governing Agreements may enact legislation that deals directly or indirectly with water. The general provisions of some Acts may be applied directly, but many or most Acts allow for the development of regulations. These regulations become the primary tool with which specified sections of the Acts are applied.

At present, the primary legal instrument related to water in British Columbia is the Water Sustainability Act (BCWSA) and associated regulations. The BCWSA and regulations link to other BC legislation such as the (BC) Environmental Assessment Act, and (BC) Wildlife Act. Additionally, the administration of the BCWSA may be informed by water and land use plans, strategies, and policies. A separate Act, the Water Protection Act, regulates inter-basin transfers of water or international sales of water. The current primary legal instrument of water management in Yukon is the Yukon Waters Act and regulations. It links to the Yukon Environmental Assessment and Socio-economic Act and regulations and to other territorial legislation.

At present, Federal legislation (and associated regulations) that may apply to waters in both BC and Yukon includes the Fisheries Act, the Navigable Waters Act, the Canadian Shipping Act, the Canadian Species at Risk Act, the Canada National Parks Act, the (Canadian) Migratory Bird Convention Act, the Canadian Environmental Protection Act, and others. Additionally, the Canada Water Act addresses waters that cross inter-provincial or international boundaries, while the 1909 Boundary Waters Treaty between the US and Canada allow contentious water related issues to be considered by the International Joint Commission. The Canada National Parks Act is limited to waters (and lakeshores) within National Parks. The federal government is responsible for anadromous Pacific salmon fisheries (international allocations, domestic catch limits, season limits, etc.), and the governments of BC and Yukon are responsible for management of anadromous non-salmon species and fresh water fish. Federal, provincial, and territorial governments have to manage the fisheries in full accordance with their responsiblilities to First Nations.

First Nations in both British Columbia and the Yukon have, and have continued to, develop capacity to allow them to participate in fisheries and fish habitat management and related activities and undertakings. This, in conjuction with their ability to enact legislation pursuant to Self Government Agreements, is expected to provide a dynamic administrative environment in the coming years.

At present, though, key points for conservation of fish and wildlife habitats include: (i) water bodies and their beds and banks (to the OHWM) almost entirely remain in the ownership of governments (British Columbia: provincial; Yukon: mostly federal but First Nations governments for some Settlement Lands (chapter 5 of UFA 1993)); (ii) ownership of fish and therefore fish population management (e.g., licensing for harvest) rests with the ownership of the water body (British Columbia: provincial; Yukon: federal but licensing transferred to territorial government by formal agreement); (iii) conservation of fish habitat is regulated by the federal Fisheries Act; (iv) boat traffic (including the size, type, and means of propulsion of watercraft) is federally regulated under the Canada Shipping Act. In British Columbia, land and water are owned and managed by the provincial government. In Yukon, devolution has resulted in the federal government transferring its ownership and management of land and water to the territorial government. In both jurisdictions, there are joint federal-territorial approaches to managing fish habitat and fish populations that cross international boundaries.

4.0 LAKE ECOLOGY

4.1 The Watershed

A watershed and its lake(s) are often considered to be a single ecosystem (Likens 1985). This is because a lake is a reflection of its watershed, dynamically linked to geomorphology, climatically-driven hydrological regimes, and ecological processes and patterns within the whole basin (Hauer et al. 1997). Ecohydrology and hydroecology are terms used to describe studies of the interactions of hydrological and ecological processes at a watershed-scale (Hannah et al. 2004). In the northern boreal mountains, the mosaic of physically and chemically different lakes reflects differences in bedrock and surficial geology, hydrological flow regimes including subsurface flow, the distribution of permafrost, the history of forest disturbance (e.g., wild fire), and patterns of deposition of sediments in lakes, floodplains, and downstream sites (Williams 1962, Gregory-Eaves et al. 1999, Betts and Jones 2009). On top of this "natural" variety of lakes and watersheds, various human activities change the timing and quality of water flows on and under-ground, thereby affecting the ecological patterns. These activities include clearing of vegetation on land for forestry, agriculture, urban areas, and transportation, plus changing the water levels in lakes and rivers with dams and diversions for irrigation.

Lakes and riparian zones have historically been managed at a local scale, and often with little reference to hydrology. This reflected a history of academic separation of the disciplines of ecology from hydrology and geology. The separation was often mirrored in the organizational structures of many government agencies and educational institutions. It reflected the difficulty that many management processes, and the political structures that enabled them, had in viewing the world at landscape scales where cumulative interactions are at play. The growing body of knowledge on watershed-scale interactions and interdependencies supports the current movement toward more attention being paid, in land use and water planning, to watershed-scale conditions that influence the development of different types of boreal lakes. These include the geological, geomorphological, hydrological, and climatic conditions, and the past glacial history of the watershed. This growing recognition of watershed-scale interactions leads to the possibility, and likely value, of classifying lakes regionally as background information for planning and management. Classification, based on sufficiently detailed inventory, can inform the relative uniqueness and irreplaceability of individual lakes or types of lakes from a conservation perspective (e.g., Gregory-Eaves et al. 1999, Devito et al. 2005).

A set of linked lakes in a watershed can be viewed as a single ecosystem linked by water flows, changes in vegetation on land, and the movements of larger animals (e.g., moose and river otters) that use many lakes (Morley Lake drainage, September 2012) (Hilary Cooke)

4.2 Geomorphology

The origins of lake basins and their current biophysical characteristics ultimately reflect the geophysical, glacial, climatic, chemical, and biological events that have taken place within their catchments (Pienitz et al. 1997, Gregory-Eaves et al. 1999). The geomorphology of a lake's catchment exerts a dominant control over the nature of its drainage, extent of erosion, the inputs of nutrients to the lake, and the volume of water entering in relation to flushing-renewal times. As an example, flat lands with little runoff and relatively high infiltration rate generally contribute less of a nutrient load to runoff than similar lands with steeper gradients (Wetzel 2001). The run-off and infiltration patterns in turn govern the distribution of dissolved gases, nutrients, and organisms, so that the entire metabolism of freshwater systems is influenced to varying degrees by the geomorphology of the basin, including the type, periodicity, and intensity of modifications throughout its history (Wetzel 2001). These patterns play important roles in how any specific lake will respond to events or disturbances within the catchment, including loss or modification of forest cover with timber harvesting, wildfire, or insect infestations.

At the end of the last ice age (c. 15,000 to 10,000 years ago), melting glaciers left broad valleys and some open plains amidst a mountainous landscape across much of the Boreal Cordillera. The erosive power of glaciers, combined with the patterns of deposition of till, morainal and glaciolacustrine materials, including residual ice, resulted in depressions in the land surface (von Finster 2004). As glaciers receded, these became lake basins, exhibiting a wide range of characteristics and located at various elevations. However, the northwest Boreal

Cordillera (notably the Klondike Plateau ecoregion of west-central and northwest Yukon) remained unglaciated during the last ice age(s), due to a lack of snowfall (Duk-Rodkin 2004). A result is that valleys are relatively narrow and well-incised, and lakes are rare and small (Waltham 1995, Senyk and Oswald 1977).

Lake basins take different physical forms in relation to surrounding topography, and this influences their ecology. Higher elevation alpine tarns tend to be small in surface area, but relatively deep. Many are relatively young, as their basins were scoured out by alpine glaciers that persisted well into the Holocene (Wetzel 2001). They are ice-covered most of the year, and relatively unproductive. They are also often separated from other lakes by headwater streams too steep for fish passage, so have simple food webs.

At lower elevations in the mountainous Boreal Cordillera, there is a significant number of long and deep lakes occupying entire valley floors. They take the physical form of a fjord, and have similar origins, being long, U-shaped valleys carved out by massive alpine glaciers, but now fully immersed in fresh water rather than sea water (Wetzel 2001). Among these lakes, the ones closest to the Coast Range Mountains tend to be relatively cold and unproductive because much of their inflow is from alpine glaciers and snowfields and because they lack extensive shallow littoral zones (Lindsey et al. 1981). This subset of fjord-like lakes contributes a high proportion of the total surface area of lakes in this ecozone (see Table 1: Atlin, Tagish, Bennett, Frances, Kusawa, Kluane Lakes, plus some others such as Tutshi Lake), but they support less fish diversity than other large fjord-like lakes farther from the Coast Range (e.g., Teslin and Laberge Lakes) (Thompson 1997). Their lower productivity stems from the steep-walled valleys in which they sit offering very limited space for riparian or littoral zones; valley sides often drop directly into the water and then quickly into deep water (e.g., mean depth of 54 m for Kusawa Lake. Thompson 1997). Their large sizes create extensive fetch for winds that persistently erode shorelines. In sum, their physical features and situations result in relatively poor conditions for high primary productivity either on adjacent land or in the water.

Many much shallower, and generally smaller, lakes and wetlands are now found in the extensive areas of glacial deposition and outwash, where water has been trapped by massive moraines and till deposits, or where blocks of ice buried in till, glaciofluvial, or lacustrine deposits melted to leave depressions (Wetzel 2001, von Finster 2004). In general, these relatively shallow lakes have higher primary production because they have more extensive shallow water supporting plant growth.

The often enormous glaciofluvial deposits of sand, gravel, and cobble that underlay most low-elevation areas of the Boreal Cordillera allow water to move through them in “aquifers”. Since most of the chemically reactive rock was structurally weak, it was ground up as it was carried downstream by the glaciers and the rivers flowing from them. The remaining materials tend to be physically and chemically stable, allowing water to flow through them with limited loss of dissolved oxygen and low uptake of dissolved solids. When this ground water emerges it tends to be of high quality and to have a relatively constant temperature (von Finster 2011). Ground water of this type discharging

(Top left) At higher elevations, alpine tarns occupy depressions scoured out by glaciers (Grizzly Lake, July 2017) (Donald Reid).

(Top right) Long, deep lakes flood the entire valley bottoms of many glaciated valleys on the north side of the Coast Range (Kusawa Lake, August 2016) (Lila Tauzer).

(Left) Where glaciers left a jumble of deposits in the valley floors, smaller lakes now nestle in the depressions (Rose and Lapie Lakes, August 2020) (Donald Reid).

(Left) Some mountain lakes are fed by glacial melt (cloudy, silt-laden water) and by non-glacial sources (clearer water) (Rose Lake, May 2017) (Gerry Whitley).

(Right) Pothole lakes, having no above-ground inflow or outflow, are fed by ground water. In this case, the soil parent material is rich in salts, creating salt pans as the lakes evaporate during summer (Takhini Salt Ponds, May 2017) (Gerry Whitley).

into Kluane Lake has been associated with spawning fall chum salmon (Wilson 2006). It is likely that this type of ground water flows both into- and out of many lakes in depositional terrain.

Most of the Boreal Cordillera has either discontinuous or scattered permafrost, where the mean annual air temperatures are -1° to -8° C (Oswald and Senyk 1977, Waltham 1995, Burn 2004). Permafrost plays an important role in northern watersheds, as only a limited portion of the ground (the active layer) melts in summer, and considerable water is sequestered in the permafrost itself, often as ice (Burn 2004). Consequently, groundwater flows are more limited compared to areas without permafrost, and surface runoff can be more pronounced because water infiltration to the ground is reduced. Increased melt of permafrost with a warming climate can dramatically influence surface features through thaw slumping which can result in more erosion of soil and organic materials into drainages (Burn 2004, Lewkowicz and Harris 2005). Lakes perched on and surrounded by permafrost (thermokarst lakes) occur primarily in the northern portions of this ecozone (Burn and Smith 1990), and can be profoundly affected by increased melting of permafrost, which effectively keeps the water in the basin. Melted breaks in the permafrost that lines the basin can result in relatively rapid lake drainage (Bello and Smith 1990, MacDonald et al. 2012).

4.3 Hydrology

The hydrology of a watershed is defined as the route that water precipitated from the atmosphere takes on its way downstream, often entering a lake. At the scale of individual lakes, water income from precipitation, surface influents, and groundwater sources is balanced by losses from surface effluents, seepage to ground water, and evapotranspiration. Each of these incomes and losses varies seasonally and geographically and is governed by the characteristics of particular lake basins, their groundwater and river geomorphology, and the climate (Wetzel 2001). As water flows over the surface of the land or beneath the ground it can pick up minerals, organic matter, dissolved gases and other soluble and colloidal materials and deliver them to the lake where they will influence the lake's characteristics.

The frequency, intensity, and time of year that rainfall or snowmelt events occur within a watershed strongly influence lake characteristics such as seasonal water levels, water temperature regimes, and nutrient distributions in time and space (Hauer et al. 1997, Wetzel 2001). Temporal patterns of water flow in the Boreal Cordillera are dominated by long periods of cold in winter when snow accumulates and lakes and rivers ice over, and by the timing of spring and summer melt (Rasouli et al. 2014). During winter cold, stream flows usually drop dramatically, and precipitation generally remains above ground as snow. Water levels in lakes generally decline during winter because outflow is not made up for by inflow. At melt, stream flows increase dramatically. Streams fed primarily by snow melt usually peak in May or June, whereas streams fed largely by glacier melt have more prolonged peak flows through the summer (Fleming and Clarke 2003, Fleming 2005).

Lakes with very small watersheds, that have no inflow or outflow streams, and that are maintained primarily by groundwater flow, are known as pothole or kettle lakes. In contrast, lakes fed primarily by inflowing streams or rivers may be called drainage lakes. In between these extremes lies a set of lakes with mixtures of inflow sources. The Boreal Cordillera includes lakes of all types. However, lakes and wetlands dominated by groundwater inflow are considered most common. This is because many lakes are in topographically complex terrain with numerous slopes producing seepage. Additionally, lots of lakes are underlain by glaciofluvial materials that are quite permeable to groundwater flow, and many lie close to the water table associated with floodplains or depressions.

Flow of groundwater into the lake from the water table under the steep slope is most evident in winter when the main body of water has an ice cover but the edges are kept ice free with warmer groundwater (Haunka Lake 2, January 2014) (Donald Reid).

4.4 Lake Thermal Structure

The thermal structure of a lake refers to the patterns of water temperature change with depth and how those patterns change over time, often seasonally. Lake thermal structure is largely influenced by air temperature (Wetzel 2001), and can be quite dynamic in strongly seasonal environments, such as in the Boreal Cordillera. Water temperatures have a strong influence on lake productivity and nutrient cycling, and also influence habitat use by fish with different fish species often preferring different temperature regimes. Thermal stratification refers to the existence of layers or strata of different temperature in the water column, and specifically the existence of a thermocline or thin layer where the rate of change of water temperature with depth is most rapid (often much greater than 1°C per metre). The strength and the seasonal timing of stratification, are strongly influenced by wind, and by volume of inflow and outflow in relation to the volume of the lake's basin, each of which are in turn influenced by basin configuration, surface area, and depths (Wetzel 2001, Hairston and Fussman 2002).

Many lakes in the Boreal Cordillera experience thermal stratification during the course of the year. Ice covers lakes in this ecozone typically for 6 to 8 months a year (Pienitz et al. 1997). In winter, surface water directly below the ice is about 0°C. Fresh water is densest at 4°C, and water at lower levels of deep lakes will often be at this temperature. Water in lower levels of shallower lakes may well be cooler than 4°C (Shortreed and Stockner 1986, Hairston and Fussman 2002). Soon after ice melt in spring, upper layer water temperatures rise to those at greater depths, often near the temperature of maximum density (4°C) (Wetzel 2001). When the water column is no longer thermally stratified (i.e. it is of almost uniform temperature at all depths), relatively little wind action, or temperature variation, can start spring turnover or mixing of water across various depths (Wetzel 2001). During summer months, sunlight increases the temperature of surface water in most lakes more rapidly than heat can be distributed by mixing (except in shallow lakes), resulting in three distinct thermal layers in the water column. Winds of relatively short duration at the surface cause the top several metres of water to mix homogeneously to form a warm surface layer called the epilimnion. Below the level of wind mixing, temperature drops rapidly through the thermocline, and below this is a region of homogeneously cool water called the hypolimnion (Wetzel 2001). In late summer and fall, when air temperatures drop, surface waters cool and become similar in temperature to water at greater depths. This facilitates autumn turnover which is most pronounced when surface waters reach highest density (4°C) and sink (Wetzel 2001). Continued cooling of surface waters leads to ice formation and lakes re-stratify with the warmest water near the bottom (Wetzel 2001). Lakes with small surface area may only mix for a few days, while larger lakes may experience circulation over several weeks. Thermal stratification does not occur in shallow bodies of water, including various lakes in Yukon (Shortreed and Stockner 1986, Mackenzie-Grieve and Post 2006a), or high altitude lakes where summers are short (Wetzel 2001), and may be weak and intermittently defined in some Yukon lakes (e.g., Kathleen Lake) aligned with prevailing katabatic or frontal winds (Mackenzie-Grieve and Post 2006a).

Larger valley-bottom lakes, with consistent in and outflow through winter, maintain open water at the outflow and at narrows. These sites are well used by semi-aquatic mammals, and by waterfowl especially during spring migration (Frances Lake, April 2016) (Hilary Cooke).

Many lakes in southern Yukon and northern British Columbia follow the pattern of annual summer stratification described above, with uniform temperatures through the water column below the thermocline and turnover of water throughout the lake twice a year, – termed dimictic (Shortreed and Stockner 1986). However, there are also numerous shallow lakes (< c. 7 m deep) that have fairly uniform and warm temperatures throughout their depths in summer and no thermocline (Shortreed and Stockner 1986). This is an important distinction in classifying lakes, because summer temperature profiles and stratification influence productivity and the diversity of habitats available for different fish species, especially species preferring cold water such as lake trout (Mackenzie-Grieve and Post 2006a) and pygmy whitefish – often referred to as glacial relict species

The dominant effect of a changing climate is increasing ambient air temperatures that are causing increasing temperatures of lake water (O'Reilly et al. 2015). Warmer water can result in earlier loss of ice cover in spring, later freeze-up, and shifts in the timing of turnover (Guzzo and Blanchfield 2017). Of particular concern is the availability of relatively cold, well-oxygenated, water that cold-water fish such as lake trout require in the hypolimnion in summer when water in the epilimnion is too warm for their survival. The highest quality cold-water habitat for lake trout in some of a set of lakes in northwest Ontario disappeared completely in summer with greater frequency over a 40-year period of monitoring coincident with warming temperatures, indicating that lake trout, and potentially other cold-water species, are at increasing risk as the climate warms because they have to survive in sub-optimal water temperatures (Guzzo and Blanchfield 2017). Using a model, Mackenzie-Grieve and Post (2006b) projected average reductions of 12%, 35%, and 40% of the suitable thermal habitat for lake trout in south Yukon lakes with mean increases in annual air temperature of 2°, 4°, and 6°C.

4.5 Flushing Rate

Flushing rate, also known as water residence time, expresses the amount of time taken to ompletely replace the volume of water in an entire lake. This is defined by the relative volume of inflows and outflows in comparison to total lake volume (Dodds and Whiles 2010). Flushing rates are highly variable among lakes, and can extend into the hundreds of years. Flushing rates in Yukon lakes are not well documented. However, they are probably quite long, especially in the larger and deeper lakes, because long winters severely reduce inflow and outflow volumes in relation to the full volume of the lake.

The flushing rate influences the lake's concentrations of chemicals that are deposited from the atmosphere through precipitation and from the watershed through surface and groundwater. Flushing rate is influential in determining the availability of chemicals driving primary production (Schindler et al. 1978). Many of these chemicals are beneficial, and can be considered nutrients in the lake ecology. Their availability enhances productivity of microbes, algae, and plants, and the organisms that feed on them. Some chemicals are contaminants, however, and low flushing rate may be a problem if these chemcials are not flushed from the lake with any speed.

4.6 Productivity and Trophic State

The productivity of a lake is measured by its ability to support growth of plants and algae. In general, the productivity of a water body is limited by levels of both inorganic nitrogen and inorganic phosphorus, so increased concentrations of these elements tend to result in increased productivity (Hairston and Fussman 2002, Pienitz et al. 1997). Kirkland and Gray (1986) found that biological productivity of Atlin, Marsh, Laberge and Tagish Lakes was nutrient limited. Shortreed and Stockner (1986) found phosphorus and nitrogen limitation in productivity of most Yukon lakes they sampled. Productivity may also be limited by light, and its ability to penetrate down in the water column. Lakes with relatively large areas of shallow water in which plants can receive light, tend to be more productive, in part because light warms the water. This pattern is also observed in Yukon lakes (Shortreed and Stockner 1986). At the high latitudes of the Boreal Cordillera, the long daylight in spring and summer can result in higher levels of sunlight affecting productivity compared to more temperate latitudes.

A lake's trophic state is a measure of its total biomass, so, as a lake's productivity increases, its trophic state changes (Carlson 1977). Lakes with low productivity are termed oligotrophic. They tend to be deep, in cold environments, and in watersheds with relatively infertile soils or underlying geologies which contribute to low inputs of phosphorus and nitrogen to the lake. By contrast, shallow and warm lakes, and those with high nutrient inputs, result in relatively high productivity, are considered eutrophic. They generally contain an abundance of aquatic vegetation, algae, and invertebrates, and may support significant fish stocks. These lakes may be subject to periodic die-offs of fish under ice in some winters when dissolved oxygen is depleted resulting in anoxic conditions. Mesotrophic lakes have an intermediate level of productivity (Wetzel 2001). If the 19 lakes sampled by Shortreed and Stockner (1986) were and still are representative, Yukon lakes tend to be oligotrophic with a small proportion being mesotrophic. The latter (including Taye, Snafu, Wellesley, Michie and Dezadeash) are relatively shallow and often un-stratified in summer. The rarity of truly mesotrophic and eutrophic lakes in Yukon may justify giving such water bodies particular attention if they occur in a planning region.

Changes in productivity, such as increases in the levels of inflowing nutrients from a drainage following forest fire (Kelly et al. 2006), can occur naturally in lakes. Typically, however, eutrophication results from human-induced nutrient inputs, especially sewage and dissolved fertiliser from agriculture (Dodds and Whiles 2010). Experimental additions of phosphorus, nitrogen, and carbon to boreal lakes in Ontario quickly enhanced primary production (Schindler 1974). An experimental addition of phosphorus and nitrogen to an Alaskan tundra lake clearly increased productivity, from enhanced phytoplankton growth to enhanced growth of lake trout (Lienesch et al. 2005).

Neither "natural" nor human-induced nutrient flows into Boreal Cordilleran lakes appear to be pushing major increases in productivity leading to eutophication at present. However, with human activities concentrated in small landscapes, there is a risk that localized changes may be occurring in a few lakes. This risk needs to be monitored, and minimized with good management practices for sewage, industrial, and agricultural runoff. A warming climate has some potential to enhance productivity by increasing the length of the ice-free growing season, by increasing water temperatures in summer, and by increasing inflows of nutrients where there are trends to increasing precipitation and increasing frequency and severity of forest fires.

4.7 Dissolved Oxygen

Dissolved oxygen is essential to the metabolism of aquatic invertebrates and fish, so the solubility and dynamics of oxygen distribution in a lake help understand the distribution, behaviour, and growth of aquatic organisms (Wetzel 2001). Oxygen enters lake water through surface inflows, by becoming dissolved from the air through wind action, and as a product of photosynthesis in aquatic plants. The oxygen within a lake may then be consumed by the respiration of living aquatic animals, and by the decomposition of dead aquatic organisms (Wetzel 2001). Most small to medium-sized Yukon lakes, being oligotrophic, are considered to have relatively high dissolved oxygen concentrations throughout the year at all depths (Pienitz et al. 1997).

Higher densities and faster growing organisms in more productive lakes, consume oxygen more rapidly, both for animal respiration and for decomposition. This is particularly noticeable near the lake bottom where dead organisms accumulate. Experimental additions of nutrients (phosphorus and nitrogen), that enhance productivity through the food web, have resulted in dramatic reductions in oxygen, even to the point of creating hypoxic conditions in the hypolimnion. Nutrient additions to an oligotrophic Alaskan tundra lake caused benthic oxygen levels to decrease dramatically, apparently being used up by greater biomass of consumers and more decomposition, with resulting decreases in recruitment of lake trout whose early life stages rely on well-oxygenated water in the benthic zone (Lienesch et al. 2005). Nutrient additions to an oligotrophic tundra lake in northern Canada had similar effects (Schindler et al. 1974).

Some of the more productive Yukon lakes have significantly reduced oxygen concentrations in the hypolimnion (lower thermal layer) (Pienitz et al. 1997), and this could restrict fish use of this zone. The problem of oxygen depletion can lead to winterkill of fishes, and is most pronounced in northern lakes in winter because of long duration of ice cover, and significantly reduced inflows of oxygenated water compared to ice-free seasons (Cott et al. 2008). Winterkill is most likely to occur in shallow lakes because their littoral zones comprise a large proportion of the lake volume, resulting in high primary production per unit volume of the lake as a whole, and therefore more intensive decomposition (with oxygen consumption) per unit water volume in winter (Cott et al. 2008, Schuter et al. 2012). Winterkill has been documented in various boreal lakes, and winter water conditions might preclude fish from existing in some northern boreal lakes (Schuter et al. 2012). Some shallow Yukon lakes (e.g., Taye Lake) are known to become oxygen depleted in some winters, with fish concentrating at inflowing seepages and streams where they keep the water ice-free with perpetual movement, but suffer some winterkill (Rivard pers. comm.).

In some lakes, water does not turnover and mix during the year, remaining layered or stratified for many years. Globally, such meromictic lakes are relatively uncommon, but they are significant in that the prolonged stratification results in extremely low oxygen levels in deeper layers, precluding much life (Wetzel 2001). A recent study found that Kluane Lake has been meromictic in the past (Brahney et al. 2010). Perhaps other lakes in the Boreal Cordillera are, or have been, meromictic, and more investigation would be useful.

4.8 Lake Chemistry

The chemical makeup of lake water and lake sediments is a function of regional climate, the bedrock and surficial geologies of the lake's watershed, the dominant vegetation types, and the deposition of airborne materials. Different bedrock types (e.g., calcium-rich, volcanic, or igneous), and the soils derived from bedrock or from glacial deposits, directly influence the chemical constituents of surface and ground water, and therefore the downstream lakes (Pienitz et al. 1997, Wetzel 2001).

Dissolved chemical elements are generally found as ions, the total concentrations of which are referred to as total dissolved solids (TDS). Both TDS and the relative amounts or ratios of different ions together influence the species of organisms that can best survive in the lake, in addition to affecting many important chemical reactions that occur in the water (Wetzel 2001). Lindsey et al. (1981) found that the average TDS in 91 lakes in Yukon ranged from 50-910 mg/L. They found that lakes in the unglaciated regions typically had TDS below 130 mg/L, which was lower than other regions.

Lakes with high concentrations of the ions calcium (Ca^{+2}) and magnesium (Mg^{+2}) are called hard water or alkaline lakes, while those with low concentrations of these ions are called soft water or acidic lakes. In the Yukon interior, most lakes have relatively high alkalinity and acidic lakes are rare (Pienitz et al. 1997). Lakes with very high calcium concentrations are called marl lakes and often support a unique assemblage of organisms, such as molluscs. Where these water bodies are rare, they deserve particular conservation attention.

Some elements and associated chemicals, such as mercury, that are commonly found in boreal lakes are contaminants because they reach concentrations in fish that are dangerous for human consumption. Even in relatively pristine lakes, contaminants such as methylmercury can reach dangerous levels in predatory fishes (Lockhart et al. 2005); this chemical is commonly found in boreal peatlands and soils. When large areas of vegetation and soil in a watershed have been disturbed, flooded, or burned, the levels of methyl-mercury in lake water, and in consumer species in the food web such as fish, can increase dramatically (Hall et al. 2005, Kelly et al. 2005). This is an ongoing risk for humans relying on food from hydroelectric reservoirs (Hall et al. 2005).

Contaminants can also reach lakes from the atmosphere via precipitation. These are mostly industrial pollutants, and include mercury, organochlorines, and polybrominated diphenyl ethers (Evans et al 2005, Yeung et al. 2019). For example, toxaphene, apparently arriving in the atmosphere, accumulated in the food web to levels of concern for human health in burbot livers and lake trout flesh in Lake Laberge in 1990 (Kidd et al. 1995). By 2005, toxaphene levels had fallen and both species are now considered safe for human consumption (Ryan et al. 2013). Overall, however, the variation in the levels of these contaminants in the ecosystem over time is not often easy to explain, and, when biomagnified through the food web, likely varies with fish age and lipid content among other factors (Evans et al. 2005).

4.9 Wind and Water Movement

Movement of surface water by wind influences water temperature, dissolved oxygen concentrations, nutrient circulation, and shoreline morphologies. Wind increases in strength as the distance over which it moves without obstacle (its "fetch") increases. In general, larger lakes provide more fetch for prevailing winds, and so more wave action. This is particularly true of the elongate lakes, commonly found in mountain valleys of the Boreal Cordillera. Consequently, these larger lakes have gravel beach or bedrock shorelines on windward shores. Shallow waters supporting marsh wetlands and emergent vegetation are only found in sheltered bays on these medium to large lakes, making such portions of the lakeshore particularly valuable ecologically. Reservoirs, where water levels are strongly influenced by water control structures, tend to have actively eroding shorelines because wind-driven water is often hitting unvegetated shorelines that are seasonally exposed by drawdown of the stored water and that have little or no history of exposure prior to the creation of the reservoir. Examples in the Boreal Cordillera include the Williston Reservoir on the Peace River and lakes that have been converted to reservoirs such as Marsh, Tagish, and Bennett in the Yukon River drainage and Mayo Lake in the Stewart River drainage.

(Left) Larger lakes provide longer distances for wind to blow without obstacle and so create bigger waves. The resulting movement of water in upper layers in spring and autumn helps to break down, or turn over, the temperature-driven layering of water that happens in winter and summer (Bennett Lake, September 2018) (Donald Reid).

(Right) Strong wave action removes lighter organic and silty soils, leaving shorelines of sand, cobble, and rock around all exposed shores of larger lakes (Tagish Lake, September 2018) (Donald Reid).

Dominant wind directions and intensities are generally dictated by the typical patterns of weather systems moving through the Boreal Cordillera. These are termed frontal winds. In addition, mountains, especially when glaciated, often induce katabatic winds because of colder temperatures at higher elevations. These are downslope winds moving air down and along major valleys towards lower elevations. They can be particularly influential on the lee slopes of the Coast Range mountains where many of the Boreal Cordillera's largest lakes occur (e.g., Bennett and Tagish Lakes).

4.10 Lake Depth

The underlying geomorphology of a lake dictates shape and depth, and consequently influences productivity (Wetzel 2001). Steep-sided lakes allow for only small areas of shallow water. Such lakes tend to be deep and relatively unproductive. A substantial number of larger lakes in mountain valleys of southern Yukon are examples (e.g., Kusawa, Bennett, Tagish Lakes). Lakes in shallow depressions with gradually sloping sides tend to have intermediate to high productivity. Examples in the Boreal Cordillera include Dezadeash, Wellesley, and Taye Lakes (Shortreed and Stockner 1986). Greater productivity of shallow lakes largely results from much more extensive areas where light has penetrated the water to the lake bottom (i.e. the littoral zone). Light is necessary to drive the growth of phytoplankton (plants, such as algae, living in the water column) and plants rooted to the lake floor and growing up through the water column (often called macrophytes). Also, in shallow water, waves are more likely to create turbulence down to the lake bottom thereby mixing nutrients from sediments into the water column where they can be absorbed by the phytoplankton (Wetzel 2001).

4.11 Position in Watershed

The ecological characteristics of lakes can vary substantially depending on their position in a watershed, from headwaters to downstream, and on their geographical position with respect to wetlands. A watershed is itself an ecological system. Water entering any one lake that has flowed through other upstream lakes and wetlands may be influenced by water chemistry, nutrient availability, and productivity of the upstream lake or wetland. This functional connectivity along a drainage system is also at the heart of the river continuum concept that outlines changes in flow regimes, nutrient availability, and species that tend to occur along the gradient from headwaters to the watershed outlet (Vannote et al. 1980). Gradients in biophysical features of watersheds can also be seen within some of the large lakes in the Boreal Cordillera. For example, the portions of Kusawa Lake closest to the main inflows of glacial meltwater are colder and less productive than portions closer to the lake's outflow (>50 km further north), and this is reflected in a gradient in lake trout body size and morphology (Don Toews, pers. commun.).

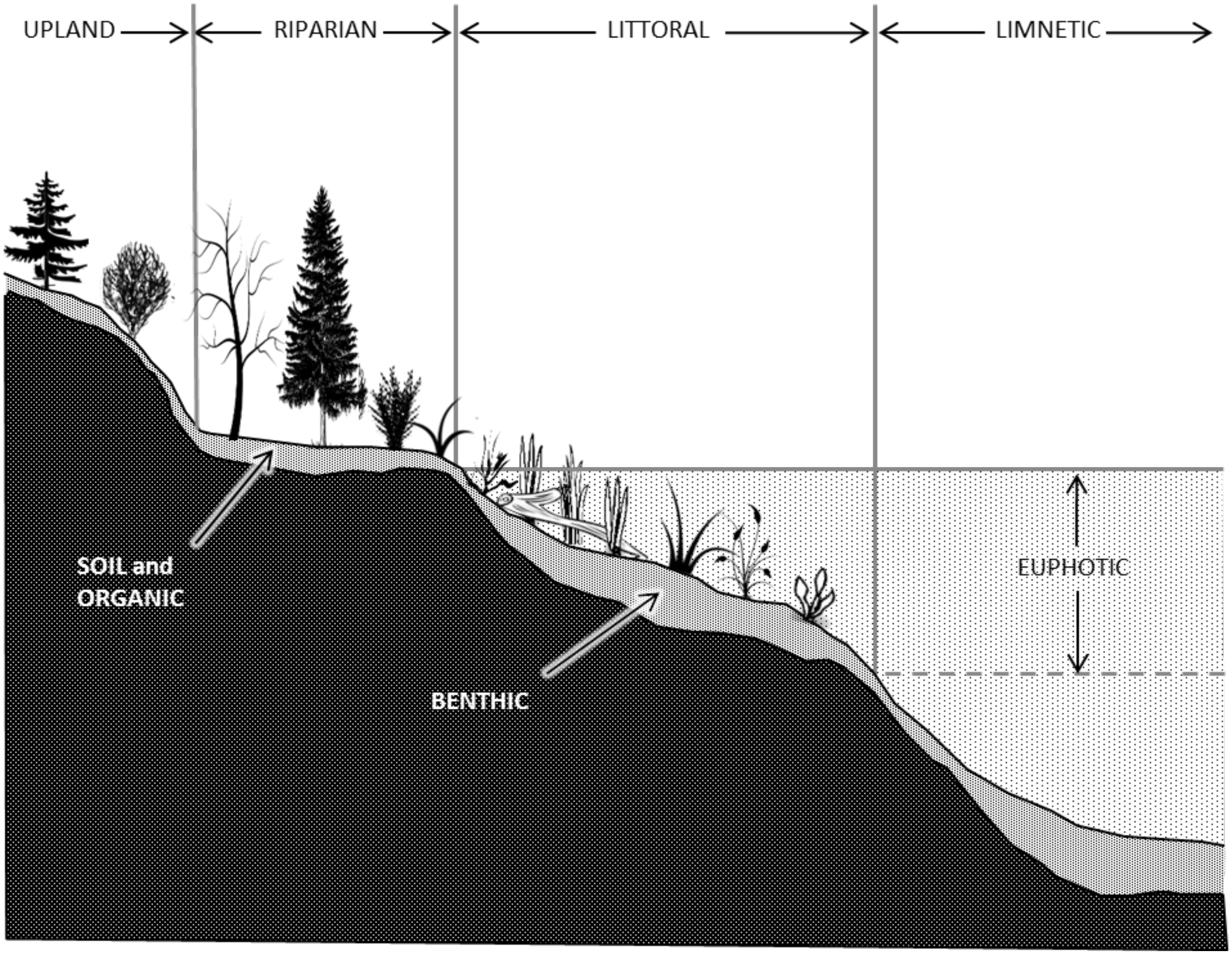
Connectivity from headwaters to outlet waters means that nutrients and many organisms such as plants and invertebrates tend to move downstream supplying key components of the downstream ecosystems. At the same time, many vertebrate and invertebrate organisms move up the continuum, sometimes in water, and more often in the air or along shore zone habitats (Ekness and Randhir 2007).

The lessons for lake planning and management are that, within a designated planning area: (i) complete watersheds are the ideal geographic units for protected areas and for planning in general; (ii) planning for a full watershed should ideally include knowledge about the major patterns of water flow through the watershed; (iii) planning for a full watershed should ideally include knowledge about the movements of key organisms that rely on more than just single lakes but also on associated streams and rivers or systems of lakes and associated streams (e.g., spawning fish, and semi-aquatic mammals).

4.12 Lake Habitats

Habitats for organisms in lakes are generally related to "zones" within the lakes. The zones are defined by whether a portion of a lake does or does not include lake bottom, and then by light availability (Figure 6). The lake bottom is termed the benthic zone. It includes the surface of the lake floor plus the layers of sediment and associated materials in and on which key chemical processes such as decomposition occur and in which organisms live. Those bottom-dwelling organisms are called "benthos". The rest of the lake is the water body above the benthic zone, and is divided first into littoral and limnetic zones (Hairston and Fussman 2002).

Figure 6. Schematic cross-section of a portion of the lake close to the shore illustrating the various aquatic and terrestrial zones which strongly influence the distribution and productivity of organisms. Although not labelled, the profundal zone lies below the euphotic zone (Diagram by Maria Leung).



The littoral, or near shore zone, is the water column from the shallowest water to depths where sunlight still reaches the lake bottom allowing photosynthesis to occur and rooted plants (i.e. macrophytes) to grow (Figure 6). Littoral zones capture much of the chemicals, sediments, and detritus coming into the lake because these generally arrive first in this zone from inflowing waters and the shoreline, and because wind often moves them to the shallows (Hairston and Fussman 2002). Many organisms depend on the littoral zone for at least one stage of their life cycle. The distance the littoral zone extends into the lake depends upon how steeply the lake bottom drops off near shore, and how turbid the lake water is with phytoplankton and suspended sediments (Hairston and Fussman 2002). Where the turbidity of shallower water varies seasonally, then the functional boundaries of the littoral zone will also vary. The limnetic, or pelagic, zone includes water too deep for light to reach the lake bottom (Figure 6). Light does penetrate the upper layers of the limnetic zone, supporting photosynthesis by phytoplankton in the water column. That portion of the limnetic zone in which light levels are greater than about 1% of their values at the surface is called the euphotic zone; below this is the profundal zone (Hairston and Fussman 2002).

4.13 Aquatic Food Webs

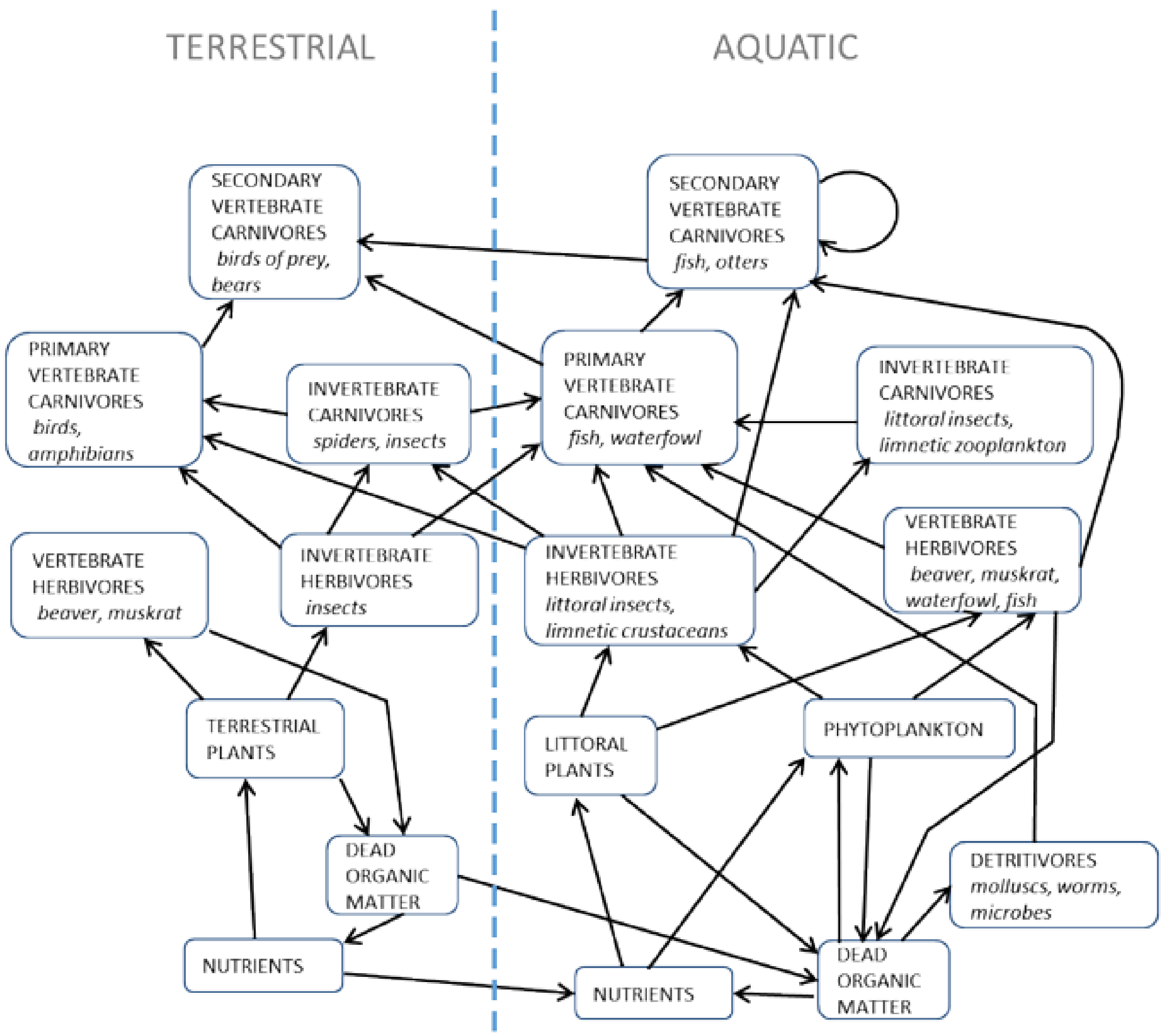
The food webs of northern and alpine lakes, such as those in the Boreal Cordillera, are often quite simple both in terms of the number of trophic levels (number of stages of energy transfer between organisms in the web) and the degree of functional redundancy (numbers of different organisms occupying a stage or level) (Figure 7) (Anderson 1970, Bahls 1992, Paul and Schindler 1994, Taylor 2004). The simplicity of these food webs may cause them to be particularly vulnerable to disturbance, such as changes in temperature regimes, nutrient additions, fish harvesting, or the introduction of new species (McNaught et al. 1999, Christensen et al. 2006).

The functioning of aquatic ecosystems centers on the cycling of organic carbon and other nutrients between living and non-living components through various stages or levels in the food web (Figure 7) (Wetzel 2001). In the open water of both the littoral and limnetic zones of the lake, phytoplankton (algae and photosynthetic cyanobacteria) are at the base of the food chain, carrying out photosynthesis in the illuminated epilimnion. In the littoral zone, this photosynthesis stage is also accomplished by rooted plants (macrophytes) and algae attached to the plants (epiphytes) (Hairston and Fussman 2002).

Phytoplankton, both in the water column and on substrates in the littoral zone, is consumed by herbivorous grazing zooplankton and invertebrates. These small herbivores are consumed by predatory invertebrates (rotifers, cyclopoid copepods, some cladocerans, and insect larvae) or vertebrates (mostly smaller fish). Fish that eat other fish (piscivores), and some piscivorous birds and mammals, sit atop the natural food webs of most lakes (Hairston and Fussman 2002) (Figure 7), except for those lakes where fish are absent. Fish-less lakes include a substantial number of pothole lakes formed soon after deglaciation, and other lakes that were inaccessible to fish after glacial melt and have remained that way (Linsey et al. 1981). These include a high proportion of isolated alpine lakes (tarns) resulting from the recession of alpine glaciers (Bahls 1992), a process that is ongoing.

In addition, the large amounts of non-living organic matter in the lake sediments, collectively referred to as detritus, support another portion of the food web. Bacteria and fungi decompose the dead matter (decomposers) (Figure 7). Some insect larvae and other invertebrates such as annelid worms live in the sediments consuming detritus (detritivores) and consuming decomposers. Detritivores support predatory invertebrates and bottom-feeding fish that are then linked into the rest of the food web (Hairston and Fussman 2002). Decomposition occurs throughout the benthic zone. In the hypolimnion, where there is not enough light for photosynthesis, decomposition dominates as a source of energy and nutrients for the food web.

Figure 7. Schematic representation of the interconnected terrestrial and aquatic food webs of the lakeshore ecosystem. The emphasis is on the energy and nutrient flow up the food web, so the diagram omits many linkages of dead organisms and their waste back to the nutrient and dead matter pools. Sunlight is omitted, but clearly drives photosynthesis for plants and phytoplankton. Details of the detritivore food chain, largely in benthic sediments, are also omitted (Diagram by Maria Leung).



It is, however, rather simplistic to present a lake as separate zones or habitats, because there are interactions and exchanges among all lake zones. Oxygen and dissolved nutrients from macrophytes at various stages of life in the littoral zone diffuse throughout the water column where they are used by bacteria, phytoplankton and fishes. Detritus from the epilimnion sinks to the benthic zone at all depths, providing nutrients for the whole food web. Nutrients in the hypolimnion are returned to the epilimnion via diffusion, turbulent mixing across the thermocline, and at seasonal turnover. Some planktonic animals migrate between thermal layers in the water column on daily cycles, excreting nutrients as they travel. Fish, especially large and mobile predatory species, such as northern pike, lake whitefish, and lake trout, move between limnetic and littoral zones, daily or seasonally, and move significant biomass around the lake through their digestive processes (Hairston and Fussman 2002).

These mobile predatory fishes may stabilize the various parts of the food web associated with individual zones by responding to shifts in abundance of prey in a density-dependent manner (Post et al. 2000). Lake trout spend much of their time in more productive littoral zone when water temperatures are cold enough (e.g., spring after ice melt) but mostly have to remain in deep and cold waters through summer (McPhail 2007). Northern pike are commonly found in the littoral zone in association with rooted plants, but frequently move into the pelagic zone when older and when water temperatures become too warm (McPhail 2007). Clearly, water temperature is a strong influence on these habitat choices. Increasing water temperatures, that reduce the amount of time these fishes spend foraging in shallow waters, may limit their growth and productivity and the stability of the food webs (Guzzo et al. 2017).

Some important characteristics of food webs need to be assessed to focus lake conservation. Although many lakes in the Boreal Cordillera probably have a fairly complete food web from primary producers to piscivorous fish, some do not. Lakes with simplified food webs include alpine tarns and lakes without above-ground water connections to the larger drainage. These types of lake are often fishless (Lindsey et al. 1981, Bahls 1992) so some of their invertebrate fauna, having evolved in the absence of fish predation, may be unique species or more widespread species growing unusually large in size and colour (Archibald 1977, Bendell and McNicol 1987, Arnott and Vanni 1993, Schilling et al. 2009). Such lakes deserve specific attention, including potential protection and consideration of prohibitions on fish stocking.

Another strong characteristic of Yukon river basin lakes is their high densities of zooplankton compared to many lakes further south in British Columbia, a pattern that is attributed largely to the low densities of planktivorous fish (such as least cisco and lake chub) that also characterize these Yukon lakes (Lindsey et al. 1981, Shortreed and Stockner 1986). A relative lack of planktivorous fish may mean that fish food for larger-bodied, piscivorous fish (such as lake trout and northern pike) may be limiting growth and productivity of the larger fish (Shortreed and Stockner 1986). The factors controlling these food web interactions in Boreal Cordilleran lakes deserve more study.

Analyses of body morphology and genetics have allowed scientists to explore the diversity of fish populations within some lakes or sets of lakes linked with streams. Some lakes in the Boreal Cordillera support multiple populations or genetic lineages of what are at present considered the same species. Two distinct morphs of least cisco co-exist in at least one lake in Yukon (Mann and McCart 1981). Pairs of lake whitefish stocks in some Yukon lakes appear to have resulted from diverging life histories during the Holocene (last c. 10,000 years), and include different habitat affinities and spawning times (Bodaly et al. 1992). Lake trout can vary in body size at same age depending on diet, with some feeding mainly on fish and others on invertebrates; this divergence occurs between lakes in the same drainage and sometimes within the same lake (Thompson 1997).

Lineages of some species are inferred to have become separated in different refugial regions during Pleistocene glaciations. In the case of Arctic grayling, these stocks do not appear to have colonized the same drainages to any large extent since the glaciers receded (Stamford and Taylor 2004), and their genetic differences may have local adaptive value.

Lakes with unusual pairing of morphs or lineages of the same species deserve specific conservation attention because the lineages are often restricted in range. Knowledge of the geographic distribution of lineages within a species is also valuable in assessing how well protected areas represent or include distributions of the various lineages. Our knowledge of such geographic distributions is far from complete, and much remains to be discovered.

5.0 SHORE ZONE ECOSYSTEMS

5.1 The Shore Zone as an Ecosystem

The shore zone of a lake is an area of strong interactions between ecological processes on land and processes in the adjacent water. It may be considered to function as an ecosystem in its own right, recognizing that the interactions between land and water create a well integrated food web linking diverse ecological processes such as nutrient flow, primary production, and energy transfers on land and in water. Its exact limits in space are difficult to define and will vary with the ecological topic of interest and over time (Strayer and Findlay 2010). For this document we define the shore zone as including three constituent sub-zones: riparian, shoreline, and littoral (after Ostendorp et al. 2004, and Strayer and Findlay 2010) (Figure 6). The riparian is the land adjacent to the lake that experiences intermittent flooding (not every year) or whose vegetation is directly affected by ground water levels linked to water levels in the lake. The shoreline itself is the area within which annual water levels normally fluctuate, and whose upper limit is generally the ordinary high water mark OHWM (see Figure 6). The littoral is the water column and underlying benthic sediments from the shallowest water to depths where sunlight still reaches the lake bottom allowing photosynthesis to occur and rooted plants to grow (Figure 6).

Shore zones are elongate areas of high energy transfer with relatively frequent and strong shifts of materials and chemicals between land, air, and water (Strayer and Findlay 2010). They are often unstable environments because they dissipate wind energy as wave action in the shoreline and littoral zones and because wind can structure riparian vegetation. In addition, fluctuating water levels cause short and long term, and often pulsed, shifts in water and nutrient availability, and interact with wind to affect shoreline morphology (Morris et al. 2002, Strayer and Findlay 2010).

Extremely heterogeneous and productive riparian, wetland and littoral areas often lie across this ahore zone (Wetzel 2001, Strayer and Findlay 2010). The riparian supports a high diversity of organisms compared to many upland areas by providing abundant surface water, abundant soil moisture, increased humidity, higher rates of transpiration, greater air movement, and periodic nutrient inputs through flooding (Oakley et al. 1985, Nilsson and Svedmark 2002, McEachern, 2003).

Although shore zones support high diversity of organisms and provide numerous ecosystem services to humans, they are among the least understood components of lake ecosystems (Wetzel 2001, Strayer and Findlay 2010). In this section, we give an overview of some of the dominant features and processes influencing the high ecological values in shore zones.

5.2 Topography and Elevation

Topography and elevation are strong influences on the size and ecological complexity of shore zones. The slope and complexity of the terrain close to a lake influences the width of riparian and littoral zones, and the physical structure of the shore zone (Strayer and Findlay 2010). Steep slopes tend to have shallow and coarse-grained soils, often with bedrock exposures. Riparian zones can be very narrow. If the slope is steep in the water close to shore, the littoral zone may also be very narrow. The dominant processes in these shore zones are generally downslope erosion and active transport of materials within and out of the shore zone, often to greater depths in the lake. There is little build-up of nutrients, and plant productivity is relatively low (Oakley et al. 1985, Strayer and Findlay 2010). By contrast, lakes with shallow slopes on adjacent land and under water tend to have riparian and littoral areas that capture nutrients and water, because downslope erosion is gradual, periodic flooding deposits new sediment, and wave action is less likely to move sediment beyond the littoral zone to greater depths. Riparian zones are relatively wide with finely textured soils, and plant productivity is higher (Oakley et al. 1985, Strayer and Findlay 2010).

The elevation of a lake at a regional scale influences its shore zone in diverse ways including length of the ice-free period, timing of water flows, nutrient content of soils, and potential plant productivity (Strayer and Findlay 2010). High mountain lakes in the Boreal Cordillera have short ice-free periods, have limited water inflow for most of the winter and spring, are often in steep terrain with poor soil development, and experience cold climates that limit potential plant growth. They frequently have very poorly developed riparian and littoral areas.

The Boreal Cordillera includes a substantial variety of mountain, plateau, and valley landforms (Figures 2 & 4), and consequently a significant variety of shore zone types associated with diverse lake types. There is no comprehensive inventory of lakes classified by geophysical parameters for the ecozone or significant portions of the ecozone. Key parameters would ideally include surface elevation, surface area, shoreline types, relative contribution of glacial melt to inflows, relative contribution of the littoral and profundal zones to lake volume, extent of the riparian zone, and dominant bedrock types in the drainage. The resulting inventory would shed light on which lakes, or portions of larger lakes, are physically or chemically unusual, likely to be productive, and able to support specific components of biodiversity such as cold-water species and semi-aquatic mammals. It would assist planning processes in understanding the value of their lakes in a much larger regional context, and in choosing zoning designations for the variety of lakes they could influence.

5.3 Hydrology and Wind

Water level in a lake can vary daily, monthly, or seasonally due to changing rates of inflow and outflow. Weather-related processes such as rates of snow melt and precipitation, and effects of drought or wet periods, all affect lake levels. Controls on rates of outflow for hydroelectrial power generaton affect water levels above and below the control dams. The outlets of smaller lakes, or mid-sized lakes in more arid areas, may be dammed by beavers, resulting in heightened lake levels when the dam is in place and partial lake drainage when the dam eventually fails. This is a frequent phenomenon in many Boreal Cordillera lakes (e.g., Snafu, Tarfu, Little Squanga Lakes).

The varying water levels in many lakes are somewhat predictable and fit within expected ranges. For example, the surface level of Teslin Lake varies by up to four metres annually (data accessible at Environment Canada 2020), being highest in early summer after snowmelt and gradually dropping through late summer and the following winter because progressively less water is entering the lake. Shore zone ecosystems are often adapted to, and even rely on, such fluctuations for ecological functioning (Hill et al. 1998, Keddy and Fraser 2000), as outlined in the following paragraphs.

Changes in water level can influence nutrient availability, productivity, species distributions and habitat values of shore zones (Keddy 1983, Keddy and Fraser 2000, Strayer and Findlay 2010). Dynamic water levels shape the structure of the shoreline zone, by erosive removal of substrates, deposition of new substrates, or relocation of substrates along the shoreline (Keddy 1983). By flooding the lower portion of the riparian area and disturbing the littoral sediments, changing water levels are responsible for the relatively dynamic and productive nutrient cycling regime characteristic of the shore zone (Keddy and Reznicek 1986, Strayer and Findlay 2010).

Water levels vary seasonally in all lakes, but to a larger degree in large lakes that experience high variation in rates of inflow, leaving wide shoreline beaches. When the lake volume is re-charged primarily by spring snow melt, then water levels drop considerably by autumn (Teslin Lake, September 2018) (Donald Reid).

Low water levels can allow light to penetrate deeper into the lake allowing a shift in location of the littoral portion the lake (Strayer and Findlay 2010). However, low water levels expose the upper portions of the littoral and may lower the water table in the riparian and can cause vegetation die-offs due to desiccation (Strayer and Findlay 2010). These effects are expected in larger lakes, such as Bennett and Teslin Lakes, with their large sand and cobble flats in spring and early summer where aquatic vegetation cannot survive. Interestingly, seasonally low water levels may be necessary to permit some plant species to regenerate from seeds buried in the benthic sediments of the littoral zone (Keddy and Reznicek 1986, Keddy and Fraser 2000).

Periodic flooding of the riparian zone changes the distribution of aquatic habitats during flooding, and helps maintain a variety of habitats in that zone, including many marshes along the lakeshore. Some fish, notably northern pike, and amphibians can feed or spawn in the seasonally flooded habitats (Wilcox and Meeker 1992, Robinson et al. 2002). Contrarily, prolonged flooding can make riparian habitat unsuitable for some species. Long lasting saturation of roots in soil can kill shrubby vegetation and even riparian trees, thereby allowing new vegetation types to invade, including marshes and wet meadows (Keddy and Reznicek 1986, Strayer and Findlay 2010).

Water levels affect the impact of waves hitting the shoreline and the downslope edge of riparian areas. At high water levels wave action can be more influential in eroding these zones, moving sediments, circulating nutrients, and uprooting plants. The spatial extent, nutrient dynamics, and plant species composition of littoral and riparian areas change as a result (Keddy 1983, Dodds and Whiles 2010). The results of wind erosion are commonly seen on small to medium-sized lakes that can maintain their water levels through the open water season. Wave action erodes the shoreline beside riparian forest, removing soils in which mature trees are rooted such that the trees lean and eventually fall into the water. This process creates denning spaces for semi-aquatic mammals in cavities created by the relocation of roots, excellent perches for fish-eating birds, and also contributes woody debris used as shelter by numerous fish in the littoral zone.

By forcing changes in the seasonal patterns of water level change, dams created by people and beavers can be detrimental to numerous organisms that have evolved to live within the flow regime before the dam existed (Bayley 1995, Hill et al. 1998, Van Geest et al. 2005). Thinking of dams built by people, the higher water levels in lakes made larger by a dam, such as at Aishihik or Mayo Lakes, cause previous fish spawning areas in the littoral zone to be lost in deeper water. Also, the wider range of water levels result in much larger areas of lake bottom being exposed to air in winter and spring making it difficult for plants to grow in the littoral zone. These and other impacts are identified in von Finster and Reid (2015). Thinking of dams made by beavers, such a blockage to water flow can halt the migratory movements of fish moving from lakes to streams to spawn; examples include lake whitefish at Squanga Lake and broad whitefish at Ta'tla Mun (Government of Yukon and Selkirk First Nation 2013; Reid, pers. obs.). Also, by permanently flooding riparian zones by lakes, beavers can kill stands of mature forest (Baker and Hill 2003).

By damming the stream and raising the water table beside the new pond, beavers killed numerous mature spruce growing in the shore zone (Unnamed Pond, June 2021) (Donald Reid).

The influence of wind and waves varies with lake size, shoreline morphology (i.e. numbers of turns in shoreline direction creating bays and headlands), and the direction of prevailing winds. Shore zones most susceptible to waves are those exposed to long fetch or distance over which the wind blows without impediment. In the Boreal Cordillera, lakes less than about 2 or 3 km^2 in surface area typically have short wind fetch (< 1 or 2 km), and relatively little wave development. A result is that waves generally do not inhibit plant growth along the shoreline. Additionally, waves are not strong enough to erode away the soil and organic materials along the shore and then sort the underlying parent soil materials such as sand, cobble, and rock. Consequently, these small lakes often have well-vegetated shoreline and lower riparian zones dominated by shrub and tree growth on a low-lying bank, or by marshes. Also, their benthic soils or "muck" below the littoral zone are relatively deep with high organic content (Yukon Renewable Resources 2001). Lakes larger than 3 km^2 generally have enough fetch for peak wave action to erode and sort sediments along some portions of the shoreline, creating sand or cobble beaches, inhibiting rooted woody vegetation close to the shoreline, and impeding growth of aquatic macrophytes in the littoral. On sheltered or lee shores, organic rich sediments can still accumulate in the littoral zone and the banks are similar to smaller lakes (Yukon Renewable Resources 2001). Lakes larger than 10 km^2 generally have sufficient wind fetch from many directions to cause sorting of sediments on most shores except protected bays or upwind shores on lakes with little variation in wind direction. The diversity of shoreline types in a larger lake depends on the degree to which changes in direction and orientation of the shoreline result in headlands that break the fetch and create protected bays. Exposed shores on these lakes are usually of sand or cobble beach, or bedrock, along with relatively unproductive littoral zones. Large lakes such as Tagish, Laberge, Kluane, and Bennett fall in this lake class (Yukon Renewable Resources 2001).

(Left) Sheltered shore zones can support forest and shrub growth to the shoreline, with roots that keep organic soils in place, and a clear bank dropping into the water (Lower Snafu Lake, July 2011) (Donald Reid).

(Right) Wind-exposed shore zones, especially in lakes with variable water levels, have shorelines of sand, cobble or bedrock (Kluane Lake, August 2019) (Donald Reid).

When the littoral zone is extensive and sloping only gradually to shore, waves break farther offshore, protecting the shoreline (Dodds and Whiles 2010). Waves are also responsible for the deposition of buoyant materials (e.g., driftwood, ice, hydrophobic liquids, trash) in the shoreline zone. These materials may be transient or quite permanent in this zone (Strayer and Findlay 2010). Waves can have additional erosive effects when they force wood and ice up against shore zone banks, or into riparian vegetation.

Littoral zones have strong influence on the kinds of fish that a lake supports because different fish species have adapted to select different substrates and other littoral conditions for particular life stages, and wave action strongly determines the availability of these littoral conditions (see Table 4). The warm littoral zones, well protected from strong winds and wave action, are often spawning sites for some species (e.g., lake chub, northern pike, lake whitefish). The young age classes of many fish species (such as lake chub, longnose sucker, white sucker, northern pike) select these littoral conditions for feeding because this is where they can find the most abundant and rapidly growing populations of plankton along with invertebrates in the benthic zone. These young fish also rely on the relatively high abundance of rooted plants and woody debris as cover from predators. The resulting concentrations of small fish and invertebrates attract larger size classes of predatory fish, including lake trout, northern pike and lake whitefish, at least during times of year when these predators can deal with the relatively warm water in the shallows. By contrast, fairly strong wave action through the water column in some littoral zones appears necessary for maintaining high quality habitat for some other life stages of certain fish species. For example, lake trout lay their eggs on cobble and rocky shoals in shallow water normally only a few metres deep. Repetitive movement of water, resulting from waves on the water surface, keeps this cobble substrate cleared of the finer organic and silt sediments that can fill the spaces and suffocate trout eggs and alevins (McPhail 2007). On some smaller northern lakes, wind direction may be quite variable year-to-year, and fetch is limited, so ideal spawning sites are not highly predictable. In one such example, lake trout appeared to spread their spawning activity over numerous cobble shoals instead of choosing a limited few shoals (Callaghan et al. 2016). Slimy sculpins frequently use these rocky and cobble habitats, possibly for reproduction in spring, with lake whitefish sometimes using them as spawning habitat in fall (McPhail 2007).

Planning for lake conservation in the Boreal Cordillera would benefit from classification of lakes by size and by the diversity of shoreline types. This could be accomplished with satellite imagery. Ideally, the full variety of lake and shoreline types would be considered for conservation. Similarly, human activities are often best directed to certain shoreline types (e.g., beaches) than others (e.g., marshes, bays).

5.4 Soils

Shore zones may have a relatively high diversity and spatial variability of soils, particularly in the riparian zone (McEachern 2003, Naiman et al. 2005). This variability stems from repeated flooding, high moisture content, local topographic diversity, and high diversity of mineral inputs coming via stream and ground water inflows (Naiman et al. 2005). In flowing aquatic systems, the mineral content of sediments is derived from the wide range of upstream bedrock and surficial geologies (Bilby 1988). When these sediments are deposited in a lake, they can be moved along the shore or deposited in the riparian by flooding or winds carrying fine materials. Shore zone soils can be more heterogeneous in mineral content than upland soils if the drainage basin has a varied geology (Bilby 1988). Water-rich soils are close to the surface in the riparian zone, and in depressions can inhibit growth of some plants, creating small bogs, meadows and shrub fields (Naiman et al. 2005). High soil moisture can lead to higher decomposition rates particularly if the soils are not permanently saturated. In highly saturated and stagnant soils, a lack of oxygen will inhibit decomposition and enhance formation of bogs (Naiman et al. 2005). Flooding and wave action change the distribution of mineral soils and organic materials. Plant production is enhanced by high availability of water and minerals, so dead organic material is produced faster in the riparian zone than in many upland sites (Naiman et al. 2005).

5.5 Vegetation

The dynamic and nutrient-rich riparian areas often support a wide variety of plant communities in a small area, with relatively productive growth in most of the plant species compared to upland sites (Naiman et al. 2005). This leads to a high diversity of vascular and other plants, of insects, and of breeding birds (McEachern 2003, Naiman et al. 2005). Riparian zones can also be hot spots of plant species diversity, supporting a substantial number of rare or uncommon species (Morris et al. 2002).

Riparian vegetation (whether living, or dead and decaying) affects biotic communities in the lake, especially the littoral, by influencing shore stability, incoming sunlight, water temperature, and nutrient flows, with potential consequences for primary production and species composition in the littoral (Dodds and Whiles 2010). Riparian vegetation includes generalized species that can inhabit riparian and upslope sites, as well as specialized species that require water-rich habitats or particular micro-habitats, including those disturbed by wave action (Morris et al. 2002). The riparian and littoral plant communities tend to be more species rich when associated with physically complex shorelines, because the complexity provides differing degrees of exposure to wind and wave disturbance, and therefore more variation in the processes of erosion and deposition within a particular length of shore (Strayer and Findlay 2010).

Plant roots bind to mineral substrates thereby enabling the shoreline and riparian zones to better resist the erosive forces of waves and flooding. This helps define lake morphology (Brinson et al. 1981, Swanson et al. 1982). Stable, large woody debris can also contribute to bank stability by providing substrates for vegetation attachment. In conjunction with logs that have not stabilized, they protect the shoreline from erosion by waves. Riparian vegetation and ground cover intercept runoff and filter some pollutants from precipitation (McEachern 2003).

The density, height, and species composition of riparian vegetation influence wind velocity over the water surface, especially in smaller lakes (<4 ha). Small lakes, well protected from wind, experience less wind-driven mixing in the water column and tend to warm faster in summer (McEachern 2003).

At northern latitudes such as in the Boreal Cordillera, cold water may be limiting to growth of many ages classes of fish, especially fry with limited energy reserves. Where shoreline vegetation is not well developed, direct sunlight will be more intense and generally of longer duration. This will result in increased water temperatures and faster changes in water temperature compared to a shore zone with vegetation of greater height and density (MacEachern 2003). These unshaded littoral zones can be valuable rearing habitats for northern pike, suckers, lake chub and other species.

Sheltered bays and channels with shallow water are particularly rich in diversity and abundance of species because water is relatively warm and stable, leading to higher production of aquatic vegetation, plankton and invertebrates, excellent rearing habitats for young fish, and excellent feeding areas for birds and semi-aquatic mammals. (Tarfu Lake, June 2015) (Donald Reid).

The effect of the shoreline vegetation canopy on light penetration in water may vary seasonally and over decades. Riparian trees and shrubs often shade the littoral areas, and shading can reduce predation risk for young fish. Riparian areas are subject to periodic disturbances (i.e. fire, landslides, and blowdown) which are followed by regrowth, generally first of deciduous shrubs and trees and later of coniferous species (MacEachern 2003). The duration and intensity of light penetration into the water column influence the rate of photosynthesis in the littoral zone, affecting productivity and composition of the phytoplankton community with consequences for the entire aquatic food web (Weisner et al. 1997). Coupled with loss of vegetative cover over significant areas burned by wild fires, the impacts on nutrient and mineral inputs to lakes and their consequent water quality and productivity can be substantial (Ice et al. 2004, Kelly et al. 2006).

Warmer water temperatures result in lower levels of dissolved oxygen, and increased rate of organic decomposition which consumes oxygen. Consequently, in some of the more productive lakes, warm summers can increase oxygen loss. During long periods of ice cover, shallow lakes with low water volume and ongoing decomposition can lose oxygen to such an extent that fish can no longer survive. Winter-kill of fish occurs in some shallow lakes in the Boreal Cordillera, such as Taye Lake in Yukon (Rivard, pers. comm.).

Northern lakes are also quite susceptible to blooms of algae, in part because, as water temperatures decrease, the growth rates of the algae themselves become gradually faster than growth rates of the plantkton that eat them (Rose and Caron 2007).

Overall, the effects of riparian vegetation on stability of the shoreline, shading of water, and protection from wind, are more prominent on smaller lakes (McEachern 2003, von Finster pers. comm.). Small lakes, well vegetated right to their shoreline, should be included in regional assessments of lake values, especially when these small lakes are well connected to other lakes by streams.

5.6 Litterfall and Coarse Woody Debris

Litterfall and coarse woody debris (CWD) may be critical components of aquatic and terrestrial ecosystems. Leaves and small branches falling from woody riparian vegetation comprise litterfall. Large branches, fallen trees, and uprooted stumps are classified as CWD (Stevens 1997, Mossop and Bradford 2004). Collectively these products of vegetation growth provide structure and nutrients to the riparian, shoreline, and littoral sub-zones (Sass 2009). Wind, fire, insects, beavers, plant diseases, waves, slope failure, ice scouring, flooding, and seasonal and long-term plant senescence are all contributing factors to inputs of coarse woody debris and litterfall to the shore zone (France 1997a, Guyette and Cole 1999, Sass 2009). Litterfall and CWD are supplied and decay over highly variable, and often very long (i.e. decades), time periods, so their removal by people may have long-lasting effects on the shore zone ecosystems (Guyette and Cole 1999).

Where present, eroded root structures and fallen trees in the littoral break up the force of waves and thereby provide shoreline stability and reduce turbidity (the amount of suspended solids in the water column) (Sass 2009). Litterfall and CWD falling into the littoral zone from land provide sources of organic and mineral nutrients to the littoral ecosystem (Sass 2009). McCullough (1998) found that litterfall can be an important source of phosphorous in some lakes, with over half of this litterfall originating within 30 metres of the lakeshore. CWD and litterfall also contribute important refuge, forage, and spawning habitats, over relatively long periods of time, for many fish, invertebrate, bird and semi-aquatic mammal species (Everett and Ruiz 1993, Stevens 1997, Bowen et al. 1998, Sass 2009, Czarnecka 2016). Woody debris often provides shade and cover for fish, and supports higher abundance of invertebrates which are potential food for many organisms in the food web (Diehl 1992, France 1997a, Sass 2009, Smokorowski and Pratt 2007). Increased habitat complexity from CWD can play an important role in predator-prey dynamics by providing refuges for prey (Lewin et al. 2004, Czarnecka 2016).

In riparian areas, decaying pieces of wood and litterfall contribute long-term accumulation of organic matter and nutrients (Stevens 1997). Large amounts of carbon are also released from these organic inputs (Maser et al. 1988). Decaying wood hosts bacteria responsible for fixation of nitrogen, a nutrient which is often limiting to plant and animal growth (Stevens 1997). CWD above the water table can also provide nesting and denning sites for small mammals and birds, and can be the most influential riparian habitat factor affecting abundance of small mammals (Carey and Johnson 1995). CWD can provide a germinating surface for tree seedlings, non-vascular plants, and fungi, thereby impacting forest succession (Harmon et al. 1986, Amaranthus et al. 1994).

Coarse woody debris and litterfall provide clear evidence that the shore zone ecosystem straddles land and water. Humans can disrupt the functional relationships that CWD and litterfall provide to both the littoral and riparian areas. Clear-cutting or high-grading larger trees in riparian forest, and removing CWD in water or on land, will reduce the types and amounts of CWD (Francis & Schindler 2006, Czarnecka 2016). Removal of submerged CWD from the littoral zone can strongly affect the aquatic food web, reducing abundances of many invertebrates and some fish (Sass et al. 2006). High value, littoral, habitats can be considered to depend in whole, or in part, on intact riparian habitats. Lakes or portions of lakes for which conservation is to be the highest or one of the highest values, should benefit from maintaining the full riparian zone undisturbed.

5.7 Nutrient Cycling

Nutrient availability is a primary control on the quality and quantity of biological production, and is influenced by bedrock and surficial geology, hydrology, vegetation, and decomposer microorganisms (McClain et al. 2003, Strayer and Findlay 2010). Plants and microbes in both littoral and riparian zones remove nutrients, such as nitrogen, phosphorus, carbon, and sulphur, from soils, sediments, and organic materials for use in their growth, and ultimately these contribute to higher levels in the food web (Strayer and Findlay 2010, Wetzel 1990).

The flow or cycling of nutrients can take place from terrestrial to aquatic zones, or in reverse. The flow from land to water tends to dominate because gravity enhances re-distribution of fallen materials, and of dissolved nutrients, downslope to ground water or surface run-off, and ultimately to the lake. For this reason, changes to riparian plant communities or to the dissolved nutrient regime of ground water or surface run-off, such as nutrient enrichment through sewage and agricultural inputs, can alter lake chemistry. The effects may be dramatic if large volumes of nutrients are added, potentially leading to toxic algal blooms, fish kills, and eutrophication (Carpenter et al. 1998). The relative ability of different groups of organisms to use the incoming nutrients also affects lake nutrient status (Hecky et al. 2004).

Nutrient flow from water to land often involves physical transport of nutrients dissolved in water via flooding or wave action, or physical movement of aquatic arthropods or fish onto land by predators or scavengers (Willson et al. 1998, Strayer and Findlay 2010). River otters consume fish and aquatic arthropods and defecate on land (Reid et al. 1994a). Grizzly bears and grey wolves consume considerable quantities of fish, often anadromous salmon and therefore nutrients from the ocean. By defecating on land and leaving partial carcasses for scavenging and decomposition in the riparian zone, they return nutrients back to the terrestrial component of the shore zone ecosystem (Maraj and Wipfli 2019).

In the Boreal Cordillera, conserving the existing nutrient status of lakes will best be accomplished by maintaining significant lengths of the riparian in a natural condition, without industrial timber harvesting or development of residential subdivisions. This includes maintaining movement corridors for large mammals that bring aquatic nutrients on to land, such as grizzly bears and river otters. Further investigation is required to understand how current nutrient inputs from human residential developments in riparian areas, and agriculture in the watershed as a whole, might be affecting nutrient status of representative northern lakes.

5.8 Natural Forces and Disturbances

Various natural forces and disturbances, including wind, wild fire, ice formation and break-up, and landslides, may have strong effects on ecological functions in the shore zone. These forces and events tend to be intermittent, and vary in frequency or intensity. Their main effect is to restructure the composition of the vegetation, and potentially the soil and benthic substrates in the riparian and littoral sub-zones, with consequent effects on the food web (Strayer and Findlay 2010).

Wind strongly influences wave action, which erodes shorelines, influences litterfall and CWD inputs from the riparian zone, mixes sediments and associated nutrients into the water column, and redistributes sediments along shorelines. In winter, lake ice naturally contracts and expands with temperature, and these shifts can gouge shorelines and benthic sediments, sometimes destroying vegetation (Strayer and Findlay 2010). During spring break-up, wind moves ice around. Ice frozen into the bed of a shallow lake or bank can be dislodged, taking frozen sediments with it (Reimnitz et al. 1991). Wind can pile ice onto shorelines where it can scour the sediments in the littoral zone, erode banks, and knock down woody vegetation (Strayer and Findlay 2010).

Wild fires do burn into some riparian zones. However, fires occur less frequently and are of lower intensity in riparian zones and wetlands than in upland habitats, probably because of higher atmospheric humidity, higher moisture content of live and dead wood, moist soils, and quite often high abundances of deciduous trees and shrubs (O'Connell et al. 1993, Pettit and Naiman 2007). The lower frequency or intensity of wild fire in riparian areas and on islands in lakes means that these areas may be somewhat refugial for old growth forest species (Bergeron 1991, Petit and Naiman 2007).

By killing live vegetation and exposing soil, fires can affect the amount of sediment that reaches lakes, can alter the supply of CWD in riparian areas, and can significantly affect vigor and type of riparian vegetation (Ice et al. 2004, Pettit and Naiman 2007, Poff el al. 2011). These changes can occur both in the short and long term, and vary with the size, frequency, and intensity of fires in the watershed, and with their proximity to the riparian zones (Pettit and Naiman 2007). In the short term, water temperatures, flow regimes, and nutrient inputs may increase (Kelly et al. 2006, Kobizar and McBride 2006), even inducing shifts in diet and enhanced growth of some fish species such that the food chain became somewhat longer with predatory fish, such as lake trout, partly switching from invertebrate to small fish (e.g., least cisco) diets (Kelly et al. 2006). Immediately following fire, the export of sediment from burnt riparian areas may increase up to twenty-fold, and burnt watersheds can export substantially more inorganic nitrogen, phosphorus, and sulphur than watersheds with timber harvesting (LaMontagne et al. 2000). Fires in permafrost areas may result in significant numbers of shallow land slides bringing trees, soil, and sediments downslope, sometimes into bodies of water (Lipovsky et al. 2005). Longer-term effects include increased organic debris and potential changes in leaf litter type and amount of sediment carried into the littoral areas (Kobizar and McBride 2006).


(Left) Fire swept through large swaths of upland and also lakeshore forest leaving grey burnt trees (distance) compared to the unburnt green stands (foreground) (Swan Lake burn (2004) and Swan Lake, May 2015) (Donald Reid).

(Right) Conifers have not regenerated well in shore zone or upland stands in this portion of an historic burn, leaving relatively uncommon shore zone forests dominated by aspen and willow (Snafu-Tarfu burn (1958) and Upper Tarfu Lake, May 2010) (Donald Reid).

Landslides can be naturally occurring disturbance events or can result from building of access routes and industrial resource extraction. These can directly or indirectly influence some riparian zones. As both erosional and depositional processes, they redistribute large volumes of inorganic (rock and soils) and organic materials down slope, creating new mosaics of habitats (Geertsema and Pojar 2007). They can impound streams and change lakeshore morphology, providing a novel array of habitats and nutrient inputs to the lake ecosystem (Geertsema and Pojar 2007). Large, deep-seated landslides in ice-rich permafrost in central Yukon expose frozen soils causing cold melt water to enter lakes which in turn can modify lake water temperatures (Lyle et al. 2004).

Beavers are a major agent of disturbance in boreal ecosystems because they build dams that change the nature of stream and lake hydrology (Baker and Hill 2003, Rosell et al. 2005). By building dams on streams, beavers flood vegetated areas creating ponds and small lakes. They also frequently build dams at outflows of smaller lakes or the outlets of larger lakes with small outflows or during drought conditions. Lake levels then rise, potentially flooding riparian areas. Nutrients and sediments are generally impounded in ponds in streams, reducing their downstream transport. Chemicals such as methylmercury are released from the flooded soil and submerged vegetation (Roy et al. 2009) and may be carried to downstream lakes.

Beaver dams create ponds and small lakes along a wide variety of streams, holding back much runoff though not all during spring flood as in this image (Unnamed Pond, June 2021) (Donald Reid).

Dams create a greater diversity of aquatic and riparian habitats than was previously present, with potentially significant impacts on the food web. Beaver dams eventually fail, especially when not maintained by beavers. Their longevity is variable but some ponds fill with sediment in less than 3 years (von Finster and Mackenzie-Grieve 2007). Lake outlet dams may fail catastrophically, resulting in significant erosion of downstream channels and sediment transport downstream (Hillman 1998, Case et al. 2003). These events are as significant disturbances as the initial dam building because the ponds and lakes can rapidly drain, leading to new river or lake systems and producing a whole new set of riparian habitats (Baker and Hill 2003).

5.9 Food Webs in the Shore Zone

The shore zone ecosystem includes interlinked food webs in both the terrestrial (riparian) and aquatic (littoral) zones. In addition, the aquatic food web is linked to inflowing water from the whole watershed, via inflowing streams, surface runoff, and groundwater seepage and springs. These sources of incoming water supply dissolved oxygen, inorganic and organic nutrients, and sediments, plus invertebrates carried as drift, to the littoral zone where they are redistributed by water movements along the shore. These external supplies of nutrients and materials are termed allochthonous supplies, or subsidies, to the food web, and are in contrast to sources that result from growth and decay of organisms entirely within the lake, which are termed autochthonous supplies.

Substantial portions of the supply of nutrients and food items to the littoral zone come from external sources, including tributary streams and directly from the riparian zone through run-off and air (Wetzel 2001, McEachern 2003). Tributary stream mouths are hot spots for the aquatic portion of the food web in part because of the incoming subsidies. External sources account for up to 70% of the energy supply (carbon inputs) for zooplankton in the littoral zone (Cole et al. 2006) and a significant portion of the biomass of aquatic insect larvae (Solomon et al. 2008). They also subsidize the pelagic zone (Pace et al. 2007, Cole et al. 2011). The importance of these external sources of nutrients is broadly related to the size of the lake and is more pronounced in smaller lakes (Cole et al. 2006, Cole et al. 2011, Pace et al. 2007). Much of this subsidy is directly from the riparian zone as dead organic matter or fall of invertebrates from overhanging vegetation, often driven by wind (Rosenfeld and Roff 1992, Nakano and Murakami 2001, McEachern 2003). Beavers also move substantial amounts of organic matter into lakes from the riparian because they forage largely on terrestrial plants, and move plant material into the water for lodge and dam construction and for winter food caches, and also defecate in the water (Baker and Hill 2003).

The terrestrial riparian zone receives reciprocal subsidies to the food web primarily in the form of emergent life history stages of aquatic insects that fly over water and into the riparian vegetation. These can make up large portions (25 to 100%) of the diet of terrestrial spiders, amphibians, birds, and bats (Iwata et al. 2003, Baxter et al. 2005). Various birds and mammals consume aquatic vegetation, arthropods, and fish, then urinate, defecate or leave food remains on land, providing a mechanism for enhanced terrestrial productivity. One of the most publicized of these is bears feeding on salmon in tributaries of lakes or in lake outlets and leaving carcasses in the riparian forest (Willson et al. 1998, Maraj and Wipfli 2019).

The food web of riparian areas is not independent of that of adjacent upland areas. However, the relatively high productivity and diversity of habitats in the riparian compared to upland areas, plus the high rates of subsidy from aquatic food webs, mean that the riparian food web includes a greater diversity of species, more species associated uniquely with it, and has faster rates of energy transfer than upland areas (Doyle 2000, Anthony et al. 2003, O'Connell et al. 2003).

Flows of nutrients and individual organisms between terrestrial and aquatic portions of the food web vary over time and space, often in a predictable manner. Primary production peaks in late spring and summer in both littoral and riparian zones, but interannual variation in temperature and precipitation can change the timing between years, or extend or concentrate it within a single year. The timing of litterfall and rates of decomposition vary somewhat between vegetation types. Coniferous and deciduous trees can provide materials (e.g., pollen, leaves, needles, seeds) throughout the year, with major pulses during high winds, but deciduous trees provide most of their material as leaf litter in the fall (McEachern 2003). Subsidies of aquatic insects to riparian predators tend to peak in spring, whereas peak transfer of terrestrial invertebrates to the littoral zone tends to occur in summer (Nakano and Murakami 2001). Life histories of the respective predator communities need to be timed to best take advantage of these pulses of food. Predictable seasonal changes in hydrology and water levels are used by many organisms (Junk et al. 1989). For example, northern pike use rising water along lakeshores as areas to spawn and shallow still water areas to digest food (Fortin et al. 1982).

Ecologically, one of the most important aspects of northern lakes is the presence or absence of ice cover, which can last for up to 8-months of the year. Lake ice cover restricts the ability of water to become re-oxygenated, restricts the mixing of water within the lake, and consequently affects lake chemistry and biology (Wetzel 2001). The timing of ice-out (break-up) on lakes is explained mostly by spring air temperatures with additional influence of total snow cover (Duguay et al. 2006). It is often hastened by rain which accelerates the candling and loss of solid structure in the ice. Primary biological production can start before ice cover is gone. For example, Schindler et al. (1974b) found dissolved oxygen concentrations in an arctic lake to be highest just under the ice in late May, when the ice was at its thickest. This reflects substantial penetration by the almost continuous sunlight in spring through lake ice after snow melt, and entrapment of oxygen in water because of the ice cover. In boreal lakes, ice-off starts along the shoreline, because land absorbs heat faster than the reflective snow and ice, and at the mouths of inflowing streams which contribute spring melt before lake ice melts. These aquatic habitats, where water warms faster than elsewhere in the lake, are crucial for growth of plankton, invertebrates and consequently young age classes of fish. Large volumes of inflowing water can raise lake levels and float the ice free of the shore.

(Left) For many winter months all lakes in the Boreal Cordillera are almost entirely ice-covered, reducing the interactions between terrestrial and aquatic components of the ecosystem. (Kettle Lake, December 2019) (Donald Reid)

(Right) At break-up, ice melts first along the shore. It also completely disappears first from smaller, and generally shallower, lakes, because sun can more quickly heat their smaller volumes of water. (Lower Snafu Lake, May 2012) (Donald Reid).

A key point from this discussion is that the entire width of the riparian sub-zone contributes to the full functioning of the shore zone food web. This is because the numerous supplies of nutrients and materials to the lake come from all portions of the riparian, and riparian organisms often use the full width of the riparian zone for their life history and movements. Human activities in the riparian areas increase the risk that functioning of these areas will be negatively affected. Stewardship practices that minimize and mitigate this degradation should be encouraged through active outreach and education.

6.0 FISH AND WILDLIFE HABITATS ASSOCIATED WITH LAKESHORE ZONES

6.1 The Value of the Lakeshore Zone – an Overview

The high ecological value of lakeshore zones is evident in the disproportionantly high diversity and abundances of invertebrates, fish, and wildlife species using the littoral and riparian zones. A wide variety of vertebrates rely on riparian zones for reproduction, predator avoidance, travel, or foraging (Brinson et al. 1981, Knopf 1985, Doyle 1990, Darveau et al. 1995, Morris et al. 2002). The littoral zones of many lakes, especially oligotrophic ones such as are common in the Boreal Cordillera, contribute disproportionately to the productivity, species diversity and habitat complexity of the lake as a whole (Vadeboncoeur et al. 2008, Hampton et al. 2011, Vander Zanden et al. 2011).

Lakeshore zones have particularly high value as fish and wildlife habitat compared to adjacent deep-water (pelagic) zones in the lakes and to upland areas on the land. This is because the lakeshore zones are the first to lose ice cover in spring, have a high diversity and small-scale patchiness of terrestrial and aquatic vegetation communities and structure, and have relatively high and predictable rates of change in water levels, temperatures, and nutrient availability across the seasons. These features combine to create an unusual diversity of habitat features, the ecosystem of highest productivity both within the lake and on land, and a rich array of ecological opportunities to which species have adapted to occupy numerous niches (Bull and Skovlin 1982, O'Connell et al. 1993, Strayer and Findlay 2010). The linear nature of lakeshore zones, and their high levels of connectedness through valley bottoms, and, when linked to river systems, through altitudinal gradients, makes them natural migratory and travel routes for many aquatic and terrestrial species (Brinson et al. 1981, Oakley et al. 1985).

The biophysical conditions defining habitat differ between species of invertebrates, fish, and wildlife. However, they frequently involve characteristics of the water itself (temperature, chemical content, depth, degree of movement), the physical and chemical makeup of the ground both on land and under water, and the species composition and structure of plant communities on land and in the water.

In the riparian sub-zone, the abundance of soil moisture, relatively high humidity from evaporation, seasonally high rates of transpiration, and substantial air movement due to differential heating of land and water and also wind exposure along the forest edge, all create favourable conditions for a wide range of plants and their primary production, as well as favourable conditions for numerous riparian wildlife (O'Connell et al. 1993). Plant communities in the riparian tend to be more diverse in their composition and structure, and are more productive than those in other parts of the watershed. As a result, relatively robust tree growth and dense vegetation provide numerous structural attributes that define habitat for riparian species (Naiman et al. 2005). Shoreline zones of lakes can be hot spots of vascular plant species diversity, and can support many rare plant species (Morris et al. 2002). Many species utilize the cooling effects of adjacent open water, particularly during hotter, drier time of the day or year. The open water also provides space where numerous amphibians, birds, and mammals can escape from terrestrial predators (O'Connell et al. 1993).

In the littoral sub-zone, warmer water temperatures in generally sheltered circumstances lead to greater primary production of phytoplankton and macrophytes, and to greater differentiation of habitats in space than is found in the pelagic zone (Wetzel 2001, Hairston and Fussman 2002). This is particularly true in littoral areas with limited wind and wave exposure, and a high diversity of structural features (Strayer and Findlay 2010).

The physical proximity of littoral and riparian zones, and their connectedness in terms of nutrient flows and structural attributes, has led to numerous species occupying niches that overlap the two zones. These species are prominent ecological integrators of food webs and nutrient regimes within the broader lakeshore zone (O'Connell et al. 2003). Some live both in the water and on land, at different times, including numerous insects (dragonflies, chironomids, caddisflies, stoneflies), many waterfowl, moose, and the semi-aquatic mammals. Some, including bats and numerous songbirds, do not enter the water, but tend to choose riparian areas as preferred habitats because of the high abundance of prey and specific vegetation communities.

In this section we review the habitat needs of various wildlife and fish species associated with the lakeshore zone in the Boreal Cordillera to better understand the habitat features that are most influential and most at risk, and to outline the gaps in knowledge that still persist.

6.2 Invertebrate Fauna

The aquatic and terrestrial invertebrate fauna of shore zone ecosystems includes a wealth of different taxa, whose distributions are not fully documented in Boreal Cordilleran lakes. These include nematodes, leeches, rotifers, crustaceans, molluscs, insects, and arachnids. Invertebrates in the littoral food web include detritivores (e.g., nematodes), primary consumers (e.g., herbivores such as mayfly and caddisfly insect nymphs, blackfly and mosquito larvae, and crustacean water fleas), and secondary consumers (e.g., predators such as dragonfly nymphs, adult beetles, and crustacean copepods). Invertebrates in the pelagic food web include benthic detritivores (e.g., nematodes, amphipods), and a suite of rotifers and crustaceans, some of which are primary consumers (e.g., eating phytoplankton) and others eating the primary consumers. Invertebrates in the riparian (terrestrial) food web include detritivores (e.g., centipedes, fly larvae), primary consumers (e.g., larvae of moths and butterflies, adult bees and beetles), secondary consumers (e.g., adult dragonflies, spiders), and parasitoids (e.g., parasitic wasps and flies). The free-flying adult stages of numerous insect taxa whose larvae grow in water, and the adult stages of numerous terrestrial insect and spider taxa that are blown or washed into water, effectively link the littoral and riparian food webs.

Many boreal lakes tend to be low in species richness compared to lakes in warmer climates, with relatively few species occupying the food web, and consequently little redundancy in the numbers of species performing a specific ecological role (Schindler 1998). Lindsey et al. (1981) described 32 crustacean zooplankton species – 23 pelagic and 9 littoral – from 70 Boreal Cordilleran lakes. A thorough inventory of invertebrate species in Boreal Cordilleran lakes, however, does not seem to have been compiled. This region could have been colonized from various aquatic refugia that persisted during the last glacial maximum (McPhail 2007), so, may support quite a high diversity of aquatic invertebrates today. This appears to be so for terrestrial plants, whose diversity and levels of endemism are high in the Boreal Cordillera (Enns et al. 2020). Overall, the higher light levels, warmer waters, greater inputs of nutrients from land, and greater diversity of structural features in the littoral zone, collectively support higher macroinvertebrate species richness and abundance than in sublittoral or profundal (pelagic) zones (Särkkä 1983), and also enhance populations of invertebrate detritivores (Polis et al. 1997, Naiman and Décamps 1997).

Crustacean zooplankton species are prominent prey for many boreal fish species, especially when young, including lake trout, various whitefish and cisco species, northern pike, and slimy sculpin (McPhail 2007). Understanding the abundance or density of these zooplankton in northern lakes is crucial for understanding the productivity and food web structure of the fish populations. Lindsey et al. (1981) found that the abundance of these crustaceans (numbers of individuals in a fixed volume of water) in Boreal Cordilleran lakes was similar to the abundances of crustaceans in the Canadian Great Lakes, indicating that the productivity of our northern boreal lakes can be quite high. Long daylight hours at high latitudes may warm water quite quickly and promote their growth and the growth of their phytoplankton foods. In a sample of 19 Yukon lakes, Shortreed and Stockner (1986) also noted high abundances of zooplankton, dominated by crustaceans, compared to boreal and sub-boreal lakes in central British Columbia.

The abundance of zooplankton, and numerous benthic and littoral invertebrates, is influenced by food availability, habitat structure, and predator abundance. As outlined in section 5.9, sources of nutrients and food from outside the lake (i.e. allochthonous) are usually highly influential in the littoral and pelagic food webs (Romanuk and Levings 2003, Francis and Schindler 2009). Overall, shorelines with high structural complexity and spatial heterogeneity tend to support greater diversity and abundances of invertebrates (Diehl 1992, Romanuk and Levings 2003, Brauns et al. 2007, Remsburg and Turner 2009). The structure that CWD supplies in the littoral zone provides refuge from predators for numerous taxa thereby enhancing their abundance (Everett and Ruiz 1993, Søndergaard and Jeppesen 2007). Levels of zooplankton biomass in lakes in the Yukon River drainage basin are among the highest observed on the western slopes of the Rocky Mountains, an observation attributed to a low diversity and density of planktivorous fishes (Lindsey et al. 1981, Stockner and Shortreed 1983, Shortreed and Stockner 1986).

(Left) This adult damselfly (probably Enallagma boreale), resting on shoreline sedge, developed in the water from egg through various larval stages, the last of which moved out of the water to shed its skin and unfurl its wings as an adult, that is then potential prey for birds (Unnamed Lake, June 2019) (Donald Reid).

(Right) Various species of Gammarus, or scuds (amphipod crustaceans), live in Yukon lakes, especially those rich in calcium. These ones are washed up on a lakeshore after a wind storm (Tarfu Lake, July 2017) (Maria Leung).

Invertebrates are a dominant component of the riparian and littoral food webs (Figure 7), because of their amazing taxonomic diversity, and their ability to fulfill numerous ecological roles from scavenging to predation to being food for most fishes. Abundant and diverse invertebrate assemblages in the littoral and pelagic zones generally support greater production of fishes. Because many of these invertebrates have life history stages that emerge from water, numerous riparian predators such as bats and birds also benefit (Iwata et al. 2003, Baxter et al. 2005). Invertebrates are therefore additionally influential as they link together the land (riparian) and water (littoral) components of the shore zone ecosystem.

6.3 Amphibians

Although the Boreal Cordillera is not rich in amphibian species diversity, the limited distributions and particular habitat affinities of these species deserve attention in lakeshore stewardship. The wood frog is the most widespread species, and, as of 2005, occurred through most of the ecozone (Corkran and Thoms 1996, Environment Yukon 2019, Matsuda et al. 2006, Slough and Mennell 2006, Slough 2013). The Columbia spotted frog and the western toad have been documented from scattered locations across the British Columbia portion of the ecozone (primarily in the lee of the Coast Range), and at a few sites in Yukon, most of which are in the Liard drainage in the southeast of the territory (Matsuda et al. 2006, Slough and Mennell 2006, Slough 2013). The boreal chorus frog has only been documented in the Boreal Cordillera from a small area of wetlands and ponds in the lower La Biche River valley near the Yukon-British Columbia-Northwest Territories borders, where it is at the northwest extremity of its range (Slough and Mennell 2006). The long-toed salamander is found in the western (in the Pacific drainages) and southern portions of the ecozone (Matsuda et al. 2006, Slough 2013).

The amphibian species of the Boreal Cordillera all require standing water, generally in small ponds and wetlands without fish, for breeding and early development of young. Egg masses are typically attached to aquatic vegetation, the underside of logs, or rocks (Corkran and Thoms 1996, MacDonald 2010). The littoral zone is crucial for their mating, egg-laying, and tadpole or larval development. They use the riparian zone as adults, for foraging and sometimes for overwintering (Nussbaum et al. 1983, Corkran and Thoms 1996, MacDonald 2010). Some species spend some part of their life cycle in upland habitats, especially when dispersing (Davis 2002). Geothermal springs (especially for western toads) and regions with heavy snowfall (especially for Columbia spotted frogs) influence the distributions of known breeding sites (Slough and Mennell 2006). Breeding sites are often repeatedly used over many years, and some species show strong site fidelity (Oldham 1965, Slough and Mennell 2006). With the exception of the wood frog, these species are uncommon, especially near the northern edges of the distributions, and breeding sites are localised and often widely separated, but inventory effort has been low (Slough and Mennell 2006). Detailed assessments of habitat selection have not been accomplished in the Boreal Cordillera. Research in the Boreal Plains ecozone indicated that the relative abundances of the western toad, boreal cho-

The wood frog is the most abundant amphibian in the Boreal Cordillera and depends on shallow water in small lakes and ponds for most of its life cycle (Unnamed Lake, July 2017) (Donald Reid).

rus frog, and wood frog responded somewhat differently to a suite of habitat features, but that all three species readily occupied the same breeding ponds and responded strongly to within-pond and riparian habitat characteristics (Browne et al. 2009).

Given the wide distribution and abundance of the wood frog, this species is not considered to be of conservation concern. Based on patterns of habitat occupancy and use by the other species, we recommend: that special effort should be put into inventory work for these species when development activities are proposed in areas that could be within their ranges; that known occupied habitats require particular conservation designations, such as wetland notations or some form of protected area establishment; and that managed habitat needs to include both the body of standing water and the associated riparian areas. These recommendations are in general agreement with Yukon government's suggested approach to conserving these species (Government of Yukon 2013).

A range of threats are driving population declines in amphibians globally and in some parts of the boreal region. These include: habitat loss and modification (especially breeding habitat); road mortality; introduced or exotic species, notably predatory fish; fungal diseases; increasing levels of ultraviolet radiation; chemical contamination of water (Seburn and Seburn 2000, Stuart et al. 2004). The western toad is listed as a species of Special Concern under federal Species at Risk legislation, with habitat loss and fragmentation, chytrid fungus infection, and road mortality being prominent threats within its range (COSEWIC 2012). Habitat loss, fish introduced to breeding habitats, fungal disease, water pollution and changing water regimes with a warming climate are all potential threats in Yukon portions of the Boreal Cordillera (Government of Yukon 2013), and are probably occurring in more heavily developed areas in British Columbia. Habitat loss is the most obvious threat, with riparian zones being cleared and otherwise modified for forestry, oil and gas, and agriculture

(Government of Yukon 2013). Threats posed by mining and residential developments in riparian areas are likely similar. Protocols are in place to assess and regulate transfers of introduced species (Government of Yukon 2013). To try to avoid these threats, surveys for amphibians (and other unique fauna) in wetlands and small lakes, especially in the breeding season, should accompany development proposals, the ability of amphibians to use riparian areas needs to be maintained, and connectivity of riparian habitats should be maintained if considered to be critical to listed or uncommon amphibians.

6.4 Fishes

In the Boreal Cordillera, the diversity and distributions of fish species have been strongly dictated by their ability to colonize present-day lakes and streams from the refugial lakes and watersheds within which they would have survived the last glacial maximum at the end of the Pleistocene (McPhail 2007). In addition, high gradient streams, waterfalls, surges of glaciers damming rivers and re-directing drainage patterns, have all influenced fish distributions in individual lakes or portions of the region in the Holocene (Lindsey et al. 1981). Today, Boreal Cordilleran lakes lack the sticklebacks and many of the minnow species that are commonly found in lakes of the Boreal Plains and Boreal Shield ecozones (Scott and Crossman 1973). Also, many fish species (most minnows, white sucker, rainbow trout, sockeye salmon, all ciscos, most whitefish) only occur in a limited number of lakes and drainages (see section 3.1.5, Table 4), so their niches are potentially empty or filled by other species in some lakes (Lindsey et al. 1981, Shortreed and Stockner 1986).

All the lake dwelling fishes use shallow water habitats, generally close to shore (i.e. littoral areas) or close to stream inlets, for at least part of their life histories or during significant periods of their annual cycle. Most salmonid species tend to be found in deeper water and far from shore (Table 5) (McPhail 2007). Of the 31 species listed in Table 5, 14 species spawn in lakes (Table 5), and, when they do so, it is generally in relatively shallow water and often close to shore (i.e. littoral areas). These spawning habitats often have particular characteristics, such as substrate size, water turbidity, and water temperature that are at risk of being influenced by human activities on the adjacent land or elsewhere in the watershed. Consequently, they need specific consideration to avoid impacts that might reduce their quality. In addition, some lake-dwelling populations of at least 9 fish species move into inlet and outlet streams to spawn (Table 4). This emphasizes the particular value of these streams as fish habitat, and the need to view them as habitat connected to the lakes themselves.

Littoral zones in lakes are used at some point in the life history of most boreal anadromous and freshwater fishes, though populations of some anadromous species may just pass through the lakes (Table 5 and Appendix 1) (Lindsey et al. 1981, McPhail 2007). In general, these near-shore portions of a lake can provide: the highest concentrations of food for many fish species; the best substrates for spawning for lake-spawning species (when off-shore shoals are also included); and the greatest structural complexity which can act as both cover from predation by other vertebrates and also ambush cover for predatory fishes. Globally, fish distribution and abundance in littoral areas of lakes have

Table 5. A summary of the use of the littoral zone of lakes for the key life history stages of fishes in the Boreal Cordillera. Throughout the Table, an "X" indicates no use of the littoral, and codes in brackets mean the behaviour is relatively uncommon compared to use of other portions of the aquatic ecosystem.

Species	General Life History[1]	Use of the Littoral Zone			
		Spawning[2]	Young of the year[3]	Juvenile[3]	Adult[3]
Arctic lamprey	M, R	X	F, C	F, C	F, C
Lake chub	R,	G	F, C	F, C	F, C, Sp
Peamouth	S	(G)	(F, C, D)	X	(F, C, D, Sp)
Flathead chub	X	X	X	X	X
Longnose dace	X	X	X	X	X
Redside shiner	R	X	F, C	F, C	F, C, D
Longnose sucker	R	(G)	F, C	F, C	F, C, (Sp)
White sucker	R	(G)	F, C	F, C	(F)
Northern pike	R	E	F, C	F, C	F, C, Sp
Chum salmon	M	X	X	X	(Sp)
Coho salmon	M, R	X	F, C	F, C	M
Rainbow Trout – resident	R	X	F, C	F, C	F, C
Rainbow trout (Steelhead) – anadromous	M	X	X	X	M
Sockeye salmon – anadromous	M, R	X	F, C	F, C	Sp
Sockeye salmon (Kokanee) – resident	R	(G)	F, C, D	F, C, D	F, C, D
Chinook Salmon	M	X	F, C	F, C	M
Bull Trout	R	X	X	F, C	F
Dolly Varden	R	X	(F, C)	(F, C)	(F)
Lake Trout	R	G, B	F, C	X	(F), Sp
Arctic Cisco	M	X	X	X	X
Bering Cisco	M	X	X	X	X
Least Cisco	R, M	G	F, C	(F, C)	Sp
Lake Whitefish	R	G	F, C	F, C	Sp
Broad Whitefish	R	X	F, C	?	?
Pygmy Whitefish	R	(G)	F, C	F, C	F, C, (Sp)
Round Whitefish	R	(G, B)	F, C	F, C	(Sp)
Mountain Whitefish	R	G	F, C	F, C	(F), Sp
Inconnu	R, M	X	F, C	X	X
Arctic Grayling	R	X	F, C	F, C	F, C
Burbot	R	G	F, C	F, C	Sp
Slimy Sculpin	R	G, B	F, C	F, C	F, C, Sp

[1] General Life History: R = Resident in freshwater; M = migratory (generally anadromous)
[2] Spawning substrate: G = gravel, cobble, B = boulder, rock; E = emergent vegetation
[3] Various age classes littoral habitat use: F = feeding; C = cover; Sp = spawning; D = diel

been linked to a wide variety of environmental variables including food availability, the presence or diversity of rooted plants (macrophytes), the abundance of structural elements such as CWD and boulders, spawning substrates such as gravels and boulders, or shoreline aspect (Scott and Crossman 1973, Helfman 1981, Werner and Hall 1988, Chick and McIvor 1994, Lewin et al. 2004, Mayo and Jackson 2006, Smokorowski and Pratt 2007). Removal of macrophytes from an entire lake system in one esperiment resulted in a loss of fish diversity and a shift in fish communities (Bettoli et al. 1993). The distribution of wood in the littoral zone is a function of wave action, slope, and wind, but unlike aquatic macrophytes wood may take decades to centuries to accumulate (Guyette and Cole 1999, Guyette et al. 2002).

Structurally complex littoral zones, with lots of macrophytes, CWD, and diversity of substrates (silts, sands, gravels and boulders) provide important spawning habitats for many populations of northern fish species (Roberge et al. 2001, McEachern 2003, Winfield 2004, McPhail 2007). Often, these spawning areas are "traditional", being repeatedly used year after year because of their specific combinations of substrates, water depths, and wind exposures. A considerable number of species may spawn in either lake or stream habitats, or move from lakes into inflowing or outflowing stream reaches to spawn, also in a repeated pattern year by year (Richardson et al. 2001, Roberge et al. 2002, McPhail 2007). Consequently, those stream reaches used for spawning and located not far from the lakes themselves should be considered to be parts of an integrated ecosystem with the lake and managed as such. Traditional spawning grounds need to be recognized as "key" or "critical" habitats in lake planning, with stewardship actions to avoid disturbance to the sites themselves and their adjacent riparian zone, and to control the amount of boat traffic and angler pressure they experience during spawning periods. Traditional spawning grounds are incompletely mapped in many Boreal Cordilleran lakes, but some focussed inventory efforts such as those aimed at lake trout on Teslin Lake (North of Ordinary 2017) are providing useful information.

Many northern species of fish rely on the shore zone of lakes and associated streams, including (left) the slimy sculpin (Unnamed Lake, July 2020) (Maria Leung), and (right) various morphs of lake whitefish (Squanga Lake, December 2017) (Allan Code).

Some Arctic grayling populations spawn on the rocky shallow shores of a lake, while others migrate to inflowing and outflowing streams often travelling significant distances for spawning and summer feeding (Brown et al. 1970, Richardson et al. 2001, Stewart et al. 2007). In lakes, northern pike select sheltered littoral areas with dense emergent or submergent aquatic vegetation, or temporarily flooded littoral environments (Fortin et al. 1982, Roberge et al. 2001). Lake whitefish can take advantage of a variety of spawning sites, from shallow streams to shallow littoral zones and even deeper rocky reefs in lakes (Roberge et al. 2001). Populations of other whitefish species that spawn in lakes do so at various depths but predominantly in littoral zones (e.g., least cisco (Roberge et al. 2001), round whitefish (Richardson et al. 2001)). Others are either riverine or move from or between lakes, or into streams and rivers to spawn (e.g., broad whitefish (McPhail 2007), inconnu (Roberge et al. 2002)). Even species that spend much of the year in deeper water, spawn in shallow water in or near the littoral zone, or on reef-like shallows which may be located away from shore (e.g., lake trout (Richardson et al. 2001), longnose sucker (Richardson et al. 2001)). Anadromous salmon (e.g., chinook and chum) often spawn in upstream reaches of rivers, sometimes far from lakes, but frequently travel through lakes to reach the spawning sites (Roberge et al. 2001, McPhail 2007). However, some chum salmon are known to spawn in discharging ground water in Kluane Lake, and sockeye salmon may spawn in lakes or in tributary or outlet streams of lakes.

Young-of-the-year and juvenile life stages of many fish species are particularly dependent on littoral areas because these provide a complex mix of shelter from predators and feeding areas (Ferguson 1958, Edwards 1983, Ford et al. 1995, Richardson et al. 2001, Roberge et al. 2001). Newly hatched pike fry remain attached to submerged shoreline vegetation, so they do not fall into the oxygen depleted substrates typical of pike spawning areas (Bry 1996). Young of the year longnose suckers (Brown and Graham 1953, Edwards 1983), white sucker (Corbett and Powles 1983), cisco (Ferguson 1958), kokanee (sockeye salmon) (Ford et al. 1995), whitefish spp. (Rawson 1951), and lake trout (McPhail 2007), along with juvenile burbot (McPhail and Paragamian 2000) and sockeye salmon (Goodlad et al. 1974) may primarily use littoral areas, taking advantage of the cover, before moving to deeper water in the fall (see also McPhail 2007).

Nutrients and foods entering the littoral zone from land or streams (i.e. allochthonous inputs) enhance the productivity of invertebrates that are the primary prey of littoral zone fishes; however, high fish densities in the littoral zones can also reduce the abundance of invertebrate prey (Lewin et al. 2004). In respose to this heavy competition for food in the littoral zone, some fish spend daylight hours in the littoral zone taking advantage of the cover provided by CWD and plants, then move to the pelagic zone at night where there is apparently less competition for zooplankton prey (i.e. diel migration) (Lewin et al. 2004, Hampton et al. 2011). When competition for prey in the littoral zone is less strong, young and adult fish of some species (e.g., longnose sucker) may undergo diel migrations in the opposite direction, moving from day-time use of benthic or pelagic habitats, where they experience a safer and colder environment, to night-time use of littoral habitats when predation risk is lower and water temperatures in the shallows have cooled (Emery 1973, Helfman 1981, Lewin et al. 2004). In some large lakes, young of the year sockeye salmon may undertake diel vertical migrations in the pelagic water column from deep water (depths close to 80 m) during the day to shallow water near the surface (c. 5 m deep) at night, in search of food (Morton and Williams 1990). In many lakes in the upper Yukon River drainage the relatively low number of fish species results in a single species (e.g., least cisco or lake whitefish) occupying different feeding niches (e.g., littoral vs pelagic) and evolving different body morphologies in each niche (McPhail and Lindsey 1970, Winfield 2004).

Some species and morphs are littoral zone residents, spending most of their life in the shallow waters. Northern pike, for example, are typically found in shallow lakes, up to 60-80% of which may be comprised of littoral areas (McPhail and Lindsey 1970). Many species, such as bull trout, dolly varden, lake trout or slimy sculpin, are so flexible in their use of lake (i.e. lacustrine) habitats, and river and stream habitats, that it is difficult to describe their use of the littoral in simple terms. Fish are remarkably plastic in their life history strategies, and have adapted to take advantage of numerous differences in habitat availability and competitive relationships (Roberge et al. 2001, Roberge et al. 2002).

Seasonal movements by fish, as opposed to diel (i.e. 24 hour) migrations, to and from the littoral zone, are typically in response to changes in abiotic conditions. Fish are cold blooded animals whose behaviour is influenced by water temperature; they will seek a thermal environment that will provide optimal growth and fitness and are sensitive to thermal changes (McEachern 2003). Changes in the thermal environment (e.g., seasonal lake stratification, or frequent shifts in temperature in shallow water of the littoral zone) can reduce the amount of habitat available to some species (McEachern 2003). Lake trout (Richardson et al. 2001), burbot (McPhail 2007), and bull trout (Goetz 1989, Richardson et al. 2001) are known to inhabit shallow water when it is still cool in winter and spring, but in summer move to deeper water (often in the hypolimnion after thermal stratification) to avoid the warm shallows. In some shallow lakes, without hypolimnion, lake trout can survive the warmer summer period by congregating in high densities at inflows of streams or ground-water discharge areas that are remarkably colder than the rest of the lake because they are fed by alpine snow and ice (Mackenzie-Grieve and Post 2006a). Some species such as the kokanee salmon (Scott and Crossman 1973) and Arctic grayling (Ford et al. 1995, Stewart et al. 2007) in some lakes move to the deep pelagic zone to over-winter, but return to shallow water in spring (Dorava and Milner 2000, Winfield 2004).

Some patterns of movement identified further south do not appear to happen in the Boreal Cordillera, probably because water temperatures are generally colder in northern lakes. These movements include young-of-the-year lake whitefish moving from shallow water during early summer to lower depths when late summer water temperatures get too warm (Rawson 1951, Reckahn 1970), whereas in Yukon lake whitefish in the first years of their lives inhabit the littoral zone all summer, taking advantage of the relatively warm water and high productivity (Toews, D. pers. commun.).

In some cases, large lakes, along with their associated inflowing and outflowing stream reaches, may encompass the full set of habitats for fish species to complete their life histories. However, in other cases, fish, such as Arctic grayling, may move relatively long distances from lakes but in streams and rivers to reach adult spawning and juvenile rearing reaches, or between summer and winter habitats (Stewart et al. 2007). Fish may move between different smaller lakes in a drainage, in what appears to be dispersal migration between adjacent populations or within a metapopulation structure (Scott and Crossman 1973, Daniels et al. 2008). The scale of, and degree to which, such seasonal movements and dispersal processes occur is largely unknown for many fish populations in the Boreal Cordillera. Regardless, there is sufficient knowledge available to justify maintaining the connectivity of aquatic habitats (lakes, streams, and rivers) as a key principle in fish population and fish habitat management.

6.5 Birds

Although lakeshore zones make up a relatively small component of the regional landscape, they provide essential habitats for many bird species during at least some portions of their life histories. The littoral zone within lakes, and the riparian zones on land, both tend to have high productivity compared to other aquatic and terrestrial ecosystems respectively. In the riparian zone, this rich plant growth includes bigger and faster growing trees and shrubs. Coupled with periodic flooding, proximity to the water table, and diversity of small-scale landforms, the riparian zone also has a high diversity of plant communities, including wetlands. High productivity and habitat heterogeneity lead to high abundance of edible plant parts (buds, flowers, seeds, berries) and arthropod prey (mainly insects). Collectively these riparian systems often support an avian community that is more diverse in species and more abundant in space than upland plant communities (Darveau et al. 1995, LaRue et al. 1995, Dobrowolski 1997, Kardynal et al. 2011). Riparian areas appear to be of greater influence on the distribution and abundance of birds in dry regions, where moisture is the main limiting resource in upland habitats and there is greater contrast in vegetation communities between riparian and upland areas (Saab 1999). However, despite these general patterns, bird communities within the riparian and adjacent upland areas can vary depending on the structure and composition of the vegetation, and the suitability of upland forest habitat (DeGraaf and Yamasaki 2000).

A number of birds depend on the shore zone for at least one key component of their lives, such as places to feed, nest, or find shelter (species accounts in Sinclair et al. 2003). These species are called "obligate" users of the shore zone, but their dependency can be on the littoral or riparian components or both of these at the same time. In the Boreal Cordillera, a considerable number of birds feed almost exclusively in the water of ponds or lakes, or right along the shorelines. Examples include Bonaparte's gull, belted kingfisher, osprey, various waterfowl (e.g., mallard, red-necked grebe), and various shorebirds (e.g., solitary sandpiper, greater yellowlegs). Many of these also depend on the riparian zone, or emergent vegetation in shore zone wetlands, for nesting sites. Examples include cavity nesters taking advantage of larger trees (Scott

Standing dead trees close to shore can provide excellent nesting cavities for some waterfowl such as Barrow's Goldeneye and Bufflehead. Although other birds, notably woodpeckers, make the cavities, the ducks rely on them for nesting (Elbow Lake, May 2021) (Donald Reid).

et al. 1977, Martin and Eadie 1999, Vaillancourt et al. 2008) and numerous waterfowl. However, some can nest significant distances from water and even in upland areas outside the true riparian zone. Examples include the belted kingfisher (nesting in cut banks), and bufflehead duck (nesting in tree cavities). Then there are obligate riparian zone species that feed in the air (often on adult insects with early life stages in water), and nest almost exclusively in the riparian zone though often associated with riparian wetlands as much as mature coniferous forests (Morissette et al. 2018, Cooke and Tauzer 2020). Examples in the Boreal Cordillera include blackpoll warbler, northern waterthrush, Lincoln's sparrow, and Wilson's warbler (Cooke and Tauzer 2020). A few species, such as the bank swallow, also feed mostly in the riparian zone but nest in old river cutbanks that are outside but close to the riparian. In summary, a substantial number of birds in the Boreal Cordillera depend on the lakeshore zone for critical life history stages, so maintaining the functioning of this zone is critical to sustaining populations. Consequently, we need to understand how much of the riparian zone must be left intact in order for riparian birds to successfully nest, what factors might reduce the quality of the littoral zone for nesting, feeding and migration, and which upland habitats (e.g., nesting habitats for waterfowl and swallows) need to be conserved and managed in conjunction with the riparian.

Apart from the obligate shore zone species, many birds can feed and raise young in a wider range of forested habitats during the nesting season. These are more flexible, or "facultative", in their habitat choices. However, many are particularly abundant in riparian plant communities. Examples in the Boreal Cordillera include American three-toed woodpecker, tree swallow, boreal chickadee, ruby-crowned kinglet, and Townsend's warbler (Sinclair et al. 2003, Cooke and Tauzer 2020). A suite of species that frequent upland habitats are often found in high numbers in riparian ecosystems when food is particularly abundant. Examples include white-winged crossbills feeding on conifer seeds, and American three-toed woodpecker and red-breasted nuthatch feeding on insects under bark. These examples add evidence for the need to pay special attention to the shore zone ecosystem.

The diversity and abundance of fish, bird, and mammal species in riparian areas attract significant numbers of predatory raptor species, such as bald eagle, osprey, peregrine falcon, merlin, and great-horned owl (James 1984, Government of British Columbia 2013). Bald eagle, osprey, and peregrine falcon often have nests sites in riparian areas, or on nearby cliffs, and use them repeatedly over many years (Sinclair et al. 2003). Great-horned owls are not so dependent on the riparian but also often return to the same nests repeatedly (Sinclair et al. 2013). These examples illustrate the need to conserve lengths of shoreline, and associated riparian and wetlands, of sufficient size to support the hunting and feeding needs of these raptors. They also illustrate the need to recognize these traditional raptor nests as critical habitats that deserve particular management actions to avoid their disturbance or destruction by people which might lead to the birds abandoning nest areas prematurely (DeGraaf and Yamasaki 2000, Government of British Columbia 2013).

Fish-eating birds of prey, such as bald eagle and osprey, build nests close to shore, and repeatedly use these nests because of the effort invested in building them and the fact that suitable trees are not very common. (Upper Tarfu Lake, October 2012) (Donald Reid).

(Left) Small islands are often chosen for nesting by ground-nesting birds because terrestrial predators such as foxes, coyotes, and bears rarely swim to the islands (Lower Snafu Lake, September 2019) (Donald Reid).

(Right) Arctic Terns frequently nest on islands in lakes (Tern Lake, July 2011) (Donald Reid).

Islands in lakes and ponds are particularly valuable shore zone ecosystems. Their isolation from the mainland during open water seasons means that bird nests are less likely to be predated by terrestrial predators such as red squirrel, ermine, marten, wolverine, red fox, coyote, lynx, and black bear. Walker et al. (2005) observed higher nest survival for waterfowl on islands, as long as those islands were not inundated during the nesting season. Mew gull, herring gull, and Arctic tern frequently nest on islands, in aggregations or colonies (Sinclair et al. 2003). Osprey frequently choose islands as nest sites, and islands probably provide superior hunting conditions because they consistently provide sheltered water in the lee of winds. Islands deserve specific conservation attention in the process of zoning lakeshores, and in more local landscape planning.

The configuration of the shoreline itself and the diversity of riparian plant communities along the shore combine to influence the relative value of different shorelines for birds. A shoreline that twists and turns, with numerous different shoreline aspects, creating bays and promontories, is of high value because there are always stretches sheltered from wind, and foraging birds have wider ranges of view. Waterfowl, such as mallards and Canada geese, use sheltered areas along the lakeshore for loafing (resting, preening, digesting food) and protection during wind and storms.

Most boreal birds migrate seasonally, and lakeshore zones are critical habitats in the migration process for many species. The littoral sub-zone is an essential foraging space for migrating waterfowl, shorebirds, gulls, terns, and some raptors (Sinclair et al. 2003). Trumpeter and tundra swans, for example, feed heavily on the tubers of aquatic macrophytes (LaMontagne et al. 2003), and these and other waterfowl species frequent late winter and spring-time patches of open water at the outlets of numerous southern Yukon lakes as migration stop-over sites (Mossop 1976). The riparian zones of larger lakes are often used heavily by migratory landbirds, probably because they provide movement corridors along the valley-bottom migration routes, and also because they provide high quality foraging areas (MacDade et al. 2011). This foraging refuels the birds for subsequent flights, and can influence migration success, the timing of arrival at the nesting grounds, and the acquisition of high-quality breeding territories and mates (Smith et al. 2005). The high foliage density associated with deciduous trees in some boreal riparian forests provides valuable habitat structure for the dispersal of some juvenile birds (Machtans et al. 1996).

Waterbirds inhabit littoral zones, and frequently move between lake and land, and between lakes, often affecting various ecosystem processes. Water birds can have an important influence on nutrient and other biogeochemical cycles by feeding both in the littoral and on land, and defecating on land when resting, foraging and nesting (Green and Elmberg 2014). However, with a few exceptions (Post et al. 1998), the role of water birds as transporters of subsidies from aquatic to terrestrial habitats, or between lakes has been overlooked (Green and Elmberg 2014). By eating larvae of biting insects, such as mosquitos, some waterfowl can provide some level of biological control of these pests (Green and Elmberg 2014). Waterfowl may also play an important role in maintaining the diversity of ephemeral or isolated wetlands, by the spread of plant and animal propagules (Green and Elmberg 2014). In addition, migratory waterfowl may help the dispersal and spread of exotic or invasive plants or animals as "hitch-hikers" (Brochet et al. 2009, Leung and von Finster 2016).

6.6 Small and Medium-sized Mammals

Small and medium-sized mammals, for the purposes of this document, refer to bats, some shrews, rodents (voles, mice, squirrels, marmots), lagomorphs (hares and pikas), and many furbearers (ermine, marten, red fox, lynx). Few of these species have periodic affinity with lakeshores, the exceptions being two bats (little brown myotis and silver-haired bat) and fisher. This group excludes semi-aquatic mammals (water shrew, beaver, muskrat, mink, and river otter) because those 5 species have a very strong relationship with the shore zone and need to be dealt with separately and in detail (see also Table 2).

Bats require roost sites for shelter, from weather and predators, and for raising young (Kunz 1982). Relatively little is known about roost site selection by bats in northern latitudes, however the majority of currently known roost sites for little brown bats in Yukon are in buildings (Slough and Jung 2008). Due to the limited surveying efforts for bats in the Boreal Cordillera, there may be a detection bias towards roosts in easily identifiable man-made structures (Randall et al. 2014). Bats generally travel to lakes, sometimes over 5 km away, for evening foraging on insects (Randall et al 2014). Randall et al. (2014) propose that the distance the bats are willing to travel between diurnal roost sites and evening foraging areas could suggest that both of these factors may be limiting resources in this region.

The particular habitat attributes that riparian zones provide for fisher are high levels of structural diversity in the forest, especially downed wood and understory vegetation, and high densities of large diameter trees, especially deciduous species. The structure provides habitat for prey, such as snowshoe hare and voles, but also provides access under the snow (the subnivean zone) for fisher to hunt effectively. The large trees provide cavity dens especially for raising young (Powell et al. 2003, Weir and Almuedo 2010). However, the riparian zones themselves are unlikely to be large enough to support a full home range for this relatively large furbearer, so useful conservation of these riparian habitat values includes consideration of habitat retention in adjacent upland areas in a larger landscape approach (Weir and Almuedo 2010, Weir and Corbould 2010).

Other mammal species in this group include a mix of insectivores, herbivores, and carnivores. Shore zones provide particularly high quality habitat for many of these species because the riparian, compared to upland landscapes, has relatively high soil moisture, downed organic matter, plant productivity, and spatial variability in plant communities. The insectivorous shrews benefit from relatively high densities of arthropods. Voles and mice benefit from relatively high availability of fungi, seeds, and berries. The predators benefit from the concentrations of diverse prey within relatively small areas. Riparian zones may act as population sources for some small mammal species, including voles and marten, in that there is a net emigration of young of these species dispersing from the riparian into lower quality habitats often in upland areas (Doyle 1990, Paragi et al. 1996).

6.7 Large Mammals

Large mammals – the ungulates, bears, and wolves – have large home ranges that frequently include lakeshore zones and many other portions of the landscape. Here we focus on their particular use of the lakeshore zone.

Moose are the large mammal most strongly associated with lakeshore zones, and aquatic habitats, although they are not dependent on these landscape features (Bowyer et al. 2003). Their association with lakes and ponds has three main features: feeding in the riparian zone year-round; feeding in the littoral zone where it supports suitable plant foods during open water; giving birth and raising young.

Moose rely on browsing woody shrubs, particularly willows, in all seasons, and the high shrub production in riparian zones often provides good quality forage for moose (Bowyer et al. 2003). During open water seasons, moose may shift their diet to aquatic vegetation (Bowyer et al. 2003). In the littoral zone they can often obtain a variety of plants (e.g., water lily, pond weed, sedge, rush, horsetail) rooted underwater but with substantial growth in and above the water column. The concentrations of some valuable nutrients (e.g., sodium, other minerals and proteins) are often higher in aquatic vascular plants than terrestrial plants, potentially making feeding on aquatic plants quite beneficial for ungulates including for antler growth (Belovsky and Jordan 1981, Ceacero et al. 2014). By feeding in the littoral zone, but resting and defecating in riparian and upland areas, moose are influential in transferring various nutrients, and especially nitrogen, from aquatic environments to terrestrial ones (Bump et al. 2009, Bakker et al. 2016).

(Left) In winter, moose frequently feed on willows in the shore zone of lakes (Haunka Lake 3, January 2014) (Donald Reid).

(Right) Shore zones often provide a good mix of places for cow moose to feed and to shelter young in fallen timber with quick access to the relative safety of water: cow with two calves (Otter Lake, June 2018) (Donald Reid).

Predation on young moose is one the strongest limiting factors on moose population growth (Bowyer et al. 2003), and mothers choose birthing sites with relatively high concentrations of food for their own feeding, good viewscapes for assessing predation risk, and closed canopies and downed logs for cover from bad weather and predators (Bowyer et al. 1999). Islands in lakes and rivers can often provide these conditions, and often are chosen as birth sites. This is probably because they are rarely visited by predators after ice break-up which fairly closely coincides with moose birthing in late May in the northern boreal (Addison et al. 1990, Bowyer et al. 1999, Bowyer et al. 2003). This lends more evidence for leaving islands undeveloped.

Caribou also can be found in association with lakes during winter and calving seasons, though they do not depend on lakes. Herds of the northern mountain population of woodland caribou are found throughout the Boreal Cordillera. In winter, lakes may provide enhanced opportunities for vigilance against predators (mainly wolves), and some foraging opportunities (Ferguson and Elkie 2005). While on the lakes, caribou can see and smell approaching predators more readily than when they are in mature forests or upland shrub growth. Also, the wind-packed snow on some frozen lakes may provide better escape opportunities at longer flight distances than the deeper and softer snow in the forest. During the winter months, caribou may be seeking supplements of all major minerals, as lichens, their primary winter diet, are low in minerals and proteins (Heard and Williams 1990, Miller 2003). Seepages of ground water along lakeshores are frequently rich in dissolved elements, and this seepage keeps open small patches of water or freezes as "overflow" on ice close to shore. Caribou are known to lick at this overflow.

As with moose, young caribou are particularly vulnerable to predation (Miller 2003). Mothers in caribou herds occupying the northern mountains of the Boreal Cordillera tend to space out, or segregate themselves, when birthing, generally heading to higher, subalpine and alpine elevations to reduce detection by predators (Bergerud and Page 1987). Caribou in other boreal herds, east of the mountains, also tend to segregate themselves when giving birth, and may do so by using islands or dispersing along shorelines (Bergerud 1985, Carr et al. 2008), or by dispersing into wide bog complexes (Stuart-Smith et al. 1997). These latter segregation strategies have not been documented in the Boreal Cordillera, but remain a possibility for some herds.

Finally, the diversity and productivity of riparian plants and wildlife species attract the omnivorous bears and large predators to these zones, at least seasonally. In mountainous regions of northwest North America, grizzly bears and black bears use a wide range of elevations and habitat types across seasons. Importantly, they use riparian zones extensively in certain seasons to forage on spring growth of forbs and horsetail, summer berry crops, and summer and autumn aggregations of spawning fish such as salmon and whitefish (McLellan and Hovey 2001, Schwartz et al. 2003, Milakovic et al. 2012), as well as to move between patches of high value habitat. Grizzlies have also been known to use dense riparian cover to ambush large ungulates that would otherwise be difficult to approach (Wilson et al. 2005).

6.8 Semi-aquatic Mammals

The semi-aquatic mammals in the Boreal Cordillera are water shrew, beaver, muskrat, mink, and river otter. All these species frequently eat foods that are only found in water or closely associated with water, so they often search for and gather food in or adjacent to the water. They often have to come on land, or into very shallow water, to actually eat the food. They must also come on land to get out of the water, which drains heat from the body much faster than air, to groom themselves, sometimes to eliminate waste, and most importantly to find shelter for resting and avoiding predators. They are sometimes referred to as riparian obligates.

Water shrews are the species we know least about. They most often occupy stream side habitats, but also inhabit meadows, bogs, and shrub thickets around ponds and small lakes (Nagorsen 1996). Their use of lakes is probably restricted to the sheltered, banked shorelines of ponds and smaller lakes, where they can forage as well as obtain lots of cover from predators. They feed mostly on aquatic insect larvae, but can catch very small fish (Nagorsen 1996).

Beavers are the most influential semi-aquatic mammal. This is because they build dams that create new water bodies and that raise the water levels of existing ponds and lakes. In doing so, they change the position of the shoreline itself, the depth of the littoral zone, and the distribution of lake-based habitats for the whole suite of species that use lakeshore ecosystems (Baker and Hill 2003). Their influence also stems from the fact that they often excavate bank burrows (often under tree roots) in the organic substrates on some sheltered shorelines, and build lodges which are their primary shelter (Baker and Hill 2003). These

A group of otters on an old beaver lodge that provides access to water in winter by having an above-water entrance through the lodge wall. Beaver lodges are frequently used by otters for shelter and access to water (Tarfu Lake, January 2013) (Donald Reid).

denning structures are essential to the beavers, but beavers do not occupy them continuously because in many situations beavers have to move periodically to get better access to the vegetation they require as food (Baker and Hill 2003). Bank burrows and lodges made by beavers are often used by the other semi-aquatic mammals. This heavy use of beaver-created habitats and structures by river otters might be described as a commensal relationship, where the otter obtains real benefits from the beaver without directly affecting the beaver most of the time (Reid 1984, Waller 1992, Leblanc et al. 2007), except that otters may occasionally force beavers out of a lodge or even eat beavers (Reid 1984, Reid et al. 1994a).

Beavers occupy a wide range of ponds and lakes. However, they do not build lodges on shorelines where ice may freeze to the bottom of the water column at and near the underwater entrance to the lodge, or on shorelines that are heavily exposed to wind which will erode the lodge (Thompson 1988). Additionally, they are absent from larger lakes (e.g., Tagish, Kusawa, Teslin) with significant seasonal changes in water levels, though the range of water levels they can tolerate needs quantification. Sheltered bays on lakes with reasonably stable water levels may be particularly valuable habitats, as they also provide fine-grained sediment and organic muck for building (Thompson 1988). Beavers eat a mix of aquatic and terrestrial vegetation, with woody shrubs and trees being particularly valuable both as food and building materials. Although they do not often travel more than 60 m inland from water to gather food (Baker and Hill 2003, Hood and Bayley 2008), we have noted feeding on preferred aspen trees up to 100 m inland in southern Yukon. Their terrestrial feeding can strongly change the structure and species composition of the riparian vegetation (Rosell et al. 2005). A lake-side riparian management zone of a minimum 60 m width, and ideally 100 m, should be considered for beaver where other biophysical features indicate that beavers could occupy the area.

When aspen stands grow within 60 m of shore, beavers have frequently cut down nearly all the mature trees, leaving open slopes on which aspen shoots continue to grow from the clonal root systems (Middle Snafu Lake, September 2016) (Donald Reid).

Muskrats tend to occupy portions of lakes with sheltered shorelines, and lakes with relatively large areas of marsh wetland and/or emergent aquatic vegetation. They feed almost entirely on aquatic vegetation, especially emergent grasses and sedges, including root systems (Erb and Perry 2003). They frequently create their own dens. Like beavers, they can dig their own burrow systems in shoreline banks, on relatively sheltered stretches of lakeshore. In addition, they make structures out of emergent and submerged aquatic vegetation. These structures tend to take three forms: a fairly permanent house (rather like a small beaver lodge), more temporary feeder huts, and winter pushups. The first two structures provide platforms just above water with thick roofs and walls of vegetation; they are often inaccessible in winter if ice freezes to the floor of the shallow water. In winter, muskrats bring vegetation through holes and cracks in the ice and build a pushup structure above the ice (Erb and Perry 2003). Sheltered bays with emergent vegetation, and marsh wetlands with high humus content in the littoral zone, need special attention in shore zone management for muskrats (Erb and Perry 2003).

River otter and mink are carnivores whose diets are dominated by aquatic and semi-aquatic organisms. Boreal otters feed mainly on fish, but will also hunt for aquatic insect larvae, molluscs, waterfowl, and muskrats (Gilbert and Nancekivell 1982, Reid et al. 1994a, Melquist et al. 2003). Otters can be found in most sizes of lakes and ponds in boreal regions, but are particularly abundant on small and medium sized lakes and along beaver impounded streams (Reid et al. 1994b, Gallant et al. 2009). Their energetic requirements are high and they

A group of river otters roll, defecate, and scent mark at a latrine on a short overland trail (Middle Snafu Lake, June 2014) (Donald Reid)

travel widely in search of seasonally available prey. Their movements frequently take them overland across fairly straight trails between water bodies or between different sections of the same water body (e.g., crossing isthmuses or meanders) (Reid et al. 1994b). These travel routes are used repeatedly by otters, and other species, and are key latrine sites where otters communicate using scat, urine, and scent secretions (Melquist et al. 2003). These trails deserve recognition as key habitats because of their high value in facilitating access to food while conserving energy.

Boreal mink feed on a wide diversity of prey types depending on what is available, but their ecology is poorly documented in boreal North America. Prey include small fish, muskrats, molluscs, crustaceans, amphibians, waterfowl (including eggs), and small mammals such as voles and mice (Gilbert and Nancekivell 1982, Larivière 2003). Mink are not as powerful swimmers as otters, and hunt less in the open water but more along the shoreline itself and in the riparian zone. They are sensitive to predation risk and are generally found in riparian habitats with ground and understorey vegetation that provides cover (Larivière 2003). They are undoubtedly competitors to some extent with otter for similar prey (notably insects and small fish) and foraging space, but appear to occupy more terrestrial riparian habitats than otters and focus more on mammal and bird prey (and less on fish) than otters (Erlinge 1972, Gilbert and Nancekivell 1982).

Otter and mink generally do not excavate dens, except for shelters in snow drifts. Rather they use the beaver-created structures or a wide range of logjams, talus rock, brush piles, and air cavities where water levels have dropped under ice. These dens can be very valuable to these predators because den sites may be relatively uncommon along many lakeshores.

Winter is the most limiting season for semi-aquatic mammals. Ice limits access to most water bodies, but all these animals must forage in water at some time. Beaver and muskrats create dens that allow them shelter out of water, and ready access to the water and their foods. The carnivores have to find other ways of accessing water. Areas of permanent open water in winter, frequently at lake outlets, ground water discharges into rivers or streams, or fast-flowing streams, are particularly valuable (Anderson and Wolff 1987). Bank burrows and beaver lodges, especially when they have an above-ground entrance, may be crucial places for otters and mink to gain access to water under the ice (Reid et al. 1994b). Otters can also gain access to beaver ponds at the dam crest, and, in some boreal regions, will excavate parts of dams to enhance this access (Reid et al. 1988). As lake and pond water levels drop during winter, ice subsides and often leaves air spaces between exposed sediments and the hanging ice. These spaces are used by mink and otter to travel considerable distances under the ice (Reid et al. 1984b).

In winter, river otters take advantage of uncommon stretches of open water, frequently at lake outflows, for feeding and associated grooming and resting (Otter Lake, January 2017) (Donald Reid).

7.0 DISTURBANCES AND THREATS

7.1 Dams and Changes in Hydrological Regime

Freshwater drainages are often modified by humans to divert water for various uses on land, or to store water for electrical power generation. To date these activities are still relatively uncommon on river systems in the Boreal Cordillera. Yukon generates most of its electricity from dams that have turned already existing lakes into the water storage reservoirs by building dams that influence the water levels and storage capacity of those lakes. The resulting reservoirs are the Marsh-Tagish-Bennett Lakes complex (Whitehorse hydro plant), Aishihik Lake (Aishihik hydro plant), and Mayo Lake (Mayo hydro plant) (Yukon Energy 2021). A considerable, though formally unquantified, number of farms pump water directly from streams and rivers on or adjacent to their private land holdings to irrigate crops, mostly hay (Reid, pers. obs.). The sustainability of this practice deserves more review by way of formal water use planning.

Although hydroelectricity is a renewable source of energy, large dams that change the hydrological regimes of large rivers, generally creating large lakes, are very damaging to natural ecosystems. WCS Canada has previously summarized the multiple negative effects of large dams on fish and lakes (von Finster and Reid 2015) in response to the proposition to build a new dam and reservoir on the Yukon River or one of its large tributaries (Yukon Energy 2014). In this document, we do not review all the large impacts of dams, most of which cannot be mitigated, in detail. They include: blocking migratory movements of numerous fish including those that cannot traverse fish ladders; shifts in the downstream timing of river flows, often including massive variability in those flows in winter; complete loss of numerous upstream river and lake habitats for various organisms; creation of reservoirs with wide ranges of water levels that make most shore zone ecosystems dysfunctional; and bio-accumulation of mercury from flooded soils and vegetation, and from inflowing streams, to dangerous levels in the food web (Cott et al. 2008, von Finster and Reid 2015). In particular, the Whitehorse hydro dam blocked the migration of anadromous salmon, partly because of a time delay between the building of the dam and the installation of a fish ladder (von Finster and Reid 2015), and also because a large proportion of the salmon have difficulty traversing the ladder (Twardek and Lapointe 2021). First Nations governments and numerous sectors of civil society strongly rejected the idea of building a new large-scale hydroelectric power dam in Yukon, and the concept has been shelved for the time being. Instead, Yukon Energy is proposing small-scale hydroelectric development (e.g., Moon Lake pump storage), and increased use of other sources of renewable energy (Yukon Energy 2020a).

Considering the lake ecosystems modified or created by dams, a dominant effect is either unusually narrow or unusually wide within-year and among-year fluctuations in water levels; the normal pattern of seasonal change in water depth is disrupted (Hill et al. 1998, Cott et al. 2008). Licensed drawdown of water in winter leaves expanses of exposed lake bottom in shallow areas and so eliminates some of the high value fish and wildlife habitat in the littoral zone (von Finster and Reid 2015). Many of the ecological linkages between riparian and littoral zones are broken or impaired because of large water level fluctuations, or because of higher flood levels that cover previous riparian habitats and expose new areas to shoreline erosion (von Finster and Reid 2015).

Some, though not all, of the more drastic negative effects of reservoir drawdown noted in other regions have been avoided in Yukon because all the dammed lakes in Yukon experienced considerable winter drawdown before they were dammed, and their fjord-like shapes and large sizes tended to give them only small littoral zones protected from strong wind action. Fluctuations in their water levels were a regular annual pattern to which resident fish populations must have already adapted prior to damming, and which already limited the types of shore zone ecosystems the lakes could support to some extent. For example, water levels in the undammed Teslin Lake fluctuate across a range of at least 4 metres annually (Environment Canada 2020), and there are few sheltered littoral zones. In addition, impoundment at the outlet to the Marsh-Tagish-Bennett reservoir has not increased the total range of winter drawdown (c. 2.4 m currently; Yukon Energy 2011) more than occurred before impoundment (Yukon Energy 2020b). However, damming does shift the seasonality of water drawdown to some extent, by keeping water in the lakes longer into the early and mid-winter than would have occurred without a dam and then dramatically dropping the water during mid winter (Yukon Energy 2020b). This can have negative effects on muskrats (Cott et al. 2008), something that was noted by Indigenous harvesters in association with the Lewes Marsh at the outflow to Marsh Lake (Southern Lakes Wildlife Coordinating Committee 2012).

In summary, we recommend that there be no new dams on major rivers, and that much smaller-scale hydroelectric generation, using run-of-the-river or pumped storage designs, and giving greater consideration to fishless lakes, be considered instead, because their ecological impacts are much smaller in geographic scale.

7.2 Timber Harvesting

The effects on boreal watersheds of large-scale, clearcut forest harvesting, with associated access and silvicultural activities, are pronounced, though varied. Loss of mature forest cover, coupled often with loss of ground cover, results in more rapid runoff of precipitation and more erosion of soils. Effects on lakes can include changes in various biophysical processes: patterns of water flow through the watershed, sedimentation, water chemistry and nutrient loading, water temperature, and riparian and littoral structure. These can lead to changing habitat suitability and changing abundances of various species (Venier et al. 2014). To some extent, wild fire has similar effects as timber harvesting (Fisher and Wilkinson 2005), but fires are also expected, natural disturbances in boreal ecosystems, so not necessarily a threat to lakes even though they may dramatically alter lake ecosystems. Their potential negative effects are discussed under Climate Change (section 7.9 below).

Public access to lakes is frequently improved when new roads for timber harvesting are accessible to the public and pass near to previously difficult-to-access lakes. The resulting increases in angling pressure, often targeted at particular species, have significant effects on fish population sizes and relative abundances of different fish species (Gunn and Sein 2000, Lewin et al. 2006, Hunt and Lester 2009). This pattern argues for controls on public access along new resource development roads if fish populations are to be conserved in close to a naturally functioning ecosystem (Hunt and Lester 2009).

Forest harvesting tends to reduce ground cover, expose mineral soil, and allow more soil erosion from precipitation and associated runoff. Streams carrying runoff from disturbed areas generally take elevated levels of water borne nutrients, such as phosphorus, nitrogen and dissolved organics, into lakes (Carignan et al. 2000, Lamontagne et al. 2000, Prepas et al. 2001). The consequent effects on the lake's food web can vary substantially. Somewhat counter-intuitively, Prepas et al. (2001) found that, in lakes of the Boreal Plains ecozone, nutrient increases are sometimes associated with decreases in zooplankton, because increased primary production of cyanobacteria produces high levels of cyanotoxins. Riparian buffers did not mitigate these changes (Prepas et al. 2001). However, in a different study of lakes in the Boreal Shield ecozone, Patoine et al. (2000) reported increases in rotifer-sized zooplankton after a burn in the catchment, but decreases in the calanoid crustacean-sized zooplankton after logging in the catchment. Some of these effects were relatively short-lived, in the order of 2 to 5 years (Carignan et al. 2000, Prepas et al. 2001).

Timber harvesting can also result in higher sediment loads in streams and rivers because soils are exposed and erosion can more easily transport particles to streams (Carignan et al. 2000, Lamontagne et al. 2000). Lakes tend to be places of sediment accumulation or "sinks", and the particle size and chemical composition are key determinants of impacts. Lake ecosystems benefit from some sediment inputs. However, sudden and/or persistent increases in sediment loads or types entering lakes can be harmful if they: increase turbidity and reduce photosynthesis or the ability of fish to feed; drop out of the water and smother fish eggs in spawning grounds; bury benthic invertebrates living on the lake bottom; reduce oxygen concentrations in benthic sediments thereby affecting decomposition and food web dynamics (Donohue and Molinos 2009). Sediment fluxes from clearcut timber harvesting can generally be substantially reduced with riparian buffer strips making these a valuable management tool in boreal forests (Lee et al. 2004). However, sediment changes following timber harvesting have been found to have less of an effect on fish population size and productivity then the increased angling pressure resulting from new access to a lake that timber harvest roads provide (Gunn and Sein 2000).

Timber harvesting in the riparian zone can reduce the shading provided by riparian forests, and may alter littoral water temperatures especially in smaller lakes (Palik et al. 2000, Steedman et al. 2001). A study on boreal shield lakes showed substantial local increases in maximum daily water temperatures where shading had been reduced, but only marginal and insignificant increases in average temperature for the whole lake (Steedman et al. 2001). These same disturbances in the riparian zone will allow increased wind fetch and therefore wind speed and wave action, with consequent sinking of the summer thermocline, especially in smaller lakes (France 1997b). A study on 63 lakes in northwestern Ontario showed increased depth of the thermocline, and consequently a decrease in lake trout habitat, 10 years after clearcutting or wildfire had removed riparian forest cover (France 1997b).

Most litterfall from riparian vegetation into water comes from a distance from the water's edge that is shorter than one-half an average tree height, and downed wood that falls into the littoral zone comes from within one tree height of the water's edge, so human actions that remove trees from the riparian zone strip closest to water can substantially reduce inputs of organic materials to a lake and its littoral zone (Palik et al. 2000). Five to 10 years following riparian logging around parts of an Ontario lake, litterfall was 60 percent of uncut riparian forest levels (France 1997c). Although litterfall input may rise again as vegetation is re-established, it may be a different composition depending oh which species of ground cover, shrubs and trees become established during succession. Downed wood can persist in water for long periods (Guyette et al. 2002), so there can be a significant lag time before the impacts of riparian logging are observed in the amounts of downed wood in the water.

Riparian forest immediately adjacent to the shoreline is rarely harvested under recent forest management guidelines, and forested buffers or leave strips are commonly used to maintain riparian functions including habitats (Lee et al. 2004). We discuss this topic in greater detail in section 9.4 below, and also with respect to habitat needs of focal species in section 9.6 below.

7.3 Stabilization and Simplification of Shorelines

Lakeshores are zones of high energy transfer and dissipation because of the movement of water and associated wind. Bedrock shorelines are considered to be "hard", and are quite stable over time. Other shorelines may be dynamic, quite often changing over time as processes of erosion and re-deposition continually occur (Strayer and Findlay 2010). Erosion can occur naturally from the ongoing action of waves, by wave action associated with power boat use, and by removal of live and dead vegetation in the littoral zone. It can occur faster with increased or decreased water levels that might occur through natural variation in precipitation and runoff or by people operating dams. Change is often undesirable for people who want to use the riparian zone for a consistent purpose over long periods of time or for agencies managing shorelines for the public's benefit. Both private and public land holders and managers often attempt to counteract the dynamic nature of the shoreline by stabilizing it. Lakeshore stabilization refers to works undertaken to protect or armour a bank or shore from erosion.

One of the most common tactics to protect shorelines against erosion is shoreline hardening. This generally involves building walls or revêtements of concrete, stone, steel, or wood. These modifications reduce the physical complexity of the shore itself and severely reduce the input of eroded materials into the littoral zone. Hardened shorelines are more stable than the natural shorelines they replace, but have numerous impacts on the ecology of the shore especially in the littoral zone (Strayer and Findlay 2010). These include reduced floating and emergent plant growth and diversity (Jennings et al. 1999, Radomski and Goeman 2001), reduced densities of fish (Beauchamp et al. 1994, Jennings et al. 1999, Trial et al. 2001), and reduced densities of birds, amphibians, and semi-aquatic mammals (Larue et al. 1995, Dobrowolski 1997). Hardened shorelines also modify the along-shore movement of sediment which can result in increased deposition or erosion of sediments elsewhere along the shoreline (Strayer and Findlay 2010). While the protection or armouring of a small section of lakeshore may prevent erosion at one location and may appear to have only minor impacts to the lake, the compounding effects of numerous individual works around a lake might be significant (Strayer and Findlay 2010). However, to our knowledge, such cumulative effects have yet to be fully addressed in boreal lakes. Some shoreline hardening with various techniques has occurred, and will likely be expanded, to protect shoreline properties on Marsh Lake (Yukon Energy 2015).

Shoreline simplification refers to the set of activities humans employ to remove physical structure in both the littoral and riparian zones. Simplification can happen at a variety of scales, and is generally part of the process of shoreline stabilization. A stabilized or hardened shoreline is necessarily one with less structural complexity and diversity, especially over time. Large-scale simplification exercises, such as removing irregularities and diverse features (bays, peninsulas, side channels, islands, lake associated wetlands), can reduce habitat heterogeneity in a very significant manner (Strayer and Findlay 2010). Fortunately, these are rare in the Boreal Cordilleran region, and should be avoided.

Smaller scale simplification or tidying actions, however, are common in association with private land ownership and boat use. These include removing wave-washed debris, fallen and standing dead wood, and live vegetation. Loss of these physical components of habitat can significantly reduce primary production and fish populations (as noted in section 5.6). To some extent docks built for boats can replace the loss of dead wood in the littoral zone as refugial habitat structure for fishes. Hennings and Remsburg (2009) found that bird and frog abundance was lower on developed lakeshores where shoreline vegetation was trimmed or removed. Many of the negative effects of simplification can be avoided with a more conscious and ecosystem-oriented view of stewardship on the part of the land-owner (see section 9.7).

7.4 Agriculture

Agriculture can have dramatic impacts on lake ecosystems when significant portions of their watersheds are converted from forest and wetland to crop land and pasture, causing relatively permanent shifts in patterns of run-off from precipitation and snow melt, along with the sediments and chemicals from cleared land (Agouridis et al. 2005, Blann et al. 2009). These changes are particularly strong when riparian areas are affected. The impacts of agriculture generally resemble those of timber harvesting, but the agricultural effects are longer-lived and often effectively permanent. In addition, agriculture in the Boreal Cordillera region has generally been limited to elevations below 800 m and concentrated in the south-central Yukon (Zebarth et al. 1997, Serecon 2007), a region that includes numerous valley bottoms with lakes. Valley bottom lakes, wetlands, and associated riparian areas are high quality habitats for many wildlife species such as moose, waterfowl, numerous songbirds, and semi-aquatic mammals, and are the most productive landscapes across all portions of the boreal forest food web in the growing season.

Conversion of landscapes to agricultural production removes some habitats completely, fragments the remaining habitats, blocks movement routes for some wildlife, and tends to simplify the structure of remaining forest in the landscape. At the same time, agricultural landscapes do provide a set of unforested, open, upland habitats for a different sub-set of the boreal food web than forested landscapes, thereby increasing habitat quality for some species (Kivinen et al. 2006). The majority of these changes are in upland areas, whereas here we focus on the impacts to lakes and shore zones.

Many of the impacts of agriculture cannot be completely avoided or removed. However, they can be reduced with careful planning and management (Blann et al. 2009). Through strategic land use planning (e.g., under Chapter 11 of the Umbrella Final Agreement. UFA 1993), zones of agricultural production need to be clearly defined and laid out in relation to the values (e.g., wildlife habitat, water supply) that the landscape supports before and without agriculture, so as to avoid an unacceptable degree of loss of the non-agricultural values. For example, agriculture zoning would ideally not overlap core winter range for ungulates. These should be mutually exclusive land uses. Similarly, agriculture zones would not overlap landscapes with high concentrations of wetlands. These should be mutually exclusive land uses.

Within zones designated for agriculture, significant policies and standards are required to minimize impacts on lakes and associated wetlands. As a matter of principle, stewardship does not need to be diluted by the assumption that agriculture will necessarily impact ponds, lakes, and wetlands in a major way. Localized zoning can keep agriculture and water bodies separated. For example,

Agricultural land owners often clear riparian forest and vegetation to the high-water mark. This raises the water table, often killing a band of trees and shrubs immediately beside the lake. The conversion of trees and shrubs to grass removes suitable habitat for numerous insects and birds (Unnamed Lakes, June 2020).

legal boundaries for individual farm properties can be delineated, prior to land auctions or in the process of establishing agricultural leases, so that they do not include lakes and wetland complexes, and that they are set back from shorelines with suitable retention of riparian areas (Poff et al. 2011). Agricultural land clearance is effectively permanent in its removal of woody vegetation and its changes to patterns of water run-off, making retention of riparian vegetation (e.g., forest and shrubs) in agricultural areas more valuable and necessary over the long term even than in the context of forest harvesting (Poff et al. 2011). As discussed in section 9.4, the current Standards and Guidelines for establishment of Riparian Management Zones in Yukon are insufficient when considering the broad array of types of wetlands, and the documented needs of breeding songbirds (Cooke and Tauzer 2020). The Yukon Agriculture Policy (Yukon Agriculture 2020, section 3.4) acknowledges the need for riparian setbacks and mitigative measures concerning impacts of livestock, but leaves the guidance on what those setbacks and measures would be to the Yukon Environmental and Socio-economic Assessment Board (YESAB) assessors and their recommendations regarding agricultural land developments. There is clearly a need and opportunity for land use planning to consider providing direction on standards and guidelines, and for the YESAB assessors to have concrete standards, guidelines, and beneficial management practices for dealing with riparian management in the context of agriculture.

To give cattle easy access to water, the great majority of riparian vegetation is often removed around ponds and small lakes, with significant reduction in habitat available to birds (Unnamed Pond, April 2019) (Donald Reid).

Access to water for livestock is a major concern, because livestock can severely simplify riparian vegetation, and, through defecation and destruction of ground vegetation, change the nutrient status of water bodies that they can reach (Poff et al. 2011). Solutions include providing water in upland dugouts or structures, or setting up fencing so that livestock can only affect a small proportion of the riparian zone of a water body..

A large number of native wildlife species that occupy or rely on small lakes and wetlands also directly benefit farmers (e.g., native bees and flies for pollination; native dragonflies, songbirds, and bats for controlling insect pests). Abundance of these species can be maintained or even enhanced in association with agricultural lands if natural vegetation is retained in well-designed greenbelts, riparian zones, hedge-rows, and forest copses (Wezel et al. 2014).

Apart from the removal of forest and wetland vegetation, agricultural practices have other effects that can affect pond, lake, and wetland ecosystems. For example, irrigation removes water from streams, rivers, or lakes to water crops. The impacts of water removal on river and lake water levels and their properties need to be better understood in order to determine what amounts of water can be extracted for numerous agricultural processes without impacting water temperatures and biophysical processes in the water bodies. In general, re-direction of surface and sub-surface water onto the land tends to result in more rapid run-off into streams and lakes (Blann et al. 2009).

Application of fertilizers often results in nutrient enrichment of local drainages through run-off, with downstream effects on the nutrient dynamics of lakes. Effects may include acceleration of aquatic plant and algae growth which, in extreme situations, can lead to eutrophication, loss of species, and a simplification of the food web (Crosbie and Chow-Fraser 1999, Blann et al. 2009). Similarly, application of pesticides can result in dispersion of these chemicals into the food web beyond the agricultural lands (Blann et al. 2009). Careful management of rates and kinds of fertilizer, and biocide applications, to agricultural lands is required (Blann et al. 2009), coupled with controls on the proportion of drainages impacted by land clearance (Crosbie and Chow-Fraser 1999). These issues are not well understood in Boreal Cordilleran ecosystems (Schindler and Lee 2010), and should be a research priority for agricultural management agencies. Schindler and Lee (2010) recommend the modeling and monitoring of water and chemical mass-balances at watershed scales to try to anticipate impacts and keep track of change.

7.5 Mining and Hydrocarbons

In the Boreal Cordillera, there are two main types of mining – placer and hard rock. These tend to have different potential impacts on aquatic ecosystems, including lakes. Placer gold deposits may be found in a number of different types of valleys, from narrow upland valleys to wide low altitude valleys, and in glaciated or unglaciated terrain throughout much of the Boreal Cordillera. Placer mining is aimed at retrieving gold from sub-surface sediments previously deposited by flowing water that had eroded bedrock containing gold and/or redistributed rock, gravel and finer materials that were originally gold-bearing bedrock. It involves mining old stream and river beds, and the gold, because it is very dense, is often near the bottom of the various layers dropped by streams over thousands of years. Hard rock mining is aimed at retrieving a wide variety of minerals (mainly metals) directly from the bedrock. It can involve open pits that are large excavations of bedrock to reach the mineral-bearing sections, and/or underground tunnels to follow and reach high concentrations of the minerals.

Placer mining usually takes place in riparian, stream-bed, and wetland sites (i.e. valley bottoms) where alluvial sediments contain gold. Typically, the land surface is stripped of organic material, which is stockpiled for later reclamation; overburden materials (upper layer sediments) are removed and piled on ground that has been previously mined; and gold bearing layers are washed to separate the gold. The processed water is discharged to a settling pond to settle sediments, and then either released or reused. Placer mining uses large volumes of water, and gravity, to wash alluvial sediments and separate out the gold particles. Much of the water will eventually return to the local stream or river channel, and this can result in high turbidity or sediment load in the stream (Madison 1981, Silk and Ciruna 2005). Streams are often diverted to allow mining of the entire valley bottom, but larger rivers are seldom diverted. Following completion of the mining, the overburden piles are smoothed and the organic material is pushed over them to start reclamation, and depressions filled with water may be reclaimed as freshwater ponds.

In general, placer mining completely removes the existing aquatic and riparian ecosystems, and has two main effects. The first is the destruction of wetlands when the placer operation is accessing gold in the sediments on top of which wetlands have formed. These wetlands can be bogs (including muskeg), swamps, fens, marshes, and small ponds. For the most part, these wetlands are effectively destroyed by the removal of vegetation and organic soils, and the rearrangement of the underlying sediments.

The second main effect encompasses changes in stream flow regime and downstream water quality resulting from rearrangement of the stream's course, and generally increasing suspended, settleable (slightly coarser materials that settle on the stream bottom), and bedload (slightly coarser materials that roll or bounce downstream) inorganic particles. Suspended sediments result in an increase in turbidity, turning the stream brown (Madison 1981, Pentz and Kostaschuk 1999, Poff et al. 2011). Increased turbidity can alter the species composition of the food web, and can reduce biological diversity and productivity with particular effects on fish spawning beds (Birtwell 1999, Donohue and Molinos 2009, Lloyd et al. 2011, Silk and Ciruna 2005). The consequences for lake ecology can be loss of spawning streams for fish that primarily reside in the lake, and large increases in sediment inflow to lakes when placer operations occur upstream.

The Yukon Placer Secretariat implements and monitors the Fish Habitat Management System, which attempts to find a compromise between the negative impacts of placer mining on aquatic ecosystems and the continued economic performance of the industry (Yukon Placer Secretariat 2010). In the Boreal Cordillera, the impacts of placer operations on lakes will depend largely on how close the mining activity is to a lake and its tributary streams, and the ability of the mining operations to control sediment releases into the streams that feed the lake. Settling ponds and reservoirs are part of the mining process, designed in part to capture sediments. These depressions can intercept surface and ground water drainage from up-valley or up-slope areas and start to function as small lakes and wetlands (Silk and Ciruna 2005), leading to the question of whether some wetland (i.e. shallow open water) values can be reclaimed.

There are no easily applied or economically feasible techniques for restoring many of the affected types of wetland because their biophysical structure and composition took millennia to develop. Consequently, the goal becomes one of reclamation – trying to construct and form some kind of wetland, such as shallow ponds with extensive littoral zones, within the transformed landscapes (Chevreux and Clarkson 2015, DUC 2018). It is not pertinent to review all reclamation techniques here. The main lesson is that the strategic land use planning process is a necessary tool for conserving wetlands and lakes through conscious decisions as to which drainages, and what proportions of drainages regionally, should be closed to all placer mining activity. Land planning needs to seriously consider these questions because placer mining will inevitably destroy wetlands and will often result in negative effects on downstream lakes, and because these effects can rarely be truly mitigated. Environmental impact assessments cannot lead to mitigation measures that return all the wetland values that have been lost; they can only set up reclamation measures that might foster a subset of wetland values, notably those associated with ponds and shallow open water.

Hard rock mining is most likely to affect lake ecosystems through short and long-term degradation of water quality resulting from discharges of metals into lakes or into drainages flowing to lakes (Sumi and Thomsen 2001). Mining increases the rate of release of metals from bedrock into aquifers and water courses (i.e. Acid Mine Drainage (AMD)) by: storing waste rock above ground exposed to air and water, processing ore, and depositing tailings in downstream ponds (Sumi and Thomsen 2001, Johnson and Hallberg 2005). It can also affect water quantity and quality by polluting water with spills of process chemicals used in treating ore (Cox 1999), and by disrupting hydrological regimes with dams and water diversions. Hard rock mining in the Boreal Cordillera region has a long history of contaminating waterways and the land with leached metals from exposed bedrock, and with chemical wastes (Kwong et al. 1997, Sumi and Thomsen 2001, Nicholson 2002). Leached metals and process chemicals can be directly lethal to many aquatic organisms or can have chronic effects on health. They can be very long-lasting in the ecosystem, and can severely disrupt aquatic ecosystems far downstream and into lakes (Salomons 1995). The potential negative effects of AMD are such that much research has gone into understanding how to reduce its occurrence, and how to remediate its impacts (Johnson and Hallberg 2005). Management practices, such as tailings ponds and return of processed tailings and AMD-producing waste rock to the mine pits or tunnels, can reduce some impacts. However, tailings ponds are an incomplete solution because of the ever-present risk of dam failure especially as climate and precipitation regimes change (Pearce et al. 2011).

Yukon and British Columbia continue to deal with the environmental damages created by legacy mines that no longer operate and become the responsibility of the public, by way of governments, to manage (BCMLR 2019, CIRNAC 2020). Despite the fact that mining companies do potentially have to post bonds to cover the costs of reclamation after mining ends, these jurisdictions are far behind in actually acquiring those bonds and pegging them at levels required to actually cover costs of shutting down a mine and minimizing ongoing risk of pollution, let alone fully reclaiming a site (BC Chief Inspector of Mines 2019, Fox 2020). With regard to watershed conservation, there is an ongoing need for governments to be more careful in how they calculate the value of bonds, how rigorously they review the engineering design of mine infrastructure, and how rigorously they enforce conditions associated with permitting under the hard rock mining and water licensing legislation.

Hydrocarbon reserves are relatively limited in the Boreal Cordillera, and have not seen intensive exploitation except in the southeast Yukon (LaBiche drainage). Such developments share, with mining and timber harvesting, a number of potential impacts on lakes and associated streams: increased sediment inputs to water bodies, noise and pressure impacts from the use of explosives, withdrawal of water (especially for hydraulic fracturing), obstructions to water flow and passage of fish by roads, loss of riparian vegetation and structure in streams, increased harvesting of fish following improved access, and contaminant spills (Cott et al. 2015). Most of these are linked to the linear infrastructure and human footprint that such resource extraction requires.

7.6 Residential and Associated Developments

Residential developments in the riparian zone, with direct access to a lake, may have direct effects on the functioning of the lakeshore ecosystem by decreasing habitat quality for many terrestrial and aquatic species, and by changing the rates at which run-off, nutrients, organic matter, and organisms move between land and water. These effects could result from removal of vegetation and downed wood, stabilization and simplification of the shore zone (see Section 7.3), pollution from human waste, and direct disturbance to wildlife causing them to avoid the area. Property owners tend to clear away vegetation to increase visibility, reduce risk of wild fire, increase air flow to reduce incidence of biting insects, to build residences, and to build access to lakeshore amenities such as boat launches and docks (Christensen et al. 1996, Jennings et al. 2003). Where vegetation is in the water, it may be removed to provide easier access by watercraft. This results in changes in sediment grain structure and compaction in the littoral zone (Jennings et al. 2003). Newbrey et al. (2005) provide evidence that some piscivorous avian species (common loon, common merganser, and osprey) avoid lakes that have been heavily disturbed by human residential developments, and Haskell et al. (2013) showed that larger carnivores tended to avoid lakes with higher levels of development. The presence of numerous domesticated dogs and cats in these neighbourhoods can increase mortality of wildlife. In addition, some mammals (e.g., bats, mice, foxes) may benefit from human-built structures, habitat modifications, garbage, and avoidance of developed areas by their predators, leading to a variety of ecosystem changes some of which may be viewed as detrimental (Haskell et al. 2013).

Extensive residential development along lakeshores may, to some extent, be inevitable, but private land owners can mitigate some of the potential impacts by retaining native vegetation. Land use planning needs to decide where on lakes such developments would be allowed, working to make sure that significant portions of lakes remain wild (Marsh Lake, June 2020).

Some residential developments have occurred in sensitive habitats, such as this one on the alluvial fan of an inflowing creek that supported a spawning run of round whitefish that would be prey for various predators (e.g., grizzly bear, bald eagle, river otter) who likely are now excluded (Little Atlin Lake, May 2017) (Gerry Whitley).

Although the effects of residential developments along Boreal Cordilleran lakeshores are still considered to be relatively minor, a considerable number of existing developments have been very close to key wildlife habitats such as stream mouths and estuaries, outflow streams, spawning grounds, raptor nesting sites, and shore zone wetlands. Proper regional land use planning, coupled with more care in the permitting of individual land parcels, could have stopped these mistakes from being made.

Land use planning at a regional scale is the best process for careful zoning of future possible residential developments along lakeshores. Such a process can classify lakes, or sections of their shore zones, to identify sensitive sites or lengths of shoreline, and identify areas where least impacts of development would occur (see Section 9.4). The high value of habitat connectivity along riparian zones means that planners should avoid numerous isolated residences or residential subdivisions along a lake's shore, and instead should concentrate such developments along specific shore segments where ecosystem values may be least compromised. At a more local or operational scale, land owners can partly mitigate many impacts by careful stewardship of the shore zone (see Section 9.7).

7.7 Recreational Activities

Recreationalists are drawn to lakes for the particular experiences and resources lakes provide, including fishing, boating, camping, hiking, hunting, and travel with off-road or all-terrain vehicles and snowmobiles. All of these activities can have impacts on the ecology of the lake and its shore zone. These impacts are generally increasing because populations are growing, citizens have increased amounts of time available for recreation, and increased wealth allows people to buy recreational vehicles and experiences, and to travel further afield (Venohr et al. 2018).

(Top left) Sites for launching boats from public roads are relatively uncommon, so are well-used. These sites need to be carefully chosen to avoid compromising key habitats in the shore zone ecosystem, such as raptor nests, mammal travel routes, and fish spawning habitats (Little Atlin Lake, May 2021) (Donald Reid).

(Top right) Lakeshores are popular places to camp, but frequent use can easily degrade shore zone vegetation. Strict controls on peoples' movements can limit the extent of vegetation loss at well known sites (Grizzly Lake, July 2017) (Donald Reid).

(Bottom left) Careful stewardship of incidental camping sites includes choosing sites unlikely to be well-used by wildlife, and placing tents in unvegetated areas or areas with vegetation that can readily regenerate (Kluane Lake, August 2019) (Donald Reid).

In the absence of regulation and enforcement, fishing can impact lake ecology by changing the total abundance of fish in a lake, and by changing the relative abundances of species based on their preference to the angler and their catchability (Gunn and Sein 2000, Lewin et al. 2006, Hunt and Lester 2009). We do not review this topic thoroughly here, as fish harvest management is beyond the scope of this review. However, two general points are worth emphasizing. First, very few lakes of any appreciable size in the Boreal Cordillera are closed to fishing, and most lakes of any appreciable size have been fished to some extent, often with aircraft access. We lack unharvested lakes that could teach us more about aquatic ecology in the absence of recreational or other fishing. Consequently, society has limited ability, through scientific investigation, to assess the role of recreational fishing in ongoing changes to fish abundance, species interactions, or general productivity. This issue could be partly addressed by zoning some lakes that are currently difficult to access (i.e. far from roads or trails, and difficult to land a float-plane) as "no-access for recreational fishing", through consultation with First Nations governments, in the lake zoning process we recommend (Section 9.4). In the absence of unharvested lakes, fishing regulations often aim to protect stocks of the fish species at the top of the food web (e.g., lake trout) as they are the most vulnerable to over-fishing (Toews, D. pers. commun.).

Second, in the context of lakeshore management, the littoral zone is often of fundamental importance to fish reproduction, growth, and population productivity in northern boreal lakes (Section 5.0). Consequently, it is highly advisable to plan and manage lakeshore developments (see Sections 9.4 and 9.6) because of the risk that development poses to littoral zones.

Recreational and commercial power boating (e.g., tourist trips) may significantly increase wave energy hitting the shore resulting in increased shoreline erosion (Bauer et al. 2002). Increased erosion can result in increased turbidity of the water, negatively affecting submerged vegetation and the fauna it supports (Asplund and Cook 1997). Motor boat wakes can also damage or drown nests, and can physically displace aquatic organisms from their position in the water column. Recreational watercraft can collide with some birds, such as loons, causing death (Micconi et al. 2000). Watercraft may disturb birds using the shore zone. For example, nesting loons or swans disrupted by human activity may abandon their nests, or be forced to reduce their foraging time (Evers et al. 2010).

Float planes are a highly desired and well used means of accessing remote lakes (Schwatka Lake, September 2019) (Donald Reid).

Human recreational activities on land can influence various ecosystem processes in the riparian zone. An understanding of these can come from more general studies of recreational impacts in terrestrial areas. A recent review (Larson et al. 2016) showed that recreational activities affected animals in over 93% of studies, and that non-motorized activities posed a larger threat than motorized activities. In many cases, animals are avoiding the routes commonly taken by recreationalists, and this means that wildlife are losing some otherwise useful portions of the landscape (Reed and Merenlender 2008). For example, Rogala et al. (2011) found that both wolves and elk in Banff and Jasper National Parks avoided hiking trails when usage increased beyond two people per hour. One study in California found that non-motorized recreation resulted in a decline in native carnivores and a shift to nonnative species (Reed and Merenlender 2008). Caribou of the Southern Lakes herds in Yukon show substantial avoidance of human residential developments (Florkiewicz et al. 2006). Dog walking has been shown to reduce bird diversity and abundance (Banks and Bryant 2007). Even relatively low recreational pressure can have negative impacts on bird species (Kangas et al. 2010).

Boaters sometimes pull beaver dams apart to make easier passage past the dam, and, in doing so, permanently reduce water levels and habitat values upstream (Nettle Lake, July 2013) (Donald Reid).

Frozen lake surfaces can be excellent travel routes in winter, and a less impactful route than a trail overland (Squanga Lake, January 2017) (Donald Reid).

Recreational ATV and snow machine use in the shore zone can cause significant impacts to wetlands and water quality, crush animals, compact sediments, kill vegetation, disrupt nesting waterfowl, and alter wildlife behaviour (Davenport and Switalski 2006, Trip and Wiersma 2015). ATV trails can concentrate runoff to water bodies from disturbed mineral soils (Brown 1994). They can also reduce the water storage and retention capacity of wetlands, and reduce filtering capacity of the wetlands (Meyer 2002). The removal of the overlying vegetation varies with soil and vegetation types but occurs after only a few vehicle passes (Meyer 2002). The effects are most pronounced in moist or wet habitats, with dry forested habitats proving more resistant (Meyer 2002, Trip and Wiersma 2015).

Although the effects of snow machine use on underlying vegetation and hydrology is not well documented, winter travel can affect water movement, runoff, water quality, and animal behaviour, and also increase the concentrations of hydrocarbons and nitric and sulphuric acids within the snow pack (Davenport and Switalski 2006, Arlettaz et al. 2007, Ouren et al. 2007). A general review indicated that snow-based recreational activities had a greater potential impact on organisms than summer activities (Larson et al. 2016). Disturbance by snow machines appears to elevate stress in wildlife, which could influence their fitness and survival (Arlettaz et al. 2007). Research on winter roads indicates that some impacts of winter travel may be minimized by waiting for sufficient snow cover to protect vegetation and by waiting long enough for underlying soil to freeze (Davis 2004).

7.8 Invasive Species

The intentional or unintentional introduction of new, or alien, species to aquatic and associated riparian systems is considered to be one of the greatest threats facing shore zone ecosystems around the world (Pimentel et al. 2000, Lovell et al. 2006, Strayer 2010). Invasive species are those alien species that have dramatically expanded their distributions, generally with the assistance of humans (i.e. they are "introduced"), and then have ecological influence that is detrimental to native flora, fauna, and ecosystems processes. In addition, year-round persistence of the alien species in its new range is often viewed as a necessary condition for the term "invasive". Not all introduced species are invasives, but many are. The potential effects of invasive species include changes in amount and types of predation and competition experienced by native species, and changes in species dominance and physical structure of ecosystems. As a result, native species can experience substantial changes in the food webs and habitats in which they have evolved, and can face displacement, population reduction, or extirpation (Ruiz and Carlton 2003, Strayer 2010).

Shore zones of lakes are perhaps particularly prone to invasion because of high rates of natural and sometimes anthropogenic disturbances and interactions within these zones, and the effectiveness of shore zones as corridors for movements of both natural and alien species (Strayer 2010). Once introduced species become invasives, they may spread by a number of pathways. Watercraft, sports equipment, and waterfowl, along with wind and water, can act as vectors for the spread of invasive species more widely through and among drainages (Johnson et al. 2001, Brochet et al. 2009, Leung and von Finster 2016).

The release of non-native fish has been and remains a common way that alien fish, and their parasites and pathogens get established (Cambray 2003), and Yukon is no exception (Environment Yukon 2010). In Yukon, two non-native fish species are known to have been introduced in lakes. Pet goldfish have been introduced into Takhini Hotsprings, and the threespine stickleback was accidentally released, with rainbow trout, into some pothole lakes. Arctic char have periodically escaped a hatchery near Whitehorse but fortunately do not seem to have become established in the local creek or in other drainages. In addition, several fish that are native to some parts of the Yukon have been released to new areas for purposes of enhancing sport fishing opportunities. Rainbow trout continue to be stocked in pothole lakes and were released to a tributary of the Yukon River near Whitehorse (Environment Yukon 2010). They appear to be slowly colonizing the upper Yukon River with spawning populations, and have been captured in Laurier Creek about 40 km downstream of Whitehorse and in several locations near Whitehorse (von Finster 2013). In 2017 a rainbow trout was gill netted in the lower Takhini River (Fisheries and Oceans Canada 2018). Kokanee salmon, bull trout, and arctic char have also been released to pothole lakes. The impacts of these introduced species on native species and ecosystems have not been well studied, and the degree to which they will be considered invasive (i.e. harmful to native species) remains an open question.

Leung and von Finster (2016) ranked the threats to Yukon aquatic ecosystems posed by a set of potential aquatic invasive species, and determined the one of highest concern was didymo, followed by zebra mussels, New Zealand mud snail, waterweed, Eurasian water milfoil, and whirling disease. Many of these potential invasives are not yet established in Yukon, but the mat forming didymo alga is widespread in Yukon drainages (Milligan 2015, Leung and von Finster 2016). Given that overland transport of invasive species by humans is a primary way they spread, Leung and von Finster (2016) recommend public education and information actions as the primary components of strategies to prevent new introductions and any spread of invasive species. Priority actions, now partly implemented, are the ongoing education of the public about the risks of fish introductions, and the need to inspect and clean all watercraft that have been used in drainages outside Yukon when they enter the territory and before they are used in Yukon waterways. Even within the drainages of the Boreal Cordillera, recreational users of lakes and streams should make efforts to clean boats and equipment used in water before transporting them between drainages. Environment Yukon (2015) has introduced new signage at many boat launches to lead this public education campaign, and British Columbia has similar campaigns.

Invasive species spread on boats that people move around between lakes. Agencies in British Columbia post signs at boat launches urging boaters to wash, clean, drain, and dry their boats to avoid moving mussels, in particular, but also any other organism that could survive the trip (Maria Leung).

7.9 Climate Change

Lakes are thought of as good sentinels, or prominent indicators, of the effects of climate change (Adrian et al. 2009, Schindler 2009). This is because the main physical and chemical outcomes of human-caused increases in the carbon dioxide concentrations in the air can directly affect lakes. These outcomes include warming air temperatures, changing precipitation patterns, increasing concentrations of carbon dioxide in water, and more frequent extreme weather events. It is also because lakes receive so many inflows of water from their watersheds or catchments that they are soon affected by, and integrate, ongoing changes to the terrestrial ecosystems in their catchments (Adrian et al. 2009, Schindler 2009).

Increasing air temperatures in the late twentieth century have driven trends to earlier loss of ice cover in spring across a large set of Canadian lakes, especially in western Canada, with warming winter and spring air temperatures driving the earlier loss of ice (Duguay et al. 2006). A corresponding delay in onset of ice in autumn has not been so significant (Duguay et al. 2006). However, in northwest Ontario, the reverse pattern held with a more significant trend to later freeze-up, though air temperatures strongly influenced the timing of ice-off and freeze-up in any year (Guzzo and Blanchfield 2017). Winter air temperatures in the Boreal Cordillera are warming faster than temperatures in other seasons (Streicker 2016). We do not know of a multi-lake data set that monitors the duration of ice cover on lakes in the Boreal Cordillera, but the ice-free season is most likely lengthening. All lakes in this part of Canada still freeze over every year. The ones most at risk of not freezing in a particularly warm winter are the larger and deeper lakes that have much higher stores of latent heat in their large water volumes, and long wind fetches for generating waves (Sharma et al. 2021). It is conceivable that shorter periods of ice cover will relax some of the physiological constraints on growth and survival experienced by fishes dealing with prolonged ice cover (Schuter et al. 2012).

Fish requiring cold water (e.g., lake trout, lake whitefish, cisco, and burbot), which is available in summer only in deeper lakes, appear to be particularly at risk from climate change. In sets of boreal lakes in Ontario, warmer spring and summer air temperatures result in warmer water in the well-mixed portions of the euphotic zone (Schindler et al. 1996, Arnott et al. 2003), and a deeper thermocline with consequent reduction in the volume of water suitable for cold-adapted fish species such as lake trout (Schindler et al. 1996, Guzzo and Blanchfield 2017). More heat absorbed by surface waters, through a longer ice-free period with warmer air temperatures, tends to push the threshold of temperature tolerance for lake trout (15°C) deeper in the water column as summer progresses. Decomposition in the benthic zone gradually removes oxygen from deeper waters during summer, thereby shrinking the volume of oxygen-rich water available for cold-water fish from below (Herb et al. 2014). The net result is a loss of space within the lake where lake trout and other cold-water species can find suitable conditions, and they may be forced to survive in water that is warmer and less oxygenated than ideal (Herb et al. 2014, Guzzo and Blanchfield 2017). Conservation planning needs to pay special attention to lakes that can continue to provide substantial cold-water habitats through summer. These "refugial lakes" are likely to be ones with proportionally large inflows from cold mountain streams (e.g., glacial meltwater) and/or cool groundwater, ones that are oligotrophic, and ones with large and deep basins that can accommodate a large volume of cold, oxygen-rich water through the summer (Isaak et al. 2016, Morelli et al. 2016).

The effects of climate change get more complicated when considering precipitation. Rain can influence lake ecology directly by bringing dissolved gases such as carbon dioxide into the water. This tends to acidify lakes because the carbon dioxide creates carbonic acid (Weiss et al. 2018). However, the actual outcomes depend on what the rain and melting snow cause to flow into the lake from the catchment. In periods of drought, a lack of rain reduces inputs of carbonic acid. Also, various other chemical interactions in the lake, reduced inflows of dissolved organic carbon, silica and phosphorous, and longer retention times of water, all tend to result in lakes becoming less acidic (Schindler et al. 1996). There is concern that trends of reduced calcium levels in soft-water boreal lakes (i.e. lakes with lower natural levels of calcium and magnesium) will lead to declines in zooplankton whose bodies are built with considerable calcium (Jeziorski and Smol 2017, Weiss et al. 2018). This suggests that lakes in watersheds with calcium-rich bedrock may be more likely to withstand ongoing acidification from elevated levels of carbon dioxide in the atmosphere, and therefore deserve particular representation in protected areas. In the Boreal Cordillera, calcium-rich bedrock is most prominent in parts of the Southern Lakes, Yukon Plateau-Central, Pelly Mountains, Mackenzie Mountains, and North Ogilvie Mountains ecoregions (Roots and Hart 2003).

Climate warming will affect numerous processes in the catchments that supply lakes with water. Resulting outcomes for the lakes themselves will likely be diverse and varied, depending on such things as relative contributions of overland and groundwater flows, the weather patterns (e.g., relative levels of precipitation, extreme precipitation events), disturbances to vegetation cover (e.g., fire, forestry, agriculture), and bedrock geology (Keller 2007). For example, record-breaking 2020-21 snowfall in south Yukon led to unprecedented high water levels in many lakes including flooding of many properties. The inputs of numerous chemicals (e.g., dissolved organic carbon, phosphorus, calcium) will drive the changes, with potential influences through the entire food web (Rantakari and Kortelainen 2005, Keller 2007). Schindler et al. (1997) documented substantial declines in dissolved organic carbon in boreal lakes of northwestern Ontario through a period of relative drought coupled with increased incidence of forest fires during which streamflows decreased. Dissolved organic carbon is particularly influential in lake ecosystems because it feeds decomposition, and it provides much of the water's colour and therefore the ability of light and UV radiation to penetrate into the water and heat it up (Schindler 1998a, 1998b). The effects of climate change are likely to vary a lot across the Boreal Cordillera because different drainages and sub-regions have different bedrock types, and will experience different trends in temperature and precipitation, and in fire regimes. To conserve lakes better, we need to consider the dominant, climate-driven, influences on water flows into lakes in the Boreal Cordillera, and whether some parts of this large ecozone will experience less dramatic change from these influences. These influences are probably fire and land clearing, and their interactions with precipitation.

Climate warming is expected to change most aspects of the fire regime in the Boreal Cordillera, with short or long-term loss of forest cover, and changes in water flow regimes (reviewed in section 5.8 above) (Johnstone et al. 2019). Do portions of the Boreal Cordillera experience fire less often, and consequently might have relatively high conservation value as "fire refugia"? The answer is probably yes (Stralberg et al. 2020). There are large landscapes with relatively low incidence of fires greater than 200 ha over the long period from 1980 to 2019 (CWFIS 2020). These include broad swaths of higher elevation comprised of the lee-side of the Coast Range, plus the Ogilvie-Mackenzie-Selwyn mountain complex, the Pelly-Cassiar ranges, the Kawdy-Edziza-Spatsizi plateaus, and the northern Rocky Mountains. Notably, these also include large forested regions, at lower elevations, made up of the Shakwak Trench (Ruby Ranges ecoregion), the Southern Lakes ecoregion (mostly in Yukon), the Boreal Mountains and Plateaus ecoregion (mostly in British Columbia), and the Tintina Trench near the divide between Yukon and Liard drainages. In contrast, fires have been most frequent in a band of forested terrain through central Yukon (Klondike Plateau, Yukon Plateau-Central, Yukon Plateau-North ecoregions) and in the Liard Basin. It is in the large landscapes with lower history of fire that we might find lakes with catchments less impacted by fire, and therefore of particular conservation interest as potential refugial lakes (e.g., Atlin, Tagish, Bennett, Marsh, Kusawa, and Finlayson Lakes), especially when considering cold-adapted lake ecosystems and species.

Many terrestrial organisms are responding to the overheating world by shifting their ranges, for example up-slope or further north (Chen et al. 2011). Aquatic organisms are much more restricted in their ability to adapt in this way. Lakes are fixed in space, and virtually the only potential routes that aquatic organisms have to move, without assistance, is via streams and rivers that connect water bodies. That may not be possible for many lake-dependent organisms that lack a stage in their life that can survive long-distance dispersal in flowing water. Some populations of those species, in specific lakes, may die out. This emphasizes the need to identify those species with lowest dispersal ability, and the lakes that might act as refuges for them. Examples could include populations of lake trout, and pygmy whitefish. It also emphasizes the need to maintain the connections that streams offer between lakes, and better understand how much dispersal happens in these streams. Interestingly, some plants may be relatively well-dispersed with the inadvertent assistance of birds that move seeds and live vegetative parts (e.g., algae), yet we do not fully understand how many species might be assisted in this way and how frequently (Viana 2017).

7.10 Cumulative Watershed Disturbances

With so many individual disturbances and threats to the stability and resilience of lake ecosystems in play, there are clearly many ways in which these disturbances, and the effects they cause, will interact in cumulative ways (Keller 2007). With their relatively low diversity of species in the food web, boreal lakes are considered particularly susceptible to major changes in ecosystem functions, such as pathways of energy transfer and abundances of individual species, following single and multiple disturbances (Schindler 1998 & 2009). There has been limited scientific work attempting to uncover the dominant drivers of change, and to understand how these disturbances or “stressors” may interact. Consequently, this discussion is limited.

The intensity and persistence of cumulative impacts will likely vary with the persistence of the stressor through time. In boreal regions, many changes to lake ecology are driven by “natural” disturbances such as wild fire and insect outbreaks, and also by human harvesting of timber (Poff et al. 2011). Some of these impacts may be relatively short-lived as forests regenerate. Also, lake ecosystems may have considerable resilience because organisms have an evolutionary history of dealing with the associated fluctuations in water chemistry, and quite broad trophic niches to deal with naturally changing abundances of plankton and prey. By contrast, some impacts are longer lasting, sometimes effectively permanent. These include land clearing for agriculture, infrastructure, and urban developments, along with chemical pollutants and the persistent trends in climate change (Schindler and Smol 2006).

A prominent driver of impacts in the Boreal Cordillera is the building of new roads and powerlines in the process of extracting natural resources such as minerals, timber, and hydrocarbons. These have numerous impacts including: increased sediment inputs to water bodies, noise and pressure impacts from the use of explosives, withdrawal of water (especially for hydraulic fracturing), obstructions to water flow and passage of fish by roads, loss of riparian vegetation and structure in streams, increased harvesting of fish following improved access, and contaminant spills (Poff et al. 2011, Cott et al. 2015). These can interact with other land cover changes in the watershed in a set of diverse cumulative impacts (Poff et al. 2011). The first road or powerline to open up a drainage or region is the most impactful, because it directly impinges on a wide suite of previously unaffected species and ecological processes, and facilitates further developments that otherwise would not have been possible (including further resource extraction, and recreational and harvesting opportunities) (Johnson et al. 2020). Such keystone infrastructure decisions require much more detailed scrutiny at a regional scale in strategic environmental assessments and cumulative effects analyses, rather than simple project-level environmental assessements (Johnson et al. 2020). Land use planning is an important process for addressing the topic of access routes and corridors, using scenarios of cumulative impacts. Limiting the spread of new roads is essential for keeping northern lakes pristine and ecologically intact.

In mountainous terrain, roads are often built close to lakeshores with immediate impacts on shoreline vegetation, and on access to lakes themselves and numerous associated valleys (Tagish Lake, September 2018) (Donald Reid).

Studies of boreal, soft-water, lakes on the Canadian Shield identified climate warming, acid deposition (from industrially-charged acid precipitation), and depletion of the ozone layer in the atmosphere as the most disturbing threats, because of their persistence over decades in inducing change and the risk they posed of pushing lakes beyond the range of physico-chemical conditions within which they had evolved (Schindler 1998b). Acid precipitation and ozone depletion have abated somewhat in recent decades as a result of international efforts, but the multiple effects of climate warming, and its role in acidification of water (see 5.9 Climate Change above), plus long-range atmospheric transport of industrial pollutants to boreal lakes, continue to pose high risks (Yeung et al. 2019).

For boreal Shield lakes in Québec, Carignan et al. (2000) found that changes in water chemistry were directly proportional to the area of land experiencing rapid loss of mature vegetation cover (fire or timber harvesting) divided by the lake's volume or area. In reviewing a suite of studies, Carignan and Steedman (2000) pointed out that the time lines for water quality changes to take hold, and the intensity of those changes, vary with watershed scale, water flushing rate in lakes, and aspects of bedrock and soil chemistry. To develop reliable models of cumulative impacts of vegetation change on lake parameters, studies specific to the region in question may be necessary (Carignan and Steedman 2000), but we know of no such comprehensive studies in the northern boreal mountains.

Currently, agriculture is the main cause of permanent land clearing (i.e. removal of forest) in the Boreal Cordillera. Agricultural land clearing is expanding (Yukon Agriculture 2020). It is likely to expand further, because climate change is relaxing the previous limiting factors of short growing seasons and summer frosts, and because demand for local food is increasing (Zebarth et al. 1997, Serecon 2007, Zabel et al. 2014). Although impacts may not yet be very severe in the Boreal Cordillera, addressing the well-known risks in advance of large impacts is the most cost-effective way to achieve a reasonable combination of fish and wildlife conservation with ongoing agricultural development (Egli et al. 2017). The cumulative effects of diverse types of agricultural developments may not just be additive (Keller 2007), and may include levels of effect from which recovery is not possible. Managing them requires integrated, landscape-scale approaches designed with regional ecological conditions in mind (Agouridis et al. 2005, Blann et al. 2009, Poff et al. 2011), and therefore considerable amounts of locally derived knowledge.

Agricultural expansion presents challenges for lake conservation that need to be addressed through land use planning, riparian management, design of land clearance, management of water supplies, and management of chemical applications. At a regional scale, zones within which agriculture is allowed need to be designated to avoid expansion through all valley bottoms, affecting all lakes. Larger lakes need to be buffered from agricultural lands with wide riparian strips to mitigate the extra run-off from cleared land. Within agricultural zones, the majority of lakes and ponds need to be excluded from private farm allotments, allowing maintenance of riparian buffers and conectivity of waterways across the landscape. In farm operations, there needs to be careful licensing and monitoring of water extraction from rivers and ponds, and more careful regulation, licensing, and use of all kinds of chemical applications (fertilizers, herbicides, insecticides, fungicides).

Humans are strongly attracted to lakes because these bodies of freshwater supply us with diverse benefits, – material, psychological, and spritiual. All of our recreational activities and influences around, on, and in lakes amount to multiple stressors in themselves, and these are poorly understood (Venohr et al. 2018). There are both ecological and social carrying capacities, or thresholds, of recreational activities beyond which the benefits we receive are seriously reduced. These are poorly researched and understood, and will require research associated with lakes and human communities in the northern boreal region for us to understand (Venohr et al. 2018).

Overall, our ability to conserve and steward lakes in the context of a wide array of stressors, is hampered by insufficient monitoring to gather data to test hypothetical relationships among stressors, and keep track of emerging trends in lake water quality and biodiversity (Schindler and Smol 2006, Salmaso et al. 2018, Yeung et al. 2019). In the absence of whole-lake, or drainage-scale, models that might project the influences of stressors on lake ecology, we need to keep track of changes and stressors as they emerge, and in ways that help us investigate their effects. At its core, this will require monitoring of the main parameters that we know to be highly influential in northern lake ecology and that are of high value to society. We need to set the monitoring up to test hypotheses about likely or suspected trends, influences, and changes. Monitoring needs to be supplemented by before-after, and ideally control-impact, studies of the ecology of specific lakes that will be subject to new stress, such as major changes in access to, or land cover in, a drainage. We cannot monitor all lakes, so need to choose a sub-set across the spectrum of lake types in the region. The larger, mountain-valley, lakes at the headwaters of our drainages (e.g., Dease, Frances, Atlin, Tagish-Bennett, Kusawa, Kluane Lakes) deserve particular attention because of their dominant influence on the hydrological regimes of large drainages, and the wealth of benefits they provide society from clean water to fish food for people. There are new techniques and tools, such as remote sensing platforms and genomic sampling, that can make our monitoring more cost-efficient and comprehensive (Salmaso et al. 2018).

8.0 KNOWLEDGE GAPS

The value of lakeshore ecosystems has tended to be overlooked in the north. Although substantial information is available from other boreal regions, new information from lakes in the Boreal Cordillera would be valuable. In particular, we often lack lake and drainage-specific information on fish movements and spawning sites, along with high value habitats and cultural sites for specific species. These bodies of knowledge can be acquired through a mix of local knowledge from Indigenous communities and people frequently using lakes, as well as new field investigations by scientists.

Some of the major knowledge gaps identified in our review are the following:

Climate Change:

- What are the relationships between warming temperatures, changing precipitation regimes, and the frequency and severity of fires and insect infestations, and their collective effects on water flows to lakes in different ecoregions?
- What are the risks to cold-water, lake-dwelling fish of ongoing changes in water temperature regimes driven by a warming climate? This includes the contrast between lakes currently fed by glacial melt from those without such water supply, and the effects of singular geomorphological events such as the change in direction of most meltwater from the Kaskawulsh Glacier in 2016 (Shugar et al. 2017). Can we identify lakes with higher ability to act as refuges from changes in temperature or other water quality parameters under a warming climate?
- How is permafrost melt, of lakeshores and of slopes in a lake's catchment, influencing the biophysical properties of lakes (notably sedimentation, turbidity, mercury mobilization in the food web)?
- What are the trends in dominant physico-chemical, and biological, parameters of lake and shore zone ecosystems across the range of lake types in the ecozone? This requires the establishment of a long-term monitoring regime applied to a set of reference lakes.

Watersheds:

- What are the watershed-scale relationships between the proportion of land and forest cleared and changes in various biophysical and ecosystem parameters in lakes and lakeshore zones, including sediment inputs, nutrient inputs, and water temperature regimes?
- How much water can agriculture take from streams and rivers for irrigation without compromising the ecosystem function of water supply to lakes from the stream and rivers?

Lakes:

- What are suitable schemes for classifying different categories of riparian (or near-shore) terrestrial habitats, shorelines themselves, and littoral zone aquatic habitats in the Boreal Cordillera?
- What are the values of ice-free water as habitat for wildlife and fish through winter? To what extent, and under what circumstances, does human activity impede wildlife from using these habitats?

Invertebrates:

- How has the species composition and relative abundances of invertebrates in lake ecosystems changed in the past decades of climate warming? Re-sampling of lakes previously sampled and reported on by Lindsey et al. (1981) and Shortreed and Stockner (1986) would be valuable.
- What are the biodiversity and ecological characteristics of invertebrate communities in fish-less lakes and ponds at various elevations? Is there evidence of species occurrences related to late Pleistocene glacial refugia such as Beringia? What levels of species-level evolutionary radiation has occurred in these spatially disjunct water bodies?
- Which plankton and invertebrate taxa are energetically dominant in the food web(s) of littoral zones, thereby supporting the growth and development of the majority of lake-dwelling fish species? How sensitive are these dominant species to changes in water temperature currently driven by a warming climate?

Amphibians:

- Where are the existing populations of amphibians through the Boreal Cordillera, and in what types of habitat are they likely to breed? Breeding sites particularly need more comprehensive inventory as they support the most spatially restricted and vulnerable life history stages.

Fishes:

- Where are the repeatedly-used spawning areas for obligate lake-dwelling fish within the lakes? Our inventory of these locations is currently incomplete.

- What are the migratory routes of fish species and populations that are seasonally present in lakes, and to what extent have populations varied in habitat use and abundance over time? Our inventory of these routes, and associated spawning migrations of various populations, is currently incomplete.
- To what extent are different morphs and/or genetically distinct populations of certain fish species currently occupying various lakes in the Boreal Cordillera? We have strong evidence of different ecotypes of the same species in numerous lakes, but incomplete knowledge of their levels of reproductive isolation and genetic differentiation.
- What are the lake habitat associations of anadromous fish species and populations through their various life history stages?
- What is the seasonal use of lake habitats (pelagic, littoral, benthic) by various non-harvested fish species such as pygmy whitefish, lake chub, and slimy sculpin?

Birds:

- What are the types and rates of transfer of organisms (notably invasive species) by birds from one water body to another?
- Where are the colonial or semi-colonial nesting sites of water birds such as gulls and terns? Our inventory of these is probably incomplete.
- What size of spatial buffers, and what types of temporal controls on human activity, should be instituted to minimize disturbances to key habitats in the lakeshore zone for birds, including open water at lake outlets when lakes are still ice-covered during spring migration (waterfowl) and colonial nesting sites (gulls, terns, cormorants)?
- Do the current Yukon Forest Resources Regulation's Riparian Management Area standards (Government of Yukon 2012a) cover the full use of the riparian zone around lakes by nesting birds, including songbirds and water birds? What changes are required to make them better?

Mammals:

- How frequently do beaver dams block fish passage from lakes to spawning or summer feeding areas in streams draining to, from, or between lakes?
- To what extent do lakeshore zones, and associated spawning streams, provide seasonal nutrient and energy supply (e.g., wetland foraging, fish spawning, riparian foraging), plus other life history requirements (e.g., snow cover shelter, denning, birthing) to large mammals, and under what ecological circumstances?
- What are the characteristics of nutrient transfer by mammals from the lake and associated stream reaches used by the lake-dwelling fish for spawning into the terrestrial ecosystem?
- What are the characteristics of nutrient transfer by mammals from riparian and upland areas into the lake ecosystem?

- How are large mammals using near-shore habitats by valley-bottom lakes? Are there specific high-use landscapes? How does human activity affect these uses?

Defining the riparian zone and levels of human and natural disturbances:

- How can we map the spatial dimensions of riparian functions and incorporate these into flexible guidelines, including buffer zones, for retaining riparian functions (e.g., sediment filtering, litterfall, downed wood, invertebrate production, bird and mammal habitats) in the context of the whole suite of human activities (e.g., timber harvesting, agriculture, recreation) that might impact those functions and the associated lakes?
- How likely is it that riparian zones of lakes of different sizes and in different ecoregions will be disturbed by wild fire, blowdown, insect dieback, and other "natural" disturbances, and how can we incorporate those patterns into our management of the riparian zones?

Recreational activities:

- How well do current regulations controlling harvest rates (e.g., size limits, harvest quotas) of recreational and subsistence fisheries work in maintaining viable, productive, and robust fish communities in various lakes?
- To what extent do humans, through recreational and subsistence fisheries, compete with mammals and birds (e.g., river otters, osprey, bald eagles, loons) that rely on harvesting fish from the same lake ecosystems?
- Where can recreational infrastructure (e.g., boat launches, campsites, trails) be sited to minimize potential negative impacts on ecosystem functioning (e.g., key habitats for over-wintering, nesting, spawning)?
- What are the effects of noise and wave action generated by motorised boats on use and survival of lakes by wildlife and fishes, especially in the littoral zones not normally subject to heavy wave action from wind?
- What are the effects of winter recreational activities, such as snowmobiling, on the ability of various organisms to use lakes in winter?
- What are the impacts of non-motorized recreational activities (e.g., canoeing, walking) on various aspects of lake and lakeshore ecology including bird nesting (loons, raptors, gulls, and terns), and semi-aquatic mammal habitat use?
- How can the diverse agencies that have at least some authority and responsibility to manage freshwater and lakes more effectively integrate their activities so that cumulative effects are intentionally addressed?

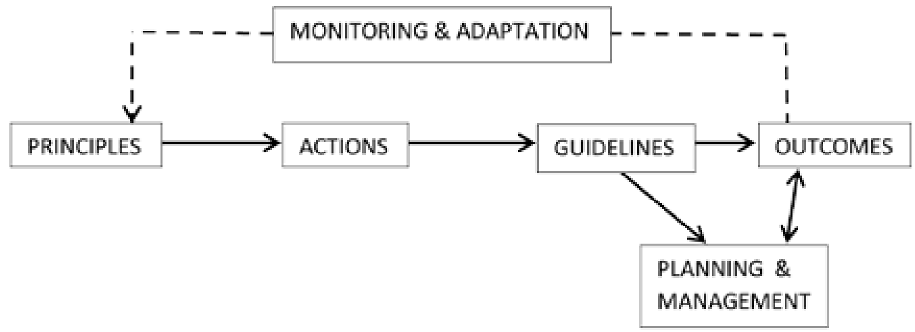
9.0 PRINCIPLES AND GUIDELINES

9.1 Overview

In this section we lay out a proposed set of Principles for planning and management of lakeshore zones. We view Principles as general statements of desired future condition. Because planning and management happen at different spatial scales, and within specific jurisdictionally-derived processes, we address Principles at the regional (strategic) scale, and at the individual lake (local or operational) scale.

Principles should lead to Actions that planning and management processes, the responsible agencies, and individual citizens, need to do to implement the Principles (Figure 8). Actions ideally result in Outcomes. These might be stand-alone finished products (e.g., maps, tables, charts) to be used directly by planning and management processes, or might be used to address other Principles in the same planning or management process (Figure 8). The Guidelines are methods and directions for implementing Actions so as to achieve Outcomes; they lay out how a Principle might be achieved (Figure 8). Guidelines can vary in the degree to which they prescribe Actions. Guidelines are the most influential part of the planning-management cycle because they enable achievement of geographically-specific Outcomes. These Outcomes can be part of a regional land use plan (i.e. strategic scale, such as under Chapter 11 of the Umbrella Final Agreement or Local Area Plans in Yukon, or Land and Resource Management Plans in British Columbia). The Guidelines themselves can also be used directly by planners at more operational scales, and by natural resource managers, environmental impact assessment processes, and individual citizens, to make decisions (i.e. Outcomes) specific to individual lakes or portions of riparian and shore zones. Monitoring and subsequent adaptation are also components of the planning and management cycle, with the goal of learning from Actions and Outcomes. However, we do not address them in this document.

Figure 8. A schematic summary of the relationships between Principles, Actions, Guidelines, and Outcomes in the processes of planning and management of lakes shore zones for conservation of their ecological and cultural values.



In the following sections we first provide a summary table outlining a set of Principles, Actions, and Outcomes, including reference to where and how we see Guidelines fitting into the planning and management process. After that we offer detailed Guidelines for achieving some of the specified links between Actions and Outcomes.

9.2 Summary Table of Principles, Actions, and Outcomes

Here we provide a summary of the Principles required to comprehensively guide planning and management of lakeshore zones, along with a justification for each Principle (Table 6). In the Table, we outline the main Actions that we feel should be undertaken to implement each Principle, and the desired Outcomes from those Actions. A particular planning process may not see fit to accept all the Actions, or the desired Outcomes; it may see fit to implement other Actions not listed here. What we provide is a synopsis of the dominant considerations from the point-of-view of conservation for wildlife and lakeshore ecosystems. Some inspiration for the Principles came from Creed et al. (2011).

9.3. Lake Classification

The primary purposes for classifying lakes are (i) to explicitly recognize which individual lakes or lake complexes provide or satisfy which specific lake-related values, and (ii) to recognize the degree to which those values are currently at risk or under threat. The specific values in question include those identified by communities, user groups, scientists, and stakeholders, as is commonly done in the Issues and Interests phase of a land planning process.

There is no single classification process that we can put forward as the best or necessary process. What we suggest is that a planning process lay out a table of values along with the set of criteria or indicators that might represent each of those values. Then, a list of specific lakes, or clusters of lakes, that satisfy each criterion can be established, or individual lakes can be ranked based on their ability to satisfy or avoid criteria. At the same time, the threats to each lake in each category can be ranked in terms of how strong the threat is and how soon it might have effects.

Table 6: A summary of the Principles required for comprehensive planning and management of lakeshore zones, along with their associated Actions and anticipated Outcomes. The Guidelines for implementing Actions are referenced in italics in association with the appropriate Actions. Principles are organized at two geographic scales (numbered "R" for Regional, and "L" for lake-specific).

Principles	Actions	Outcomes
Regional Planning Scale		
R.1. Establish the full set of ecological and socio-cultural values associated with lakes and their shore zones in the planning region. *(Lakes and their shore zones have diverse potential values (e.g., key habitats, water quality, climate refugia, aesthetics, fish harvest, human residences, travel routes) for various organisms and humans, and planners need to know the scope and distribution of those values)*	R.1.1. Encourage values to be expressed by interested and knowledgeable parties in an Issues and Interests stage of planning. *Guidelines: None outlined in this document.*	R.1a. A summary of expressed values, ranked in some way (e.g., by interest group, or by watershed). R.1b. Database and map of known and expressed values, by lake and shore zone, watershed, or group of lakes/wetlands. R.1c. Send Outcomes for action under Principles R.2., R.3., & R.4.
	R.1.2. Review and summarize documentation and databases regarding historical and current information on ecological and socio-cultural values of lakes and their shore zones. *Guidelines: None outlined in this document.*	
R.2. Consider a whole hydrological system (watershed) approach to subsequent planning and management considerations. *(Lakes and shore zones are strongly influenced by the riparian and upstream hydrological regime and actions within the watershed)*	R.2.1. Review information on the hydrological watershed influencing lakes regionally to determine whether topographic watersheds are suitable planning units[1], and then develop catchment maps (likely to be watersheds) for planning assessment. *Guidelines: None outlined in this document.*	R.2a. Maps expressing possible designations (e.g., protection, traditional uses by all sectors of society, integrated development) for entire watersheds, and putting forward those watersheds most valuable for high conservation attention in a planning process. R.2b. A compilation of lakes, and/or groups of lakes and wetlands, at sub-watershed scales, summarizing their values, and ranking them by need for conservation attention. Send this information to Principle R.3.
	R.2.2. Assess catchments for their potential as protected areas, or other designations, based on criteria such as size, representation of ecological and socio-cultural values, and uniqueness, and based on information from Principles R.1. and R.3 integrated with information on terrestrial and wetland components. *Guidelines: None outlined in this document.*	

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Principles	**Actions**	**Outcomes**
R.3. Include in legally designated protected areas (e.g., Territorial or Provincial Parks) a set of lakes and/or aquatic and wetland complexes that well represent the range of different types of lake ecosystems found regionally, including rare and unique lake types within the Boreal Cordillera. *(Lakes and their shore zone ecosystems have high habitat value for numerous organisms and humans, and need to be included in the suite of regional and national protected areas. Some already protected such as Kusawa Lake and Tat'la Mun in Yukon, and Cold Fish and Tatla Tui Lakes in BC)*	R.3.1. Classify all lakes, or at least the prominent lakes and lake/wetland complexes, based on geophysical, limnological, ecological, and cultural criteria to assess each one's ability to represent regional ecosystems plus rare or unique ecosystems. *Guidelines: See 9.3 Lake Classification* R.3.2. Determine how best to protect (e.g., within watershed zones, or sub-watershed units) a set of lakes that are of high conservation value because they: satisfy a large set of criteria or values (i.e. they have high representation of criteria); have unique (irreplaceable) or rare features. *Guidelines: None outlined in this document.*	R.3a. Table of lakes classified based on criteria outlined in section 9.3 (or other criteria deemed valuable by the planning process), and ranked by importance for protection and/or specific conservation action. R.3b. Send the outcomes to Actions in Principle R.4.
R.4. Specify allowed ranges of human influence, including conservation zones (see L.1.), on individual lakes and/or lake shores with a lakeshore zoning system. *(Without clear management targets, lakes incrementally lose their values through cumulative effects of individual development activities (often in the shore zone))*	R.4.1. Zone all lakes and lakeshores regionally, or at least the larger and most prominent lakes, in a Lake and Lake Shore Management Zoning system that can be applied to shore zones for whole lakes or specific stretches of shore zone around larger lakes. *Guidelines: See 9.4 Lake and Lake Shore Zoning*	R.4a. Planning document that mandates management zones for whole lakes, or separate stretches of lakeshore on lakes, where zones define management intent and allowed levels of human development and activity.
Lake Scale		
L.1. Maintain the variety of riparian and littoral habitats a lake shore zone would have within its typical range of natural variability, at spatial scales that function well ecologically. *(Lands, and adjacent water, that are maintained in conservation zones ideally include examples of all the riparian, shoreline, and littoral habitats found around the lake in large enough units to support the species that rely on them)*	L.1.1. Map the spatial extents of the littoral and associated riparian zones for as many lakes as possible, with focus on those worthy of formal protection. This mapping should include the estuaries of influent streams and the outlet of the lake for a distance considered to be directly influenced by the lake and used by lake fish. *Guidelines: Use appropriate lake and riparian inventory systems to map the littoral and riparian zones in and around the lake and the specified influent and outlet streams* L.1.2. Classify and map components of the riparian, shoreline, and littoral zones, as "habitats", and develop an index of habitat diversity to compare different portions of the lakeshore zone for conservation value. *Guidelines: See 9.5 Habitat Mapping in the Lake Shore Zone*	L.1a. Interactive map that shows the riparian, shoreline and littoral habitat classes, and provides an index of habitat diversity for user-chosen portions of the lakeshore zone. L.1b. Send this mapped information to Action steps of R.4. (above) and L.2. (below).

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Principles	**Actions**	**Outcomes**
L.2. Maintain high levels of terrestrial (riparian) and hydrological (littoral & streams) connectivity at the individual lake scale. *(Land-based and water-based organisms require the ability to move along and through the linear habitats of lake shore zones and associated stream reaches in order to complete their reproduction, seasonal feeding, and migration)*	L.2.1. Map the available combination of stretches of lakeshore zone that: (i) connect high value inflow streams with the outflow stream; (ii) minimize breaks in the riparian zone due to human activity; (iii) include a wide variety of habitat diversity (from L.1. above). *Guidelines: See 9.4 Lake and Lake Shore Zoning*	L.2a. A proposed lakeshore zone that provides good riparian and littoral connectivity at the scale of the individual lake, and also high lake shore habitat values. L.2b. Send outcome to Actions under R.4. (above) for inclusion in lake shore zoning.
L.3. Provide protection for key and critical habitats for focal species whose scale of habitat needs is easily impacted by the scale of new human developments and activities. *(Many species use specific sites or landscape features repeatedly over many years making these places particularly valuable and worthy of site-specific conservation action no matter what lakeshore zone they fall within. Examples of existing protection include Lewes Marsh and Tagish River Habitat Protection Areas, but modes of protection are required, but often lacking, for less expansive sites)*	L.3.1. Map the critical or key habitats in the lakeshore zone for designated focal species. L.3.2. Apply management measures to remove, reduce, or mitigate the risk that human activities will compromise the ability of focal species to use and live in those key habitats. *Guidelines: See 9.6. Management for Key Habitats*	L.3a. Protection for key habitats, as far as these have been inventoried, for each lake.
L.4. Minimize negative impacts of development in the riparian zone. *(Many developments will occur in the riparian zone, but their impacts on lake shore ecosystems can be minimized with good stewardship practices)*	L.4.1. Apply management measures within the developed lands along shore zones to reduce and, where possible, remove risks to lakeshore ecosystems. *Guidelines: See 9.7 Riparian Stewardship*	L.4a. A set of developed lakeshores that continue to maintain significant habitat values and minimize the deleterious effects to lakes of pollution (including noise) and other activities on land.
L.5. Minimize risk of introduction of invasive species to lakes. *(A number of invasive species are known to be spreading into the Boreal Cordillera, and most are spread by humans)*	L.5.1. Apply best practices for cleaning and managing boats and other equipment that might be moved from one water body to another. *Guidelines: See Environment Yukon 2017b and Invasive Species Council BC 2017.*	L.5a. Lakes that are not being invaded by unwanted species (e.g., exotic mussels, plants, algae, and arthoprods)

[1] Topographically defined watersheds are the normal or default way of mapping catchments. However, sub-surface flows may cross watersheds, so, if these are known (e.g., in karst landforms), alternatives other than topographic watersheds may need to be considered (Devito et al. 2005, Creed et al. 2011).

The classification process should be aimed at assessing which lakes are clear candidates for consideration in various management zoning categories (section 9.4), ranging from full protection to intensive use. The classification process provides a semi-quantitative means of ranking lakes for consideration under zoning. Despite efforts to find generalities from large sample sets of boreal lakes (e.g., Gregory-Eaves et al. 2000) or searches for specific indicators of lake biodiversity (e.g., Sahlén and Ekestubbe 2001, Schilling et al. 2009), we currently lack any particular criterion or indicator that can be universally applied to rank lakes ecologically. The other values are similarly challenged. So, the approach at present must rely on choices of criteria and evaluations of risk reached collectively by locally knowledgeable people in a planning process, and supplemented where possible with published information. In Table 7, we lay out a set of values and associated criteria that could pertain to lakes in the Boreal Cordillera.

9.4. Lake and Lakeshore Zoning for Management

Management zoning of the entire shore zone around whole lakes, or sections of lakeshore zone on large lakes, is analogous to the land use zoning used in most regional land use planning processes, such as those recently undertaken in Yukon (NYLUPC 2009) and British Columbia (Taku River Tlingit 2011). In those plans, the region is divided into Land Management Units (LMUs), each of which is given a management zone designation such as protected area, wilderness area, or integrated management area of varying levels of human development. In those plans, lakes and their shore zones automatically fit into the designation for the entire LMU (which is most often delineated with watershed boundaries), so the terrestrial designation is dominant. In this document we propose that land planning processes undertake management zoning explicitly for lakes, based on the combined values of the lake itself and its shore zone (including riparian). The resulting lake-related designation might be the same as the designation for the rest of the watershed, but it could be different. Management Zoning is the link between the broad regional consideration of values and more localized, day-to-day, operational management of human activities. (This use of the term "zone", in the context of managing a whole lake and its riparian areas, is different from how the term has been used through much of this document which was to distinguish between components of the ecosystem (e.g., riparian vs littoral zones)).

Laying out different potential management zones along a lakeshore leaves open the question of how far inland the zone should extend. How wide should the elongate strip of land beside the lake be to best manage the values in question? Many jurisdictions have industry-specific, or geographically-based, regulations or standards as their answer to this question (e.g., Government of Yukon 2012a). These are frequently referred to as riparian management guidelines or standards (often called riparian buffers). In boreal regions they have largely been developed in response to the potential negative impacts of timber harvesting close to water. There is a large literature on this topic, well summarized by Lee et al. (2004). Later in this section we provide a short discussion of this topic ("Riparian Management Guidelines") after we have presented a potential system of lakeshore management zones.

Table 7. Possible set of values associated with lakes, or clusters of lakes, in the Boreal Cordillera and their associated criteria for classification. Values are those relevant to fish and wildlife conservation.

Value Category	Criteria For Classification
Geophysical – watershed scale	• Bedrock types (basic vs acidic; rich in calcium or other elements?) • Glacial pre-history (Beringian or not) • Current water sources (proportional contribution of glacial melt, nival melt, rain, ground water) • Risk of permafrost melt within watershed
Geophysical – lake scale	• Surface area (various size classes) • Bathymetry and volume (littoral zone as proportion of total surface area; total volume as proportion of surface area) • Shoreline types and diversity (proportional length of shorelines of different geomorphological substrates (bedrock, boulder, cobble, sand, organics)) • Depth (maximum, mean, and/or likelihood of bi-annual turnover) • Configuration (ratio of shoreline length to surface area) • Prominence in the watershed (ratio of lake surface area to watershed surface area)
Ecological – watershed scale	• Prominence of lakes (for each bioclimate zone, the ratio of surface area of lakes to total surface area of the bioclimate zone within the watershed) • Connectivity or clustering of lakes (linear distances of stream or river connections to adjacent lakes) • Broad vegetation cover types (conifer, deciduous, mixedwood, bog, other wetlands) within the drainage • Watershed intactness (a watershed without permanent human infrastructure or claims is fully intact; the surface area of infrastructure and claims (including linear corridors (roads, power-lines), quartz or placer claims, timber harvest zones, private land holdings, agricultural lands) is calculated and subtracted from the total watershed area • Refugial ranking in relation to climate change (proportion of drainage classed as refugial, from fire risk or warming risk)
Ecological – lake scale	• Primary productivity of lakes (oligotrophic, mesotrophic, eutrophic) and riparian vegetation covers • Trophic diversity in aquatic (lake has what proportion of fish species in the drainage) and riparian food webs • Trophic uniqueness (rare food webs built on unusual geochemistry, such as marl lakes) • Islands (number and surface area as a proportion of lake surface area) • Rare or at-risk species associated with lake itself • Rare or at-risk species associated with riparian zones • Focal or high-value species occupancy or habitats (spawning for lake trout, burbot, and whitefish species) • Wetland associations (spatial extent of wetlands with at least seasonal surface water directly linked to lake) • Position in watershed (in which bioclimate zone: alpine, subalpine, boreal high (Spruce-Willow-Birch), boreal low (Boreal White and Black Spruce)) • Refugial ranking in relation to climate change (climate projections regionally, coupled with likelihoods of changing water quality and quantity in upstream areas, plus evaporation rates, and incidence of fire and insect infestations)
Socio-cultural	• Historic sites (camps, burials, battles, sacred places) • Historic refugia (survival lakes in times of famine) • Current subsistence uses (fish camps, hunting grounds, trapline cabins) • Current spiritual uses (culture camps, sacred places) • Current recreational uses (campgrounds, boat launches, beaches) • Access (roads to lake shore (numbers in relation to lake area), roads/trails traversing the riparian zone (% of total riparian affected)) • Private landholdings influencing riparian (number and % of total riparian)

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Value Category	Criteria For Classification
Economic	• Business land holdings influencing riparian (lodges, farms, outfitter camps (numbers and % of total riparian) • Business activities influencing fish (fishing lodges, commercial fishing) • Watershed intactness or inverse of human footprint (measure of intensity of human uses and activities, such as proportion of watershed as linear corridors (roads, power-lines), quartz or placer claims, timber harvest zones, private land holdings, and agricultural lands)

The zoning system built into a particular regional plan is chosen by the planning process following assessment of values and how those values might best be conserved, maintained, and promoted. So, there is no one zoning system that is necessary or sufficient for all regional planning processes. Here, we present one zoning system for consideration. It describes the Criteria that could be used to make the designation, and a list of Considerations or questions for the planning process to address in developing the plan. We expect that regional planning processes may gain some ideas from this system, but may well choose to change it with other zones and/or considerations. Our aim is to express the range of land use designations or management zones that might be considered for lakes. These management zones could be applied to whole lakes and their associated riparian buffers, or to certain stretches of lakeshore on larger lakes.

1) Wilderness Lakes

Criteria: Natural processes are dominant at lake and within-watershed scales; no permanent infrastructure; human use minimized to allow experience of wild nature; no past use by motorized vehicles or watercraft.

Considerations:

- Managed to maintain natural features and ecosystem functions in watershed context without infrastructure
- Limited or no commercial development or activity on the lake or in the lakeshore zone
    - Should trap line and outfitter cabins be allowed?
- Limited or no development in the watershed
    - Allow development in the watershed to a certain % of surface area, or maintain no surface infrastructure and vegetation disturbance?
- Access management
    - Disallow road development within watershed and to the lake?
    - Any controls on air access (frequency, vehicle type)?
- Noise and light pollution restrictions (electric lights; generators)?
- Motorised vehicles
    - Restrictions on off-Road Vehicles in the watershed?
    - Determine legal means of controlling powered watercraft on the lake.
- Numbers of visitors on the lake per day
    - Should there be quotas?

- Suppression of fire and insect infestation
  - Is suppression necessary in this zone?
- Angling opportunities
  - Should there be limitations (catch and release? Low catch limits?)

2) Environmentally Sensitive Lakes

Criteria: Particularly unique or rare natural value, or value of high sensitivity to human disturbance (e.g., rare fish species, unusual food web (perhaps fishless), biophysical properties (perhaps calcium-rich or geothermally influenced)) with need for strong protection and/or focussed management.

Considerations:

- Maintain natural ecosystem components, processes, and functions with respect to the unique or rare value
- Assess the sensitivity of the natural value to disturbances across time and space to decide on how many of a certain type of lake, and how much of an individual lake, needs protection and/or focussed management, and during what seasons
- Private, commercial, and public land developments and infrastructure in the riparian of lakes chosen for protection
  - Preclude private and commercial land holdings on the whole lake or within the zone?
  - Preclude publicly available infrastructure on the whole lake or within the zone?
  - How to judge outfitter and trap line cabins?
- Access management
  - No boat launches or road access for whole lake, or within the zone?
  - Minimum allowed distance from any road to the lake?
  - Seasonal controls on access to the sensitive zone?
  - Controls on use of motorised vehicles in or on the lake and riparian?
- Suppression of fire and insect infestation
  - Not necessary in this zone
- Light and noise pollution restrictions?
- Angling restrictions?

3) Culturally Sensitive Lakes

Criteria: Particularly high cultural, historic, aesthetic, and spiritual values requiring whole lake, or zoned recognition in protective or management measures.

Considerations:

- In consultation and collaboration with Indigenous, or non-Indigenous, organizations that hold the cultural value, develop a vision for the future of the lake to address the values in question, and how recognition of values is best realised in diverse management options (from intensive development to promote and interpret a site, to wilderness-style protection for a refugial value)

- Assess the sensitivity of the cultural value to disturbances across time and space to decide on how much of the lake needs protection and/or focussed management, and during what seasons
- Private, commercial, and public land developments and infrastructure in the riparian
  - Preclude private and commercial land holdings on the whole lake or within the zone?
  - Preclude publicly available infrastructure on the whole lake or within the zone?
  - How to judge outfitter and trap line cabins?
- Access management
  - No boat launches or road access for whole lake, or within the zone?
  - Minimum allowed distance from any road to the lake?
  - Seasonal controls on access to the sensitive zone?
  - Controls on use of motorised vehicles in or on the lake and riparian?
- Light and noise pollution restrictions?
- Suppression of fire and insect infestation
  - Will occur in this zone to protect human infrastructure
  - May not be necessary throughout the zone
- Angling restrictions?

4) Natural Environment Lakes

Criteria: Sustaining nature is the dominant goal (i.e. full complement of species, ecosystem processes and functions); some aspects of nature would be at risk from significant development and activity by humans; limits on human development and activity levels

Considerations:

- Assess the lake for the strongest risks to sustenance of populations of native species and ecosystem processes (e.g., watershed scale development or forest conversion; riparian forest disturbance; angling; noise)
- Limit the spatial extent (% of surface area) of forest and land clearance in the watershed?
- Limit the proportion (%) of the riparian area that can be developed (vegetation clearance) by private, commercial, and/ or public interests (e.g., 1 to 5%).
- Direct where along the shoreline, riparian developments would be allowed, avoiding buffered key fish and wildlife habitats and cultural sites (section 9.6).
- No development or infrastructure on islands
- Access management
  - Limits on numbers of public access points with boat launches
  - Direction on locations of access points to minimize impacts
  - No access points within buffered key fish and wildlife habitats (section 9.6)
  - Signage to notify and educate public on sensitive areas

- Motorized vehicles
  - No off-road vehicle trails in the riparian?
  - Winter only off-road vehicle use of trails (defined by minimum of 15 cm frozen ground or 30 cm snow cover)?
  - Determine legal means of controlling powered watercraft (e.g., motor size limits) on the lake?
- Commercial activities allowed (e.g., trapping, big game outfitting, wilderness tourism)
- Suppression of fire and insect infestation
  - Will occur in this zone to protect human infrastructure
  - Not necessary throughout the zone
- Angling subject to regular jurisdictional controls on daily catch and possession, with signage?

5) Moderate Development Lakes

Criteria: Sustaining nature is the dominant management goal, but significant development of riparian and shoreline areas, and human activity on the lake, are allowed.

Considerations:

- Assess the lake for the strongest risks to sustenance of populations of native species and ecosystem processes (e.g., watershed scale development or forest conversion; riparian forest disturbance; angling; noise)
- Limit the spatial extent (% of surface area) of forest and land clearance in the watershed?
- Limit the proportion (%) of the riparian area that can be developed (vegetation clearance) by private, commercial, and/ or public interests (e.g., 5 to 30%).
- Direct where along the shoreline, riparian developments would be allowed, avoiding buffered key fish and wildlife habitats and cultural sites (section 9.6).
- No development or infrastructure on islands
- Access management
  - Limits on numbers of public access points with boat launches
  - Direction on locations of access points to minimize impacts
  - No access points within buffered key fish and wildlife habitats (section 9.6)
  - Signage to notify and educate public on sensitive areas
- Motorized vehicles
  - No off-road vehicle trails in the riparian?
  - Winter only off-road vehicle use of trails (defined by minimum of 15 cm frozen ground or 30 cm snow cover)?
  - Horsepower limits for motor boats?
- Commercial activities allowed (e.g., trapping, big game outfitting, wilderness tourism)
- Suppression of fire and insect infestation
  - Will occur in this zone to protect human infrastructure
  - Not necessary throughout the zone

- Angling subject to regular jurisdictional controls on daily catch and possession, with signage?
- Suppression of fire and insect infestation
    - Will occur in this zone to protect human infrastructure
    - Not necessary throughout the zone
- Publicize stewardship measures that land owners with riparian developments can apply to reduce negative impacts of development on the entire lakeshore (e.g., waste water management; maintenance of vegetation composition and structure; retention of wildlife habitats)

6) High Development Lakes

Criteria: Human developments and activities dominate at least the riparian areas of the lake and tend to be concentrated fairly continuously along stretches of shoreline

Considerations:

- Assess the lake as a whole to consider whether this zone should apply to the whole lake, or to a limited stretch of the shoreline
- Lay out the zone to minimize net loss of high value wildlife and fish habitats at the lake scale, by allowing development in the least valuable shore zones for fish and wildlife
- Encourage new developments to occur in this zone rather than elsewhere on the lake
- Limit the proportion (%) of the riparian area within the zone itself that can be owned and developed (vegetation clearance) by private, commercial, and/ or public interests (e.g., 30 to 70%)
- Limit the proportion (%) of the riparian area for the whole lake that can be owned and developed (vegetation clearance) by private, commercial, and/ or public interests to a maximum of 50%, and keep the minimum 50% without development in as close to a single stretch of shoreline as possible
- Provide for public access point(s) within this high development zone, so access is not limited to private riparian land owners
- Access management
    - Direction on locations of access points to minimize impacts
    - No access points within buffered key fish and wildlife habitats (section 9.6)
    - Signage to notify and educate public on sensitive areas
- Motorized vehicles
    - No off-road vehicle trails in the riparian?
    - Winter only off-road vehicle use of trails (defined by minimum of 15 cm frozen ground or 30 cm snow cover)?
- Island development
    - No development on islands < 40 ha in size, or any islands with key fish and wildlife habitats
    - Developments on larger islands limited to 20% of riparian length
- Angling subject to regular jurisdictional controls on daily catch and possession, with signage?

- Suppression of fire and insect infestation
    - Will occur in this zone
- Publicize stewardship measures that land owners with riparian developments can apply to reduce negative impacts of development on the entire lakeshore (e.g., waste water management; maintenance of vegetation composition and structure; retention of wildlife habitats)

Riparian Management Guidelines: Riparian management guidelines generally restrict cutting of trees and other vegetation, or limit clearing, excavation, or other development activities, within certain distances of a water body or water course. The management action is undertaken to reduce the risk of sediment and nutrient release to the water body, maintain water quality, and maintain habitats for riparian organisms (Lee et al. 2004). In boreal regions, the context has most often been timber harvesting, but it is clear that other types of land development and vegetation change (e.g., agricultural fields, domestic animal grazing, residential development, roads, trails, mining) can have impacts on riparian functioning that might influence an assessment of how much riparian forest to retain. In Yukon, the earliest legal context for riparian management was the establishment of private land holdings beside waterways: a 100 foot (30 m) zone adjacent to the ordinary high water mark, retained as public land, was built into deeds, though now effectively useless for conservation (see Section 3.2.2). The various ecological functions provided by the riparian zone do not uniformly stop at some specific distance from water, so a more flexible and function-oriented approach to riparian buffers is warranted (Holmes and Goebbel 2011), for example with reference to the ecological and socio-cultural values of specific lakes and their shore zones.

Ideally the buffers of retained riparian vegetation would be wide and diverse enough to conserve habitats for all wildlife. Numerous studies have addressed the question: how wide is wide enough? For example, recommended buffer widths in selected areas have ranged from: 30 m to protect rainbow trout habitat (Raleigh et al. 1984); 159-190 m for amphibians (Semlitsch and Bodie 2003); at least 60 m for some forest-nesting birds (Darveau et al. 1995) but a minimum of 200 m for the same purpose in another study (Hannon et al. 2002). For birds relying on older-aged forest conditions, buffers of about 200 m seem to be required, but other birds may well persist well with much smaller or even no buffers (Kardynal et al. 2011, Marczak 2010). For small mammals, recommended buffers could be as small as 20 m wide, but their efficacy may well depend on competitive relationships among species including those occupying habitat adjacent to the buffers (Darveau et al. 2001). Large terrestrial mammals travel widely, so buffers are seldom designed with them in mind.

Suitable buffer widths are very likely to vary among ecoregions or ecozones and also will vary with the species that use them. Studies within the pertinent ecozone or ecoregion, and with the local species, are required for accurate assessments of buffer widths and good justification for riparian management area standards. The most pertinent study for the Boreal Cordillera is that of Cooke and Tauzer (2020) who investigated the use by breeding songbirds of mainly white spruce riparian forests adjacent to streams and wetlands. Their findings suggested that only an unharvested riparian zone 200 m wide could cover at least 75% of the space use by 5 of the 8 passerine bird species that commonly frequented the riparian forests, and that only three species would likely have most of their needs satisfied within 100 m of the water's edge.

Retaining undisturbed buffers uniformly along all riparian zones may be counterproductive if natural disturbance of riparian forests by wild fire or other agents (insects, wind) is changed by humans and does not occur as frequently as it would in the absence of human interventions. For example, in valley bottoms and along lakeshores where humans rapidly suppress wild fires, cutting riparian vegetation including mature forests may be periodically warranted to create young shoreline forest stands, as long as a mosaic of forest stands of all ages in proportion to their natural frequencies remains at landscape and regional scales (Kardynal et al. 2009). However, prescribed burning to emulate otherwise suppressed wild fires, can be detrimental to beaver populations partly because prescribed burning does not necessarily follow the natural seasonal timing of wild fires (Hood et al. 2007).

Across boreal North America riparian guidelines often define buffer widths that vary depending on waterbody type (lake vs stream), waterbody size (lakes of different surface area), shoreline slope, and presence or absence of fish (Lee et al. 2004). They also are often variable in width and may be open to limited timber harvesting, so need professional interpretation at the scale of the timber harvesting (Lee et al. 2004). For example, the Yukon standards for lakes (Table 8) prescribe buffers ("Riparian Management Areas") of variable widths depending on lake surface area. These buffers include a strip of complete protection close to water ("Reserve Zone") and an adjacent strip within which some limited forest harvesting could take place ("Management Zone"). Table 8 also includes the Yukon buffers for Marshes, a wetland type frequently making up part of lakes.

In British Columbia, the government prescribes very little retention of forested riparian zones along lakeshores (Table 9). The only lakes getting a Reserve Zone are moderate-sized (i.e. >5 but <1,000 ha; class L1)) or lakes 1-5 ha in some regions (class L2). Largest lakes (>1,000 ha; part of class L1)) and smallest lakes (classes L3 and L4) get no Reserve Zone. Total Reserve Zone and Riparian Management Area widths are remarkably narrow, and of questionable value for retention of most riparian ecological functions.

Considering wetlands, British Columbia's riparian management area standards are more comprehensive in that they apply to all wetland types (shallow open water, bogs, fens, swamps and marshes) (Government of British Columbia 2004). However, for open water and marshes, they offer considerably less real protection of riparian vegetation than the Yukon standards (Tables 8 and 9).

It is noteworthy that, in Yukon, the Reserve Zone may be reduced if an acceptable rationale is provided in the Timber Harvest Plan or Site Plan (Government of Yukon 2012a). It is also noteworthy that no lakes in either jurisdiction can receive protection from harvesting of a full 200 m mature forest Reserve Zone which appears to be the optimum width for conservation of birds relying on mature riparian spruce forests, at least along streams and beside wetlands (Cooke and Tauzer 2020).

Table 8. The Riparian Management Area (RMA) standards for retention of undisturbed vegetation (i.e. Reserve Zone) and partly undisturbed vegetation (i.e. Management Zone) within slope distances from the ordinary high water mark of lakes and of marshes. These figures are taken from published Standards derived from the Yukon Forest Resources Act Regulations (Government of Yukon 2012a & 2012d).

Lake Class	Surface Area (ha)	Reserve Zone Width (m)	Management Zone Width (m)	RMA Width (m)
L1	>50 ha	40 - 60	80 - 140	120 - 200
L2	>5 - 50	20 - 60	40 - 80	60 - 140
L3	1 - 5	20 - 40	20 - 60	40 - 100
Marsh Class	**Surface Area (ha)**	**Reserve Zone Width (m)**	**Management Zone Width (m)**	**RMA Width (m)**
W1	<1	5	60	65
W2	1-5	60	40	100
W3	>5	60	140	200

Table 9. The Riparian Management Area (RMA) standards for retention of undisturbed vegetation (i.e. Reserve Zone) and partly undisturbed vegetation (i.e. Management Zone) within slope distances from the ordinary high water mark of lakes and wetlands in British Columbia. These figures are taken from the Ripairan Management Area Guidebook (Government of British Columbia 2004). Only Classes L1 and L3, and W1, W3, and W5, apply in the Boreal Cordillera.

Lake Class	Surface Area (ha) & Biogeoclimatic Zone location	Reserve Zone Width (m)	Management Zone Width (m)	RMA Width (m)
L1	>5	10	0*	10
L2	1-5 & in southern Zones	10	20	30
L3	1-5 & in northern Zones	0	30	30
L4	0.5-1 & in southern Zones	0	30	30
Wetlands	**Surface Area (ha) & Biogeoclimatic Zone location**	**Reserve Zone Width (m)**	**Management Zone Width (m)**	**RMA Width (m)**
W1	>5	10	40	50
W2	1-5 & in southern Zones	10	20	30
W3	1-5 & in northern Zones	0	30	30
W4	0.5-1 & in southern Zones	0	30	30
W5	Wetland complexes	10	40	50

* Management Zones are in effect in some Regions, requiring contact with regional foresters

When a wetland is part of a lake such that the Ordinary High Water Mark (OHWM) for the lake coincides with that for the wetland, then, from an ecological point of view, it seems that riparian management area standards for the lake should also apply to the wetland part of the shoreline. That may not be the case in Yukon. Yukon only prescribes standards for two types of wetland – shallow open water and marshes. Marshes frequently border lakes, but the Reserve Zone and Riparian Management Area widths for marshes are different than those for lakes (Table 8). It is not clear whether the Standards for lakes (Government of Yukon 2012a) would apply from the OHWM in portions of the lake where marsh is the shoreline as they do with other shoreline types in the same lake. Yukon provides no option for serious protection of forest buffers around swamps, fens, or bogs (Government of Yukon 2012d).

Given a need to conserve ecological functions of lakeshore zones, it is clear that the standards for riparian management in British Columbia and Yukon are inadequate. Some of these inadequacies can be addressed by land use planning processes. Such processes need to explicitly discuss and judge whether the current Standards are sufficient to retain the values that the planning process decides are the focus of each lake's management. Technically, the current Standards (Tables 8 and 9) only apply to forest harvest planning and implementation, so they can be ignored by other land uses such as agriculture, residential developments, and public infrastructure, unless other planning or policy interventions prescribe specific buffers. This is despite the fact that they may have become "normal" guidance for riparian management in all circumstances in some regions. This is a gap that Regional Land Use Plans need to address. Various quasi-governmental (e.g., Renewable Resources Councils in Yukon) and non-governmental organizations need to advocate for riparian protection as part of their engagements with regional and sub-regional land use planning processes.

9.5. Biophysical Mapping in the Lakeshore Zone

The goal of biophysical mapping is to develop an index of diversity and scale of the various biological and physical features of lakeshore zones so as to compare different lakes or different portions of one lake as to their relative conservation value. Biophysical features include different vegetation communities in the riparian zone, different substrates in the riparian and along the shoreline, different shapes of shoreline at the interface of water and land, different substrates and plant communities in the littoral zone, plus the size of the littoral zone with respect to shoreline length. The assumption is that a stretch of the lakeshore will be of higher value to fish and wildlife, and therefore of higher conservation value, if it has a greater diversity of these geomorphological and vegetative features within it because they are key components of "habitats".

Integrated biophysical mapping of the entire lakeshore zone does not appear to be a well established practice, so we do not put forward a specific scheme or set of methods. More research is needed to determine the spatial scales at which diversity of vegetation communities and shoreline substrates translate into functionally useful units of habitat for fish and wildlife. For example, small patches of one or other vegetation type may not be large enough to be of much use to a population of a fish or bird species, but may be sufficient for smaller-bodied insect species at a population scale.

Biophysical mapping of the riparian, shoreline, and littoral zones would ideally be done for all lakes in a region for complete comparisons. However, regional planning processes could prioritize such mapping for a subset of lakes based on criteria including relative risk to lakes from expected developments, relative strength of known lake values, or lake sizes.

Suitable soils for agriculture are often associated with valley bottoms close to lakes and wetlands. Land use planning needs to prescribe riparian set-asides or buffers around the lakeshore and associated wetlands to protect water quality from agricultural run-off and maintain wildlife habitat around the lake edge (Shallow Bay, Lake Laberge, May 2017) (Gerry Whitley).

Here we provide some of our thoughts on the most useful biophysical features that would be mapped so as to calculate a variety of indices illustrating the diversity of habitats so that comparisons can be made among a set of lakes or portions of lakes.

Riparian zone

- Width is chosen to draw boundaries on the Riparian zone: At a minimum, follow the British Columbia or Yukon standards and guidelines for Riparian Management Areas (see Tables 8 and 9 in Section 9.4), using the upper limit of ranges of slope distances from the ordinary high water mark to define the extent of the Riparian Management Areas (RMA). However, there is no ecological reason why the width of the terrestrial buffer should vary with lake surface area. Also, a number of wildlife species, that depend on the lakeshore zone, use the riparian and upland forests up to and beyond 100 m from the shoreline. For example, mean distance from water for nests of 6 waterfowl species in boreal parklands ranged from 55 to 161 m (Clark and Shutler 1999). Beaver regularly forage within 60 m, and up to 100 m, from water in boreal ecosystems (Hood and Bayley 2008, pers. obs.). These RMA widths or buffers will sometimes go well beyond the riparian as defined just by the bottom of steep slopes that border the land influenced by the lake's water table and flooding. For other stretches of shoreline, however, these RMA widths may not even include all of the wetlands closely associated with a lake. Choice of width may vary depending on the specific ecological and socio-cultural values being addressed, and land planning needs to address this question explicitly.

- Natural vegetation communities are mapped because these are the key units of habitat: This mapping should be taken from a formal ecological land classification and mapping of vegetation communities. In Yukon, such mapping is based on the Yukon Ecological and Landscape Classification and Mapping Guidelines (Environment Yukon 2016) and associated guidebooks (e.g., Environment Yukon 2017c). In British Columbia, such mapping is based on the field guides specific to each biogeoclimatic zone (e.g., Banner et al. 1993, DeLong et al. 2011) or to wetlands (Mackenzie and Moran 2004), and maps created following the Terrestrial Ecosystem or Predictive Ecosystem Mapping guidelines (Government of British Columbia 2020). In the absence of prior mapping of vegetation communities, it might be necessary to use the juridiction-specific inventories of forest stands. Quantify the area of all vegetation communities in the riparian zone, and the number of discrete polygons or patches of each community. Where riparian vegetation has been permanently altered from patterns of natural plant succession (e.g., agricultural or residential developments), these sections of the riparian zone need to be removed from the calculations, but quantified separately (bullet below).
- Richness and evenness of natural vegetation communities are calculated because these indicate which lakes have the most biological diverse and complex riparian areas: For the riparian zone of each whole lake or subset of shore zone, calculate indices of habitat diversity based on richness (number of different vegetation communities) and frequency (number of discrete polygons or patches of each vegetation community OR total area of all polygons or patches for each vegetation community). These data can be used to calculate indices of richness of vegetation communities and of their evenness (similarity in frequency), analogous to procedures used to calculate species diversity and evenness. However, the data will be complete inventories of riparian zones, rather than random samples, and the frequency data would best be as proportions in order to standardize measures across riparian zones of different total size. Krebs (1999) outlines numerous indices, and we suggest the following: (i) community richness (a direct count of distinct vegetation communities), (ii) heterogeneity (Simpson's index because it uses proportions of occurrence of units (communities)), and (iii) evenness (Camargo's index also because it uses proportions of occurrence). These indices are not useful in terms of their absolute values, but are useful in comparisons across a set of lakes.
- Permanently altered vegetation communities and their fragmentation are calculated to get an index of how much of the riparian zone has been affected by permanent human footprint: Calculate the number of discrete parcels within the riparian zone where riparian vegetation has been permanently altered from patterns of natural plant succession (e.g., agricultural or residential developments, campgrounds, boat launches), the proportion of the entire riparian zone they take up, and

the number of separated parcels (fragments) of natural vegetation that result from the changed patterns. Note that timber harvesting, and natural disturbances such as wild fire, are not considered to have permanently altered the vegetation, as they generally result in successional vegetation communities that may occur naturally in riparian areas.

Shorelines

- Substrate types are mapped and quantified because a variety of substrates reflects a greater diversity of ecological conditions and because some substrate types are of particular value or lack of value for certain species: Quantify the length of various classes of shoreline substrate at the ordinary high water mark including at least: organic peats and soils (often sitting above water-washed sand, gravels, cobbles or rock, and generally well vegetated and banked); mud and silt; sand; cobble and gravel; boulder; bedrock. The diversity, heterogeneity, and evenness of these types of shoreline substrate can be calculated following the same procedures as for vegetation communities in the riparian zone (see Above).
- Shoreline sinuosity or degree of bending is mapped as more sinuosity generally offers more diversity of habitats for organisms using the shoreline itself: A. The ratio of the total length of a shoreline section to the linear distance between the two ends of the same shoreline section (this can be calculated iteratively for partly overlapping or for bordering sections of shoreline). Ratio of one is for a straight shoreline, and higher ratios represent greater sinuosity. B. The ratio of the total length of shorelines including islands to the surface area of the lake. A modification of this is the shoreline development index ($D = L \div \sqrt{4\pi A}$) in which the shoreline length is L and surface area is A (Kent and Wong 1982), however the same scale must be used for all shoreline measurements as shoreline length is scale dependent (Kent and Wong 1982).

Littoral (We note that littoral zones are rarely mapped, and such mapping often requires specialized remote sensing applications at least including air photos, so this step might be relatively difficult or impossible to accomplish for some planning processes).

- Substrate types, and their diversity and evenness, are mapped and calculated because more variety is an indicator of more biological richness and higher conservation values: Quantify the contributions in area of all the types of underwater substrate in the littoral zone, including at least the following classes: organic coarse materials (decaying wood); organic fine materials (muck); mineral dominated muds and silts; sand; cobble and gravel; boulder; bedrock. The diversity, heterogeneity, and evenness of these types of littoral substrate can be calculated following the same procedures as for vegetation communities in the riparian zone (see Above).

- Natural aquatic vegetation communities (defined by rooted aquatic plants) are mapped because these communities provide valuable food for various wildlife and shelter for various fish: Quantify the contributions in area and potentially volume of the full suite of natural vegetation communities, including at least the following classes: none; emergent horsetail; emergent rushes and graminoids; surface floating-leaved species; submerged species. Valley et al. (2005) outline a complicated technique for estimating volume of submersed aquatic vegetation. Mackenzie and Moran (2004) provide a short classification for shallow open water ecosystems in British Columbia, similar to this list. The diversity, heterogeneity, and evenness of these types of littoral substrate can be calculated following the same procedures as for vegetation communities in the riparian zone (see Above).
- Permanently altered vegetation communities and their fragmentation are calculated to get an index of how much of the littoral zone has been affected by permanent human footprint: Calculate the number of discrete parcels within the littoral zone where vegetation has been permanently altered from natural patterns (e.g., boat launches, residential developments, boating routes), the proportion of the entire littoral zone they take up, and the number of separated parcels (fragments) of naturally vegetated littoral zone that result from the changed patterns.
- Prominence of littoral zone as a proportion of the entire shore zone is calculated on the assumptions that a more prominent littoral zone enhances productivity of each component of the shore zone, and that the littoral is essential fish habitat in boreal lakes: The relative contribution of the littoral zone can be assessed with respect to the aquatic and/or the terrestrial components of the shore zone ecosystem. Considering the aquatic component, quantify the surface area of the littoral zone as a proportion of the total surface area of the lake. Considering the terrestrial component, quantify the ratio of the surface area of the littoral zone divided by the surface area of the riparian zone.

9.6. Management for Key Habitats and Cultural Sites

Apart from the extensive questions of considering lake values in planning, and developing a zoning system for lakes, there is a suite of fairly site-specific or intensive ecological and cultural values that should be considered in management. These include key habitats for numerous fish and wildlife species, such as spawning and nesting areas or sites, and also include specific sites of high value to human culture and society, such as burial grounds, subsistence camps and sacred places.

Key habitats for fish and wildlife species should be recognized and considered for protection no matter in what lake zone they occur. The need for protection is based on the likelihood that human activities will disturb individuals using the habitats with negative consequences for their survival and productivity, and possible negative consequences for the whole population. Protection

Graves are fairly often located on prominent features close to water, and deserve inventory and protection with spatial buffers (Frenchman Lake, June 2017) (Donald Reid).

measures can be put in place to remove or reduce the risk of diminishing the species' ability to fully use the key habitat. However, protection measures cannot be developed for all species independently. Protection measures should therefore be put in place for species that: are highly vulnerable to human activity; have widely dispersed key habitats that are relatively uncommon and very site-specific throughout a regional set of lakes; are highly valued by people. We assume that lakeshore zoning with conservation emphasis will be sufficient to cover habitat needs of many organisms, but that a select subset of lakes or lakeshore zones will require more complete regional protection because of their higher vulnerability.

These key habitats and cultural sites need to be recognized no matter in what lake zone they occur, with protection measures in place to remove or reduce the risk of diminishing their value. The most straightforward measures are spatial buffers, but timing windows can also be used when their value is seasonal. Spatial buffers delimit the space around a key habitat or site where no permanent infrastructure or human development should be allowed, and within which even temporary human activity should be minimized where possible. Timing windows are the periods of the year during which the key habitats or sites should be avoided, if such avoidance is not required throughout the year. Table 10 summarizes a set of spatial buffers and timing windows for a set of ecological and cultural values. We propose these management measures, based where possible on published science, as the best starting point for local scale management of particular developments and activities.

9.7 Riparian Stewardship

Here we outline recommended practices in the riparian zone to minimize negative impacts of human activities (Table 11). These are targeted primarily at privately-owned lakeshore properties that are not legally subject to the Riparian Management Guidelines that apply to public lands (e.g., Government of Yukon 2012a) (see section 9.4 above). Ideally those Guidelines would be followed, but the recommendations here are seen as the next best alternative.

(Top) Water at the outflow of many, large valley bottom lakes stays open all winter, attracting wildlife, with fresh river otter and Canada lynx tracks at this location (Tarfu Lake, January 2016) (Donald Reid).

(Bottom) Land owners can retain significant habitat value in their privately-owned part of the shore zone ecosystem, by retaining most of the continuous mature forest within at least the 30 m strip adjacent to high water, as well as a strip further inland, plus by not clearing to the edge of the wetland that borders the lake. These stewardship practices help mammals and birds to move along the lake, and they mitigate some of the risk of increased water runoff from cleared land (Little Atlin Lake, May 2017).

Table 10. Summary of key habitats and sites which are repeatedly used by a particular species over many years, along with proposed spatial buffers for no development and timing windows for avoidance. In this Table, "riparian management area" refers to the buffer widths laid out in Yukon's riparian management guidelines (Government of Yukon 2012a).

Key Habitat or Site	Species	Spatial Buffers for No Development	Timing Window for Avoidance	Reference
Cultural and Historic Sites	Human	100 m undeveloped	Year-round	Government of Yukon 2012b
Unvegetated banks close to water	Belted kingfisher; Bank swallow	Minimum 30 m from top of bank, undeveloped	Nesting season: 1 May to 15 August	Lynch et al. 1985
Open water in winter	River otter, mink, muskrat, American dipper, numerous waterfowl	Entire riparian management area plus 100 m downstream and upstream	15 October to 1 May[1]	*Untested*
Islands	Numerous. Particular value for nesting birds (e.g., colonial gulls and terns) and ungulate rearing	Maintain undeveloped.	15 April to 15 August	Walker et al. 2005; Bowyer et al. 2003
Confluences of inflow streams at lake	Numerous fish, waterfowl and mammals	Entire riparian management area for 100 m upstream and along lake shoreline in both directions, undeveloped	15 October to 1 May	*Untested*
Outflow stream at lake	Numerous fish, waterfowl and mammals	Entire riparian management area for 100 m downstream and along lake shoreline in both directions, undeveloped	15 October to 1 May	*Untested*
Wetland adjacent to, and at same water level, as lake in winter	Numerous fish, waterfowl and mammals	Apply riparian management area standards for lake (rather than wetland), plus 50 m buffer along shoreline in both directions, undeveloped	15 October to 1 May	*Untested*
Fish Spawning	Restricted spawning beds within lakes (Lake trout, burbot, northern pike)	Entire riparian adjacent to shallow-water spawning, plus 100 m on each side, undeveloped	Avoid during spawning periods	*Untested*
	Restricted spawning beds in streams (Arctic grayling, various whitefish, salmon)	Entire riparian management area adjacent to shallow-water spawning, plus 100 m on each side, undeveloped	Avoid during spawning periods	*Untested*
Amphibian Reproduction	All species	0 - 30 m no development; 30-230 m with <25% surface area developed	Avoid during spring mating and egg development	Calhoun et al. 2005
Amphibian Seasonal Movements	All species with known repeatedly used routes	Entire route with 30 m buffer on each side, undeveloped	At time of movement	Government of British Columbia 2014
Semi-aquatic Mammals overland trails	River otter, mink, beaver, muskrat	Entire trail length plus 100 m buffer on each side, undeveloped	1 May to 30 October	*Untested*

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Key Habitat or Site	Species	Spatial Buffers for No Development	Timing Window for Avoidance	Reference
Raptor Nests[2]	Low tolerance: Northern goshawk	500 m undeveloped	March 7 to August 21	Government of British Columbia 2013 (Tables 2 and 6), but see Government of Yukon 2012c
	Moderate tolerance: Sharp-shinned hawk, Peregrine falcon, Northern harrier	500 m undeveloped plus 100 m quiet zone during timing window	Varies with species – see reference	
	High tolerance: Osprey, Great-horned owl, Bald eagle, Merlin	200 m undeveloped plus 100 m quiet zone during timing window	Varies with species – see reference	

[1] May 1 is chosen to mark the start of the open water season, at which point lake ice is in rapid decay and the extent of open water is increasing rapidly.

[2] Note that Yukon has published less restrictive buffers but we advocate using the British Columbia recommendations (see References)

Table 11. Summary of a set of ecological values at risk from development within the riparian zone, with suggested best practices for stewardship of these values.

Ecological factor at risk	Best stewardship practice	References
Lake water temperature (especially small lakes)	Retain 30 m wide buffer of uncut vegetation adjacent to high water mark to keep as much shading as would normally occur	Beschta and Weatherred 1984
Submerged structures (mostly CWD) in littoral zone that provide cover	Retain all trees in buffer of one mature tree height adjacent to high water mark and allow trees to fall into lake if dead or blown over	Robinson and Beschta 1990; Van Sickle and Gregory 1990
	Avoid clearing submerged dead wood and large boulders from the littoral zone	Sass et al. 2006
Water clarity by sediment inflow; water quality by nutrient enrichment (too much nitrogen and phosphorus inflow to lakes); water quality by pesticide and pathogen inflow.	Reduce the sediment load in water run-off flowing from upland and riparian zones into lakes, by encouraging growth of grass and other perennial vegetation in cleared areas. Sediment levels in runoff are higher when upland and riparian lands are cleared. Perennial grass growth can act well as filter, but wider strip of grass close to shoreline is required for finer sediments (5 m for sand to 100 m for clay). This technique is less useful for trapping nutrients before they enter the lake	Wilson 1967; Magette et al. 1989; Houda et al. 2000. Untested in northern boreal context; nutrient flows are lower concern in Boreal Cordillera except around agricultural lands.
	Keep livestock out of the riparian and littoral zones by fencing, provision of salt in upland areas, and provision of water in features or structures well away from natural ponds and wetlands	Kauffman and Krueger 1984; Agouridis et al. 2005.
	Reduce risk of sewage and waste water contamination of ponds and lakes by building adequate septic systems and waste water filtration systems	Local jurisdictional regulations. (e.g., Yukon Health and Social Services 2017, HealthLinkBC 2017)
Riparian connectivity on land to help organisms move along lakeshores (e.g., mammal movements within home range and seasonally; bird nesting and migration)	Retain a strip of forest vegetation as wide as possible across the land parcel to join the riparian zones on either side of the land parcel along the shore. Such a retained strip would ideally be within or close to the riparian zone, and would be broken as infrequently as possible by forest clearing (e.g., roads, power lines)	Brinson et al. 1981; Brusnyk and Gilbert 1983; Darveau et al. 1995; Spackman and Hughes 1995; Darveau et al. 2001

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APPENDIX 1.

Life History Parameters and Habitat Affinities of Boreal Cordilleran Fish During Different Life Stages, with Major Emphasis on Lakes

Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
Arctic Lamprey	Freshwater and Anadromous	Migration corridors; Freshwater populations except for spawning	• Spring / summer	• Streams and rivers • Gravel riffles and runs • Out of main channel	• 2-3 weeks	• Streams	• Muddy margins or lakes, backwaters of rivers • Eat algae, organic matter, aquatic invertebrates	• Oceans and lakes • Parasitic, feeding on bodies of other live fishes	c. 5 years; max. age 5-6 years
Lake Chub	Freshwater	All life stages	• Early summer	• Poorly known • Streams near Lakes – under rocks or over gravels • Lakes – shallow littoral over rocky substrates	• 5-10 days	• Streams	• Streams and lakes	• Lakes, rivers, streams • Benthic and shallow water • Sand with boulders • Woody debris, undercut banks • Eat aquatic insects	1-4 years; max. age 5 years
Arctic Grayling	Freshwater	All life stages	• Spring • Soon after ice breakup	• Rivers and lakes • Lakes – at inlet and outlet streams, and sometimes under ice • Range of substrates – sand, silt, gravel and vegetated areas	• 2-3 weeks	• Lakes - shallow littoral • Streams – pools • Overhead vegetation and boulders • Eat aquatic insect larvae, crustacean zooplankton	• Overwinter in lakes • Rocks, cut banks, overhanging vegetation • Eat insects, crustacean zooplankton, fish, small mammals	• Lakes and streams • Lakes – rocky shorelines, often near inlet and outlet streams • Sand, silt, gravel, cobble, overhanging vegetation • Planktivorous	5 years; max. age 9-22 years

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Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
Northern Pike	Freshwater	All life stages	• Spring (May - June) • Right after ice breakup	• Sheltered littoral with lots of emergent or submergent vegetation; well-oxygenated • Sand and mud with roots • 0.2 – 0.7 m water depth • Eggs stick to vegetation	• 4-14 days	• Stick to vegetation up to 10 days • Murky backwaters with 40-90% cover of vegetation over substrates • Eat macroinvertebrates	• Shallows of lakes / ponds (< 7 m deep) • Lots of submergent vegetation • Eat fish	• Spring-fall: Weedy littoral in lakes, and slow-flowing rivers • Summer – winter: Deeper lakes and rivers • Eat fishes	5 years; max. age 21 years
Burbot	Freshwater	All life stages	• Winter – early spring (December – March) • Under ice	• Lakes, rivers and streams • Shallow (1- 10 m deep) near shore or off-shore reefs • Sand, gravel, cobble, free of silt	• 2-3 weeks	• Shallow, littoral areas with gravel and cobble • Limnetic – in the water column • Eat copepods, rotifers	• Become mostly nocturnal and benthic • Cover of boulders and debris in littoral • Eat insects and increasingly fish	• Cool water (< 11°C) • Below thermocline in summer; benthic • Some movement to shallows in fall, associated with other spp. spawning • Eat fishes	7-15 years; max. age 20 years
Trout-perch	Freshwater	All life stages	• Spring - summer	• Lakes – littoral sand and gravel • Streams – rock, gravel riffles	• 20 days	• Deep water in lakes	• Lakes and steams	• Lakes and streams • Lakes in summer – near thermocline in day, moving to littoral in night • Rivers – muddy backwaters • Lakes – littoral sands	1-2 years; max. age 4 years

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Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
Rainbow Trout	Freshwater	All life stages (Introduced in Yukon)	• Spring (mid-April to late June)	• Inlet and outlet streams • Sand / gravel riffles near vegetated banks • May use littoral gravels in lakes	• 4-7 weeks	• Streams and lakes • May move to lakes soon after emergence, or stay in streams for long periods	• Streams and lakes • Lakes – mostly littoral (3-6 m deep)	• Stocked in pothole lakes • Can occupy a range of lakes • In day, near rocks, woody debris, and other cover • In night, benthic over sand, gravel, cobble • Eat aquatic insects, molluscs, crustaceans, other fish	2-4 years; max. age 8 years
Rainbow Trout (Steelhead)	Anadromous	Migration corridor	• Spring (May)	• Streams	• 4-7 weeks	• Streams	• Streams for 1 or 2 years before migrating to ocean	• Ocean for 2-3 years before first spawning • Small numbers return to ocean, and then return to spawn in later year	3-5 years; max. age 8-9 years
Lake Trout	Freshwater	All life stages	• Fall – early winter	• Lakes, but occasionally streams • Coarse rocks, boulder, cobble and gravel in littoral or on reefs • Varying depths but requiring well oxygenated waters	• 15-21 weeks	• Stay in spawning substrates for weeks to a few months • Eat invertebrates	• Shallows in lakes; littoral • Eat invertebrates, molluscs, fish eggs	• Mostly in deep, cold water • Often below thermocline • In shallows when water cold in spring or at inlet streams • Often piscivorous, but can eat mainly crustacean plankton	5-11 years; max. age 25-30 years

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Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
Dolly Varden	Freshwater in Boreal Cordillera	All life stages; mostly as adults	• Fall	• Gravel bottoms of streams and rivers	• 3 months	• Streams • Coarse gravels and cobble	• Stream residents for 1 – 4 years	• Lakes, streams and rivers • Variety of depths but often littoral • Return to original streams to spawn	2-6 years; max. age 10-12 years
Bull Trout	Freshwater in Boreal Cordillera	Mainly as adults	• Fall – early winter	• Inlet and outlet streams from lakes, and in rivers far from lakes • Gravels in slow-moving water near cover of log jams, undercut banks, overhanging vegetation	• Emerge in spring	• Shallow streams	• Stay in streams for up to 4 years before moving to lakes; some entirely in rivers	• Lakes, streams and rivers • Lake populations in large, oligotrophic lakes • Move widely in lakes	4-5 years; max. age 10-21 years
Chinook Salmon	Anadromous	Migration corridors; rearing	• May - September depending on length of migration	• Rivers / streams, and sometimes lakes • Streams – gravel and cobble • Lakes – littoral gravels	• Emerge in spring	• Streams and rivers • Gravel and cobble beds	• Usually moving water of streams and rivers • Gravel and cobble beds, but various during migration	• Migrate to ocean in May or June of first or second year • In ocean 2-3 years before returning to natal streams to spawn	2-5 years; max. age 5-6 years
Chum Salmon	Anadromous	Migration corridors; rearing	• August-January	• Silts and gravels of streams • Generally where ground water discharges or upwells into streams	• Emerge Dec-Feb	• Spend small amount of time in spawning reaches • Migrate directly to ocean in June – July • Use debris and vegetation for cover	• Ocean	• Ocean • Migrate upstream in rivers to spawn • Eat primarily invertebrates	3-6 years; max. age 6 years

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Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
Sockeye Salmon	Anadromous	Migration corridors; rearing	• August - September	• Streams between lakes, but also in lakes	• Emerge at time of peak plankton (May)	• Move into rearing lakes and streams • Generally littoral or shallow backwaters in stream • Some move to ocean in first year	• Lakes and streams • Diurnal movements between limnetic and littoral zones • Migrate to ocean in spring of second to fourth year	• Ocean • Migrate upstream in rivers to spawn	2-5 years; max. age 6 years
Sockeye Salmon (Kokanee)	Freshwater	All life stages	• August - September	• Mostly rivers close to lakes, but sometime littoral in lakes • Clear water with coarse sand and gravel bottom	• 39-140 days • Often in spring	• In lakes • Some limnetic (planktivorous) and some littoral	• Similar to adults	• Limnetic zone of lakes • Diel vertical movements to access food in night • Planktivorous	2-3 years; max. age ?
Coho Salmon	Anadromous	Migration corridors, with some rearing	• September - November	• Streams • Flowing water over gravels, and with ground water upflows	• December to May	• Some migrate rapidly to ocean • Some stay in freshwater, in still water of large river systems (oxbows, backwaters)	• May stay 1-4 years in freshwater • Mostly streams with still water • Some use of littoral in lakes, often in winter	• Ocean for 1 – 3 years	4-6 years; max. age 5-6 years
Least Cisco	Freshwater and anadromous	All life stages	• Fall – early winter	• Inlet and outlet streams • Littoral zones of lakes • Sand and gravel substrates	• Emerge in spring	• Primarily in lakes	• Similar to adults	• Limnetic zone of oligotrophic lakes • May do diel movements with nocturnal feeding in shallower water • Often school • Eat zooplankton	3-4 years; max. age 8-20 years

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Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
Lake Whitefish	Freshwater	All life stages	• Fall – early winter	• In rivers close to lakes, and in lakes • Rivers: sand, gravel, cobble • Lakes: shallow water over rocky reefs or gravels	• 40-140 days varying with temperature • Likely overwinter in most sites	• Mainly lakes; also streams • Switch from limnetic to benthic feeding • Littoral with vegetation in summer, moving deeper in winter • Eat copepods	• Mainly lakes with some river populations	• Mainly lakes with some river populations • Cool water, so deeper in summer • Eat benthic invertebrates	4-10 years; max. age 12-28 years
Broad Whitefish	Freshwater, but some anadromous populations	Most life stages, except spawning. Some populations riverine	• Early winter	• Mainly in rivers often close to lakes • May spawn in some lakes • Gravel beds	• Incubate overwinter • Hatch in spring at break-up	• Shallows of lakes and streams • Deeper water in winter	• Probably littoral of lakes • Benthic feeders	• Mix of lake and river, but poorly known • Some populations migrate seasonally • Benthic feeders	5-9 years; max. age 15-35 years
Pygmy Whitefish	Freshwater	All life stages, except perhaps spawning	• October and November	• Mostly inlet streams close to lakes, but may be some sites in lakes • Gravels, riffles	• Likely incubate overwinter with spring emergence	• Lakes, littoral, and benthic • May move offshore in day	• Lakes • Group in schools • Benthic feeders	• Lakes • Cold water species – may be in hypolimnion in summer • Possible diel movements into littoral at night • Benthic feeder	2-3 years; max. age 3-9 years
Round Whitefish	Freshwater	All life stages, except perhaps spawning	• October and November	• Often in rivers and streams close to lakes • Rivers: gravels, but also sands • Lakes: reefs with gravels and cobble at various depths	• Likely incubate overwinter with spring emergence	• Lakes and streams • Shallow water	• Lakes and streams • Shallow water	• Poorly known • Lakes and streams • Likely at various depths • Spawning migrations • Benthic feeder	4-7 years; max. age 8-22 years

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Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
Mountain Whitefish	Freshwater	All life stages, except perhaps spawning	• November - January	• Mostly in streams • Some in lakes at upwellings • Gravels	• Incubate overwinter with spring emergence	• Lakes and streams • Shallow water over sands and silts	• Lakes and streams • Often associated with gravels and boulders, and shallow water	• Lakes: seasonal shifts from shallows in fall and spring to deeper water in winter and summer • Pelagic and benthic feeders	3-6 years; max. age 12-23 years
Inconnu	Freshwater and anadromous	All life stages, except spawning	• September-October	• Rivers and streams, sometimes far from lakes • Sands and gravels	• Incubate overwinter with spring emergence	• Lakes near river inlets, or estuaries • Move rapidly downstream in spring	• Lakes and rivers • Various movements in rivers and within lakes	• Annual migrations from estuarine or lake winter habitats to spawning habitats • Great variety of habitat conditions	5-9 years; max. age 17-24 years
Longnose Sucker	Freshwater	All life stages, except perhaps spawning	• Early spring	• Mostly in streams • Gravels in moderate current	1-2 weeks	• In streams and littoral of lakes • Shallows and sites with reduced flow	• In backwaters of streams, and shallows of lakes (but deeper in summer)	• Mostly in lakes, but some stream populations • Associated with cold water, but habitat generalist • Eat aquatic insects, molluscs, crustaceans, fish eggs	5-9 years; max. age 19+ years

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Species	Freshwater or Anadromous	Use of Lakes	Spawning Time	Spawning Sites	Incubation	Young of Year	Habitat for Juveniles	Habitat for Adults	Maturity
White Sucker	Freshwater	All life stages, except perhaps spawning	• Spring (May-June) soon after breakup	• Streams: coarse gravel riffles • Lakes: gravel beds often near inflow streams • Nocturnal	• 1-3 weeks	• In lakes, primarily, and some rivers • Shallow, well vegetated littoral or backwater sites	• Shallow, warm, and well vegetated littoral, or backwaters of main stem rivers	• Various depths, but not below thermocline, in lakes • Slow moving reaches of large rivers • Eat aquatic insects, molluscs, crustaceans, fish eggs	3-5 years; max. age 18 years
Slimy Sculpin	Freshwater	All life stages	• Spring (April-May)	• Streams: rocky with gravels • Lakes: rocky shoals with cobble and gravels	• 4-5 weeks	• Lakes: may be planktonic through to winter • Streams: shallows near banks	• Lakes: various depths and mostly benthic • Streams: Shallows with gravels and sands	• Lakes: mostly littoral with sands and gravels • Streams: Mostly cold water, with more movement at night • Eat crustaceans, aquatic insects, small fish	4-5 years; max. age 8 years

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