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Information in support of a Recovery Potential Assessment of Pygmy Whitefish (*Prosopium coulterii*), Great Lakes – Upper St. Lawrence populations (DU5)

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Foreword

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

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ABSTRACT

Pygmy Whitefish (*Prosopium coulterii*) was first captured in Lake Superior in 1952. In November 2016, COSEWIC assessed Pygmy Whitefish, Great Lakes–Upper St. Lawrence populations (DU5) as Threatened. The reason given for this designation was that “this small-bodied freshwater fish has experienced dramatic declines in abundance over the last several decades, with an overall estimated decline of 48% since 2000. The continued presence of invasive fishes and recovery of native predatory fishes may threaten or limit recovery, respectively” (COSEWIC 2016). The Recovery Potential Assessment (RPA) provides background information and scientific advice needed to fulfill various requirements of the federal *Species at Risk Act*. This research document provides the current state of knowledge of the species including its biology, distribution, population trends, habitat requirements, and threats, which will be used to inform recovery plans. A population status assessment indicated that the density of Pygmy Whitefish in Lake Superior has declined since 2013. A threat assessment indicated that the greatest threats to Pygmy Whitefish within DU5 are climate change, invasive species, and pollution; however, the impact of these threats is currently unknown. Predation from top predators such as Lake Trout (*Salvelinus namaycush*) and Burbot (*Lota lota*) may be limiting population growth.

INTRODUCTION

In November 2016, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed Pygmy Whitefish (*Prosopium coulterii*), Great Lakes–Upper St. Lawrence populations (Designatable Unit [DU] 5) as Threatened. This designation was based on a decline in abundance over the last several decades along with the potential for invasive species and/or native predators to threaten or limit recovery (COSEWIC 2016). The Recovery Potential Assessment (RPA) process has been developed by Fisheries and Oceans Canada (DFO) to provide information and scientific advice needed to fulfill requirements of the federal *Species at Risk Act* (SARA) including the development of recovery strategies and authorizations to carry out activities that would otherwise violate SARA (DFO 2007). This document summarizes the biology, distribution, population trends, habitat requirements, threats, and limiting factors to Pygmy Whitefish, Great Lakes–Upper St. Lawrence populations (DU5) to inform the RPA. The RPA process is based on DFO (2007) and updated guidelines (DFO unpublished) that involve the assessment of 22 recovery potential elements. Elements addressed in this document include **Biology, Abundance, Distribution and Life History Parameters** (Elements 1–3); **Habitat and Residence Requirements** (Elements 4–7); **Threats and Limiting Factors to Survival and Recovery** (Elements 8–11); and, **Scenarios for Mitigation of Threats and Alternatives to Activities** (Elements 16–21).

This document accompanies two other documents – 1) a quantitative assessment of population trajectory, habitat characteristics, and available habitat for Pygmy Whitefish in Lake Superior (van der Lee and Koops 2020; Elements 2, 4, and 14); and, 2) recovery potential modelling of Lake Superior populations (van der Lee and Koops 2021; Elements 3, 12–15, and 22). Collectively, these documents provide information on the recovery potential of Pygmy Whitefish within the Great Lakes–Upper St. Lawrence (DU 5).

BIOLOGY, ABUNDANCE, DISTRIBUTION AND LIFE HISTORY PARAMETERS

Element 1: *Summarize the biology of Pygmy Whitefish*

SPECIES DESCRIPTION

Pygmy Whitefish is a coregonine member of the Salmonidae family, belonging to the genus *Prosopium*. It is the smallest of the whitefish species with a maximum total length of 159 mm for the ‘regular’ form found in Lake Superior (USGS unpublished data). The ‘giant’ form, found in western North America, can reach a maximum total length of 260 mm (COSEWIC 2016). Pygmy Whitefish has a cylindrical body that is only slightly laterally compressed near the caudal peduncle (Scott and Crossman 1973). The back is brownish green in colour, the belly is white, and sides are silvery (Scott and Crossman 1973). The head length is slightly longer than the body depth and eye diameter is greater than the length of the snout (Scott and Crossman 1973). Pygmy Whitefish has a single nasal flap between the nostrils along with a ventral notch in the adipose eyelid – two characteristics of the genus *Prosopium* that are not present in other coregonines (Sullivan and MacKay 2011). Eleven rows of scales above its lateral line differentiate Pygmy Whitefish from Mountain Whitefish (*Prosopium williamsoni*) which has six rows of scales. Multiple morphological characteristics distinguish Pygmy Whitefish from Round Whitefish (*Prosopium cylindraceum*) including an elongated head, blunt nose, large eye, and small adipose fin (COSEWIC 2016).

During the breeding season both sexes of Pygmy Whitefish exhibit orange coloured ventral fins as well breeding tubercles on their head, back, sides and pectoral fins (COSEWIC 2016). Sexual dimorphic attributes include longer rayed fins in males and a deeper and broader body in females (Eschmeyer and Bailey 1955). Two morphological forms have been identified based on gill raker count, dorsal fin rays, and caudal peduncle scales referred to as ‘high-raker’ and ‘low-raker’ (McCart 1970). The two morphological forms are thought to occupy different trophic levels. However, individuals from Lake Superior do not fall into either group (inferred from COSEWIC 2016). A full morphological description of Pygmy Whitefish from Lake Superior is described in Eschmeyer and Bailey (1955).

LIFE CYCLE

The majority of male Pygmy Whitefish in Lake Superior reach maturity at age two while the majority of females mature at age three (Eschmeyer and Bailey 1955). However, the ageing in Eschmeyer and Bailey (1955) was based on scales and may slightly underestimate the true age at maturation. Spawning has not been observed in Lake Superior but unripe individuals have been caught in October and spent individuals have been captured in January indicating that spawning is likely during the period from November to December (Scott and Crossman 1973). Although specific spawning habitat for Lake Superior is unknown, Pygmy Whitefish in Washington state broadcast eggs in riverine habitat containing gravel substrate (Barnett and Paige 2014). These spawning areas were influenced by the lake, with eggs likely settling in low-gradient stream habitat or near the lake/river confluence (Barnett and Paige 2012, 2014). Although growth in Lake Superior is slower in comparison to other DUs (COSEWIC 2016), immature individuals grow rapidly, reaching 50% of their maximum size at year 2 for males and at year 3 for females. The maximum recorded age in Lake Superior is 9 years for females and 7 years for males (Stewart et al. 2016).

FEEDING AND DIET

Pygmy Whitefish is a bottom-oriented species that occupies deep water habitat in Lake Superior (Yule et al. 2008) where it feeds on a variety of prey items. Primary prey items for Pygmy Whitefish in Lake Superior include amphipods (*Diporeia* spp.), copepods, chironomids, ostracods, and coregonoid fish eggs (Anderson and Smith 1971, Scott and Crossman 1973). In particular, copepods appear to be an important prey item for young fish (Eschmeyer and Bailey 1955). Mysid crustaceans and bivalve molluscs are less important prey items but have been observed in stomach contents of individuals from Lake Superior (Eschmeyer and Bailey 1955, Anderson and Smith 1971). The acquisition of food items varies by season with crustaceans important from spring through fall, insects important from late spring through fall, and fish eggs important from winter through spring (Eschmeyer and Bailey 1955, Anderson and Smith 1971). Stable isotope analysis of individuals from Lake Superior indicates that the majority of Pygmy Whitefish nutrition is obtained through benthic pathways (Sierszen et al. 2014), providing a trophic link between *Diporeia* spp. and top predators such as Lake Trout (*Salvelinus namaycush*; Stewart et al. 2016).

DISPERSAL AND MIGRATION

Relatively little is known about the dispersal and movement of Pygmy Whitefish in Lake Superior. However, unlike populations in western North America, individuals in Lake Superior are believed not to migrate long distances within tributary streams (Barnett and Paige 2014). There is some evidence that adults in Lake Superior exhibit a mixture of diel vertical migration and diel bank migration (Gorman et al. 2012). However, diel vertical movements are less pronounced compared to other prey fishes such as Cisco (*Coregonus artedi*) and Bloater (*Coregonus hoyi*) (Gorman et al. 2012) and may help reduce predation from Lake Trout (Pratt et al. 2016). Unlike adults, immature Pygmy Whitefish do not exhibit diel vertical migrations but will undertake diel movements towards shore (Gorman et al. 2012).

Element 2: *Evaluate the recent species trajectory for abundance, distribution and number of populations.*

DISTRIBUTION

The Pygmy Whitefish, Great Lakes–Upper St. Lawrence Designatable Unit (DU5) is found entirely within Lake Superior (Figure 1). The species went undetected in Lake Superior until 1952, likely due to its small size in relation to the large mesh size of deep water gill and impounding nets used in commercial fisheries (Eschmeyer and Bailey 1955). Pygmy Whitefish is found in deep nearshore (15–80 m) and offshore (> 80 m) waters of both Canada and the United States.

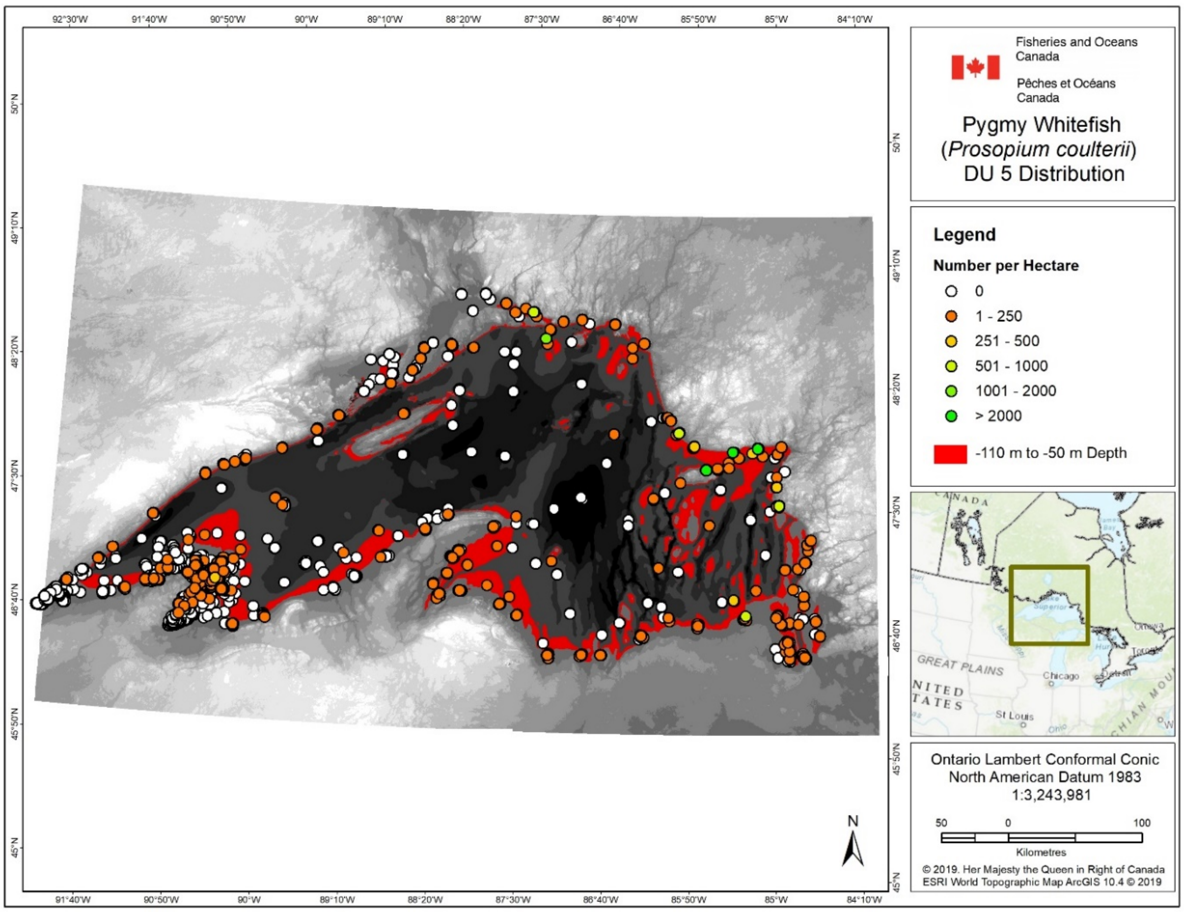

Figure 1. Detections of Pygmy Whitefish, Great Lakes–Upper St. Lawrence populations (DU5), in nearshore and offshore bottom trawls conducted by USGS from 1963–2018. Values are provided as number per hectare. The depth strata between -110 m to -50 m depth is highlighted. Data provided by Mark Vinson, USGS.

Much of what is known about the distribution of Pygmy Whitefish in Lake Superior has been informed by annual bottom trawling conducted by the United States Geological Survey (USGS) as there are no regular survey efforts to assess this species by Canadian agencies. In operation since 1963, numerous USGS index stations are fished routinely allowing trends in Pygmy Whitefish occurrence to be documented. Beginning in 1989, the USGS began sampling deeper habitat on the Canadian side of the lake. Therefore, current trends in population trajectory cannot be readily compared with estimates prior to 1989 (COSEWIC 2016). In this document, all trawls from 1963 onwards were used to inform distribution whereas only nearshore trawls from 1989 onwards were used to inform the population status of this species. Nearshore trawls (n = 2,314), defined as those along the perimeter of the lake at depths ranging from 15–80 m, were conducted using a 12 m Yankee bottom trawl with 6 inch rubber roller foot rope. The majority of trawls were hauled during May and June during daylight hours. Starting in 2011, offshore sites, defined as those > 80–300 m in depth, were sampled using the same trawling gear during the summer months. Since 2013, each trawling effort involved the collection of accompanying water profile data including water temperature, specific conductivity, pH, dissolved oxygen, chlorophyll a, and photosynthetic active radiation (PAR; USGS 2018). Depth was recorded at the beginning and end of each trawl.

van der Lee and Koops (2020) used information from nearshore and offshore trawls to 1) evaluate the relationship between Pygmy Whitefish occurrence and biomass with depth using the spatially explicit modelling technique Integrated Nested Laplace Approximation (INLA) and 2) project the lake-wide biomass density and occurrence of Pygmy Whitefish using Lake Superior bathymetry and the relationship between occurrence and biomass with depth. Figure 2 presents the depth-based projection of Pygmy Whitefish biomass in Lake Superior based on INLA analysis (see van der Lee and Koops 2020 for details). Based on the analysis, at least seven distinct spatial areas of Pygmy Whitefish occurrence and biomass exist: 1) a large area beginning west of Wawa, south and north of Michipicoten Island; 2) an area along the eastern shoreline from Old Woman Bay to Agawa Bay; 3) an area immediately west of the Slate Islands; 4) an area east of the Slate Islands; 5) an area north of the Apostle Islands, MN; 6) several patches north of Munising, MI; and, 7) a large area south of the Keewenaw Peninsula, MI. Although the species appears to exist at low density throughout Lake Superior, density appears to be higher near parts of the north shore of Lake Superior, particularly in the vicinity of Michipicoten Island (Figures 1 and 2). Spatial predictions of biomass using the INLA model were estimated in van der Lee and Koops (2020). Biomass was predicted to be highest near parts of the north shore near Michipicoten Island as well as outside of Keweenaw Bay (Figure 2; van der Lee and Koops 2020)

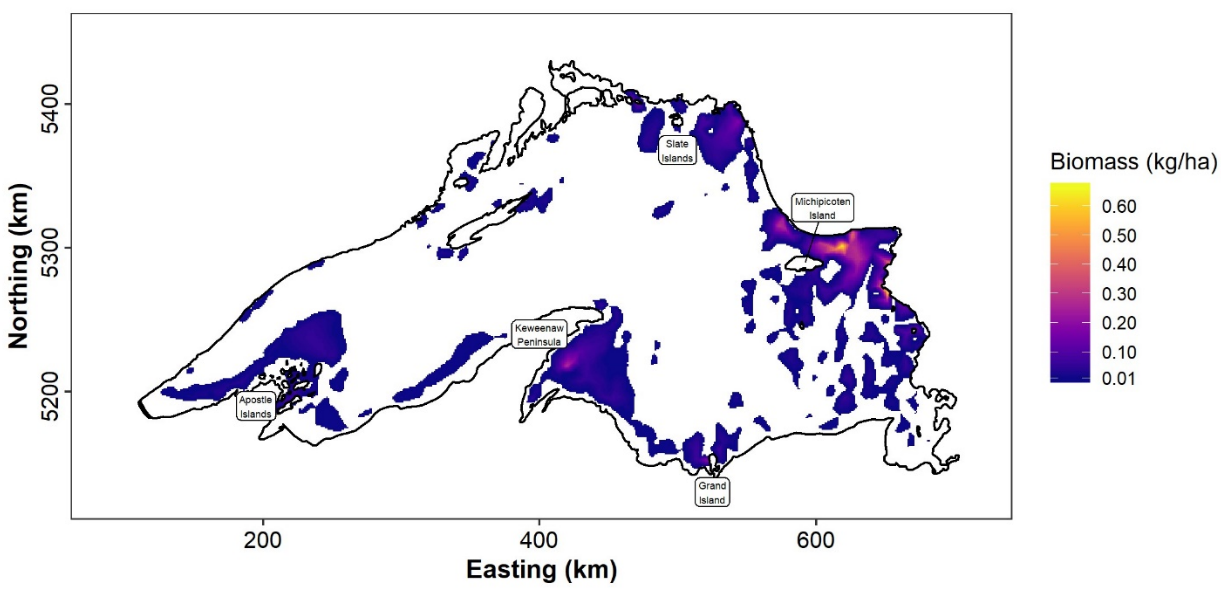

Figure 2. Spatial prediction of Pygmy Whitefish biomass (kg/ha) from combined spatial occurrence and biomass INLA models based on Lake Superior bathymetry. The x- and y-axes are Eastings and Northings (km) respectively, the z-axis is the average biomass (kg/ha) over ~ 1 km² grid squares (reproduced from van der Lee and Koops 2020)

CURRENT STATUS AND POPULATION ASSESSMENT

Relatively little is known about population structure of Pygmy Whitefish within the Great Lakes–Upper St. Lawrence DU (DU5) owing to the lack of information about reproduction and dispersal. Analyses to evaluate genetic exchange within the lake have not been conducted. Low levels of Pygmy Whitefish biomass exist throughout suitable depth ranges (See Figure 10 in van der Lee and Koops 2021), and although at least seven distinct areas of above-average Pygmy Whitefish biomass exist throughout the lake, it is likely that genetic exchange occurs among these patches.

Trends in abundance per hectare for nearshore trawls indicate that density is much higher on the Canadian side of Lake Superior in comparison to waters in the United States (Mark Vinson, USGS, pers. comm.). Empirical trawl data suggest that lake-wide median annual density has declined slightly over the last three decades.

To assess the Population Status of the Pygmy Whitefish Great Lakes–Upper St. Lawrence populations (DU5), all individuals in Lake Superior were assumed to belong to a single population owing to the lack of information about reproductive isolation. The population was ranked in terms of its population trajectory, assessed as Decreasing, Stable, Increasing, or Unknown based on the best available knowledge about the current trajectory of the population. Using only nearshore trawls conducted by the USGS since 1989, van der Lee and Koops (2020) estimated biomass using a spatial depth-centered INLA model. This model indicated that Pygmy Whitefish exist at low density (e.g., a median biomass of 0.036 kg/ha) where the species is predicted to occur (van der Lee and Koops 2021). The spatial INLA model accounted for complex covariance structures in spatial-temporal data, thereby providing lake-wide biomass estimates corrected for the changing spatial distribution of sampling locations across years. The model found that spatial correlation in occurrence residuals exists up to ~70 km from a trawl location and the only significant habitat predictor for occurrence and biomass was water depth. Based on the spatial model, biomass followed periodic fluctuations since 1989 and more recently there appeared to be a decline in biomass since 2013 or approximately one generation (Figure 3). The Pygmy Whitefish biomass in 2018 was estimated to be 68,707 kg (CI: 2,465–1,357,612). The spatial model was ultimately used to inform the population trajectory assessment and the trajectory is described as decreasing for this species in Lake Superior. The authors also used a non-spatial Generalized Linear Model (GLM) to make comparisons with the spatial INLA model (see Figure 3). The GLM estimates of biomass were an order of magnitude greater than the INLA model and showed a greater decline over time. However, the GLM is biased towards larger catch values.

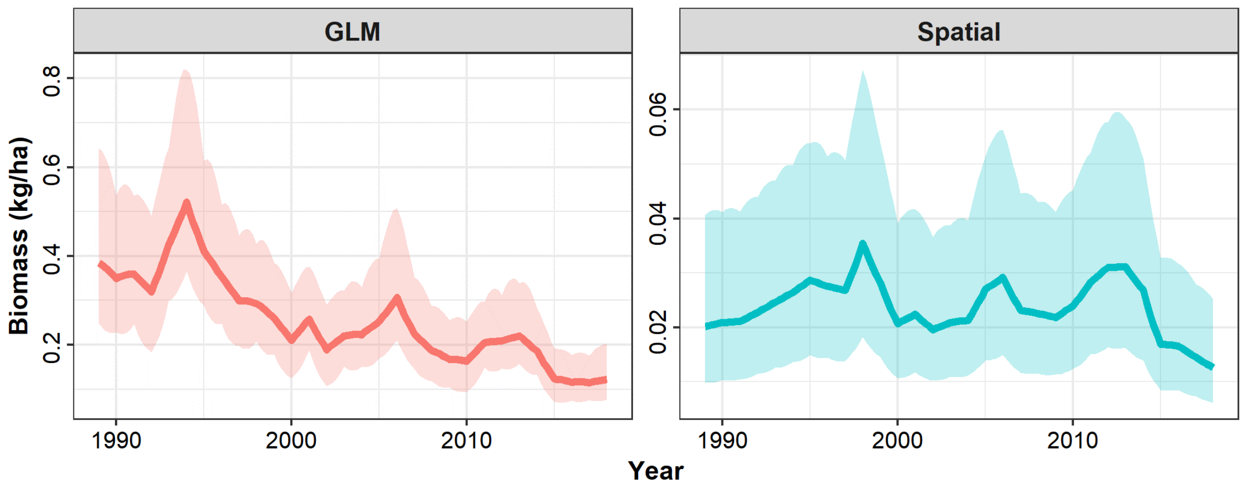

Figure 3. Predicted lake-wide biomass (kg/ha) through time. Relationships were fit to long-term nearshore bottom trawl data using a spatial model and non-spatial GLM. NOTE: y-axis scales differ by an order of magnitude between panels (reproduced from van der Lee and Koops 2020).

A comparison of occurrence and biomass trends for Pygmy Whitefish for Lake Superior in Canada and the United States revealed differences between these areas. The probability of occurrence through time was relatively consistent in waters in the United States while a steady decline was observed in Canada since 2011 (Figure 4) according to the spatial model (van der Lee and Koops 2020). Trends in biomass from the spatial model indicated that biomass is much higher in Canada but has also been decreasing over the last 5 years (Figure 5). Biomass in the United States appears to be decreasing only slightly over the last 30 years (Figure 5).

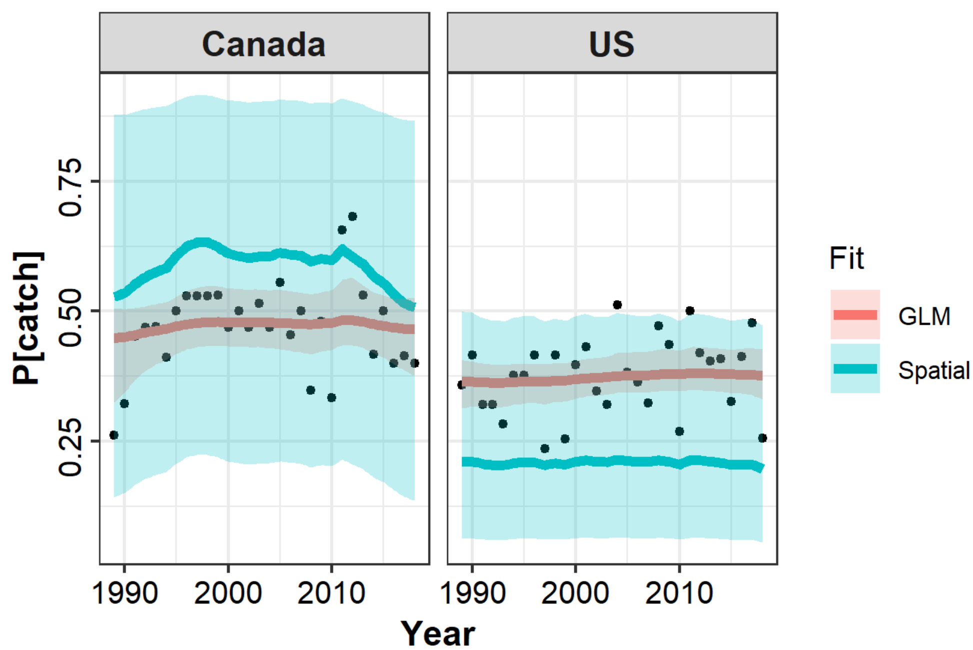

Figure 4. Predicted occurrence (P[catch], likelihood of capture in a trawl) through time for Pygmy Whitefish in Canada versus the United States (US) in Lake Superior. Relationships were fit to long-term nearshore bottom trawl data using a spatial model and non-spatial GLM.

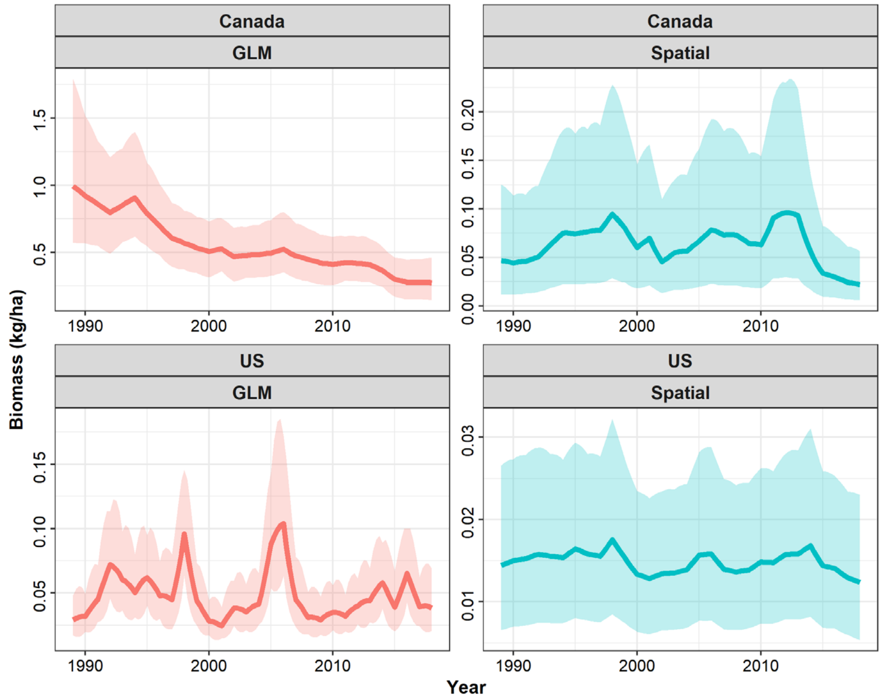

Figure 5. Predicted lake-wide biomass (kg/ha) through time for Pygmy Whitefish for Canada versus the United States (US) in Lake Superior. Relationships were fit to long-term nearshore bottom trawl data using a spatial model and non-spatial GLM. NOTE: y-axis scales differ between panels.

Measures of biomass at six trawl sites supporting the largest catches (Figure 6) revealed that catch trends have been highly variable among sites over the last 30 years (Figure 7; van der Lee and Koops 2020). Periodic fluctuations in annual mean biomass can be seen for two sites (Sites 455 and 463) while increasing biomass (Sites 466) and high variability with strong declines (Site 450) can be seen in others (Figure 7). In particular, Site 450 has not been trawled since 2003 so the extent of recovery following declines in 1999 cannot be evaluated. Most sampled locations indicate a period of poor recruitment in the last three to five years (Figure 7). Without knowledge of population structure, the biological significance of these patterns are difficult to interpret indicating that the evaluation of biomass at the lake-wide level is more appropriate from a DU perspective. Nonetheless, trends at smaller spatial scales warrant further investigation to better understand local environmental influences.

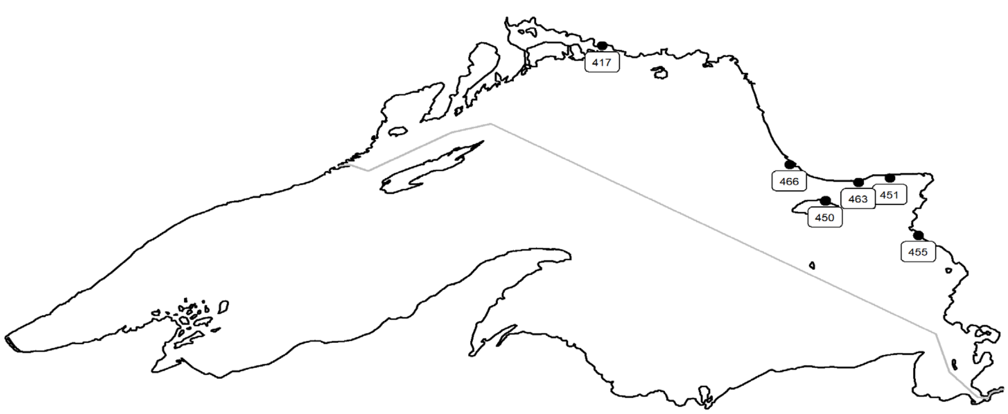

Figure 6. Trawl locations and station numbers where catches have exceeded 3 kg/ha, 1989–2018 (reproduced from van der Lee and Koops 2020).

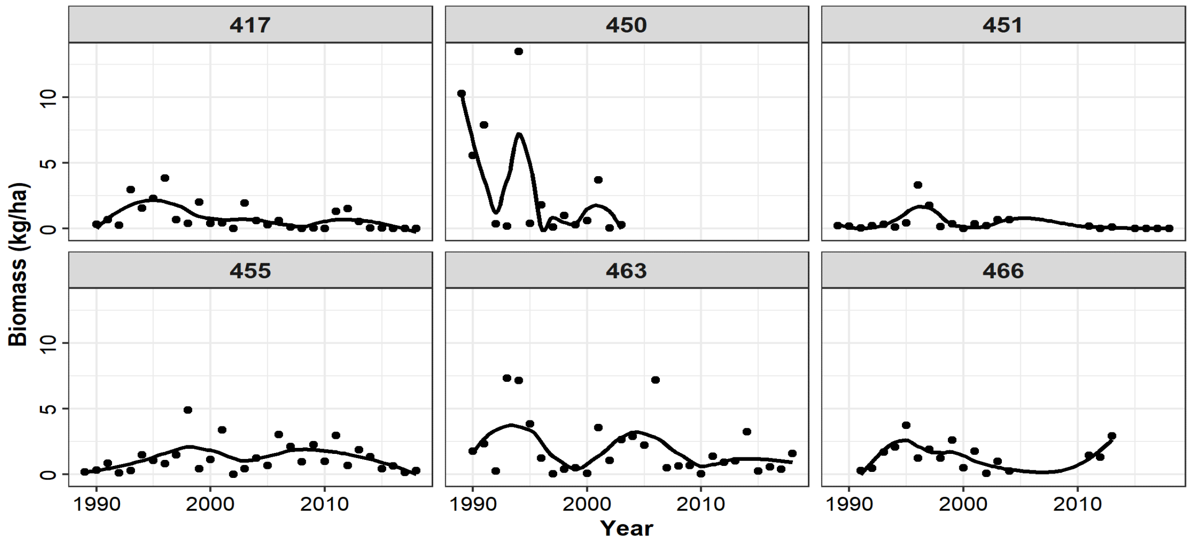

Figure 7. Time series of trawl captures at locations where captures have exceeded 3 kg/ha (reproduced from van der Lee and Koops 2020).

The minimum viable population (MVP) size for Pygmy Whitefish in Lake Superior was estimated to be approximately 4,000 adult females or 75 kg age-1+ biomass assuming a 99% likelihood of persistence over 100 years with a 15% catastrophe rate per generation (van der Lee and Koops 2021). The median 2018 density estimate from van der Lee and Koops (2021) was used to calculate the minimum area for population viability (MAPV), defined as the quantity of habitat required to support an MVP-sized population. The analysis revealed a MAPV of approximately 21 km^2 which indicates that a large number of MVP-sized aggregations of the species may exist in Lake Superior (see Figure 10 in van der Lee and Koops 2021).

Element 3: *Estimate the current or recent life-history parameters for Pygmy Whitefish (DU5).*

LIFE HISTORY PARAMETERS

Age of sexual maturity differs between the sexes with the majority of males becoming sexually mature at age 2 and the majority of females reaching sexual maturity at 3 (Eschmeyer and Bailey 1955). The maximum age as estimated from otoliths is seven for males and nine for females (Stewart et al. 2016). Ova are roughly 2.0 mm in diameter and egg counts of gravid females indicate that fecundity ranges from 93–597 eggs per female with a mean count of 362 eggs (Eschmeyer and Bailey 1955). Fecundity values from Eschmeyer and Bailey (1955) indicate a mean of 26 eggs per gram of fish.

Individuals grow more slowly in Lake Superior in comparison to other populations in North America likely due to oligotrophic conditions. However, growth is rapid early in life where half of a fish's expected length is reached by year 2 and year 3 for males and females, respectively (Stewart et al. 2016). Length at age data have been published for Pygmy Whitefish in Lake Superior in two studies (see Eschmeyer and Bailey 1955, Stewart et al. 2016). Total length of young of the year measure approximately 50 mm or less, while age-1 fish are less than 70 mm in total length (Eschmeyer and Bailey 1955, Stewart et al. 2016; Mark Vinson, USGS, pers. comm.). However these studies indicated considerable overlap between size classes and age groups likely driven by sex differences and varying growth rates in different parts of the lake. For example, individuals from the Apostle Islands area grew more rapidly than those from Keweenaw Bay and Siskiwit Bay where growth was slowest (Eschmeyer and Bailey 1955). Differing lengths between sexes at age four and age six have been documented with males being smaller than females (Stewart et al. 2016). However, this disparity did not exist for individuals at age 2. At Keweenaw Bay, the majority of males reached maturity at a total length of 86–89 mm while the majority of females reached maturity at 107–109 mm in total length (Eschmeyer and Bailey 1955). Length frequency distributions of all individuals captured from USGS surveys in Lake Superior from 1963–2018 indicated total lengths from 20 mm to 159 mm, with ~ 50% of captures between 85 mm and 114 mm (Figure 8).

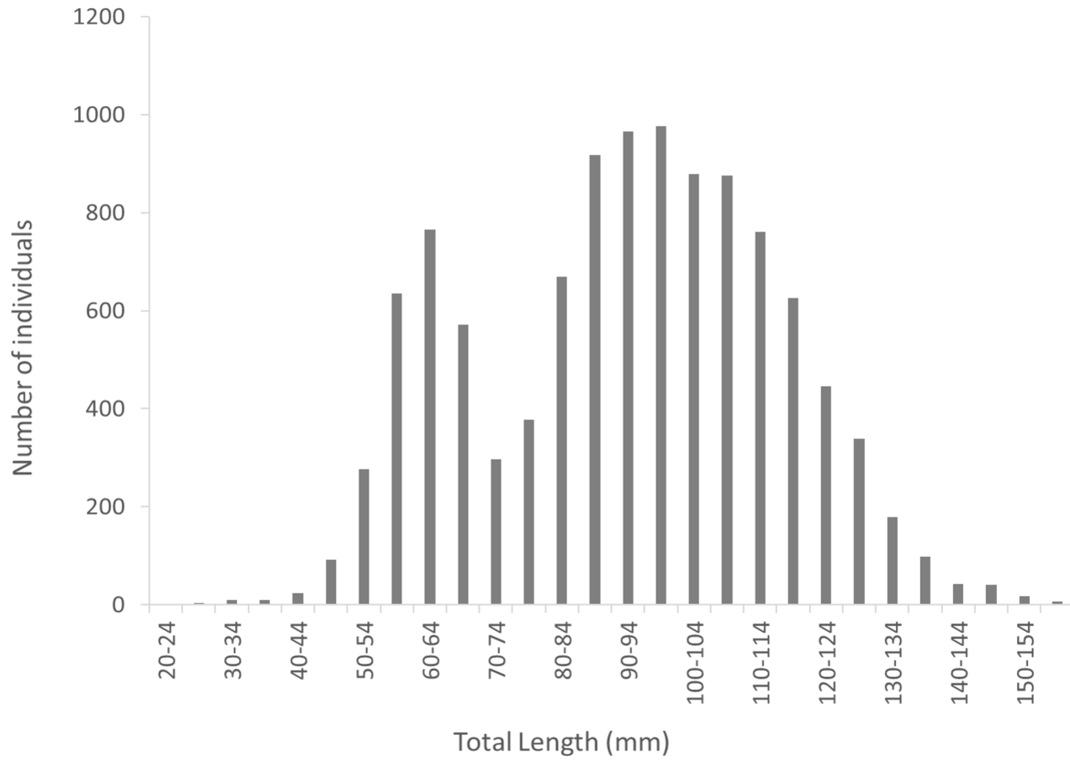

Figure 8. Length frequency distribution for Pygmy Whitefish in Lake Superior captured from 1963 – 2018. Data provided by Mark Vinson, USGS.

HABITAT AND RESIDENCE REQUIREMENTS

Element 4: *Describe the habitat properties that Pygmy Whitefish (DU5) needs for successful completion of all life-history stages. Describe the function(s), feature(s), and attribute(s) of the habitat, and quantify by how much the biological function(s) that specific habitat feature(s) provides varies with the state or amount of habitat, including carrying capacity limits, if any.*

The following section describes habitat and residence requirements for Pygmy Whitefish in Lake Superior. In some cases, habitat information has been summarized from the literature. In other cases, habitat information is provided based on van der Lee and Koops (2020) as well as empirical summaries of USGS trawl data. Where empirical summaries are presented, both nearshore and offshore trawls have been used to inform habitat requirements.

SPAWNING

Spawning has not been observed for Pygmy Whitefish in Lake Superior. Pygmy Whitefish in western Canada and the United States has been observed to migrate one to four kilometers upstream to spawn in riverine habitats while spawning in the shallow waters near shorelines has also occurred (Barnett and Paige 2014). The use of tributaries for spawning in Lake Superior has not been documented. Rather, spawning in Lake Superior is hypothesized to occur in shallow nearshore waters with eggs broadcast over coarse gravel substrate and larvae emerging in the spring (Eschmeyer and Bailey 1955, Scott and Crossman 1973). The capture of gravid female Pygmy Whitefish in October and spent females in January suggest that spawning occurs in November or December in Lake Superior. Elsewhere, spawning has occurred in water temperatures ranging from 2 to 5 °C (Barnett and Paige 2014).

JUVENILE

Juveniles occupy shallower areas of Lake Superior relative to adults (Eschmeyer and Bailey 1955). For example, Eschmeyer and Bailey (1955) found that all individuals caught between 18 and 26 m were young of the year. Gorman et al. (2012) indicated that ontogenetic shifts in depth distribution may occur with small fish occupying shallower depths relative to larger adults. However, the study considered fish < 100 mm to be juveniles, a size category that would also include adults according to length-at-age information from Stewart et al. (2016). Therefore, results from Gorman et al. (2012) pertain to small versus large fish but do not exclusively reflect the depth distribution of juveniles. Fish size also increased with depth in Yule et al. (2008), who analyzed Lake Superior bottom trawl surveys to determine the effect of sampling factors on the biomass of bottom-oriented species. Analysis of juvenile Pygmy Whitefish catches (individuals < 70 mm total length) from the USGS dataset (1963–2018) indicated that the occurrence of juveniles in relation to bottom water temperature, depth, and dissolved oxygen did not differ substantially from adult Pygmy Whitefish (results not presented). In general, knowledge of juveniles in Lake Superior is poor as trawls rarely captured individuals less than 40 mm, with 20 mm as the minimum detected total length (USGS unpublished data).

ADULT

Scott and Crossman (1973) indicated that Pygmy Whitefish in Lake Superior has been captured at depths ranging from 18–89 m with the majority captured from 55–70 m. Similarly in Keweenaw Bay, Eschmeyer and Bailey (1955) reported that the majority of Pygmy Whitefish were caught at depths ranging from 46–71 m but the species was captured at all depths sampled (11–101 m). In another study, biomass of Pygmy Whitefish peaked at 60 m depth (Yule et al. 2008). Seasonality was found to have little effect on depth of capture in Lake Superior (Dryer 1966, Yule et al. 2008) while another study showed that Pygmy Whitefish inhabit deeper waters in the spring in comparison to the summer (Selegby and Hoff 1996). USGS data from 1963–2018 indicate that adult Pygmy Whitefish have been captured at mean bottom trawl depths ranging from 5–161 m. Based on van der Lee and Koops (2020), depth was the only significant predictor of biomass out of a candidate set of habitat variables that included water temperature, specific conductivity, pH, dissolved oxygen, chlorophyll a, and photosynthetic active radiation (PAR). Peak biomass occurred at 80–95 m depths while a greater than 50% probability of occurrence was observed at trawl depths ranging from ~ 50–110 m (Figures 9 and 10; van der Lee and Koops 2020). The median depth of trawls that captured Pygmy Whitefish was slightly deeper in comparison to median depth of all trawls (Figure 11; USGS unpublished data).

Across the North American range, Pygmy Whitefish inhabits water temperatures less than 10 °C (COSEWIC 2016). USGS data indicate that approximately 75% of individuals collected from Lake Superior have been in waters ranging from 2.5 to 5.5 °C (USGS unpublished data). Long term data collected by the USGS show that the majority of Lake Superior individuals are found in waters with dissolved oxygen levels ranging from 12.5–13 mg/L (Figure 11; USGS unpublished data).

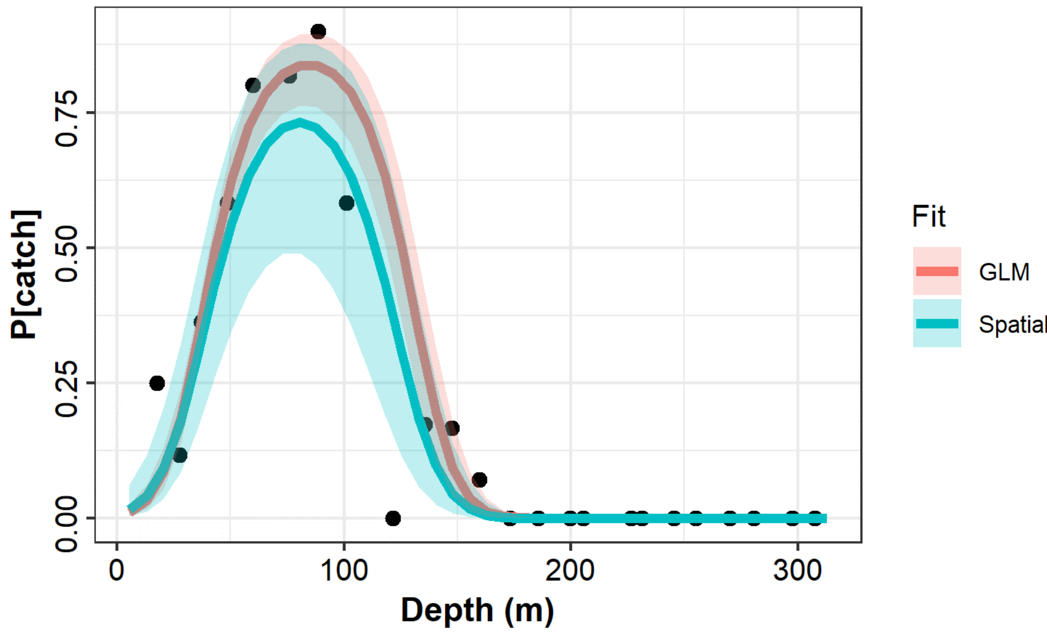

Figure 9. The predicted relationship between depth and Pygmy Whitefish probability of occurrence using the GLM and spatial INLA models. Depth was fit as a second degree polynomial (reproduced from van der Lee and Koops 2020).

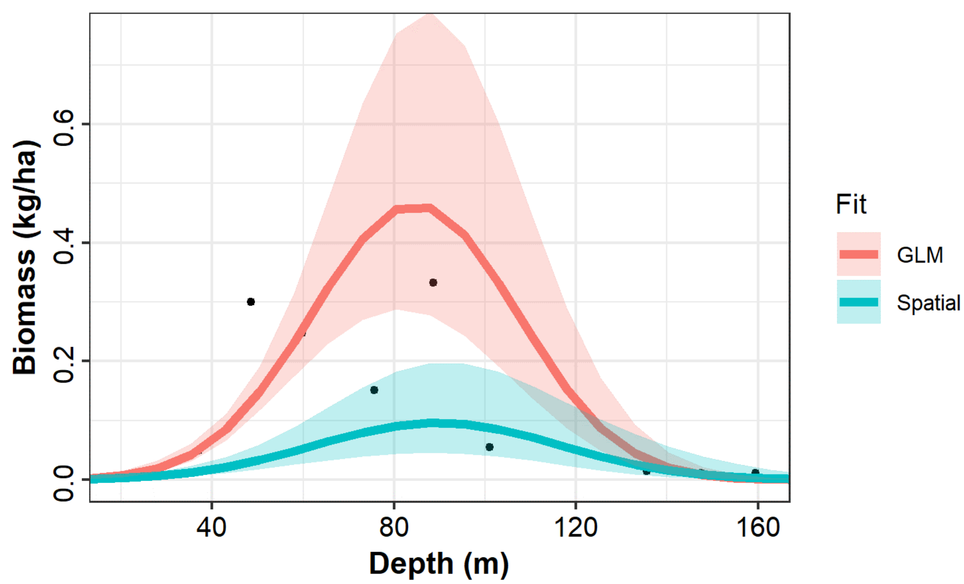

Figure 10. The predicted relationship between depth and Pygmy Whitefish biomass (kg/ha) using the GLM and spatial INLA models. Depth was fit as a second degree polynomial (reproduced from van der Lee and Koops 2020).

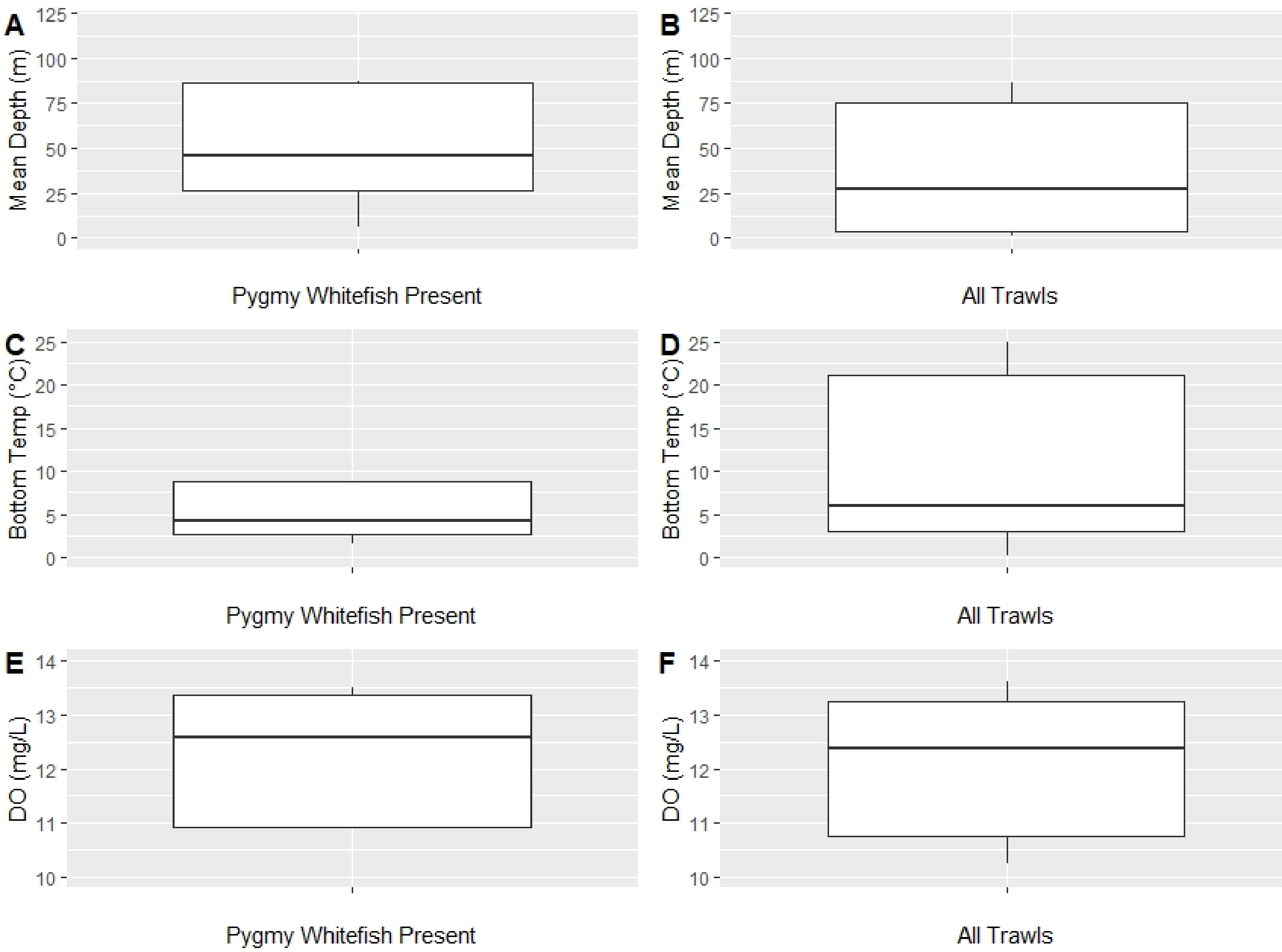

*Figure 11. Depth (A), bottom temperature (C), and dissolved oxygen (DO; E) for Pygmy Whitefish captured from Lake Superior from 1963–2018. The depth (B), bottom temperature (D), and dissolved oxygen (F) for all trawls for that time period are shown for comparison. Boxes represent the 95th percentile of captures and Y-error bars extend from the hinge to the largest value no further than 1.5 * interquartile range from the hinge. Depth was calculated as the mean of the trawl start and end depth. Data provided by Mark Vinson, USGS.*

FUNCTIONS, FEATURES AND ATTRIBUTES

A description of the functions, features, and attributes associated with Pygmy Whitefish (DU5) habitat can be found in Table 1. The habitat required for each life stage has been assigned a function that corresponds to a biological requirement of Pygmy Whitefish. For example, individuals in the larval to juvenile life stage require habitat for nursery purposes. In addition to the habitat function, a feature has been assigned to each life stage. A feature is considered to be the structural component of the habitat necessary for the survival or recovery of the species. Habitat attributes have also been provided, describing how the features support the function for each life stage. This information is provided to guide any future identification of critical habitat for this species.

Table 1. Summary of the essential functions, features and attributes for each life stage of Pygmy Whitefish (DU5). Habitat attributes from published literature and USGS capture records have been used to determine the habitat attributes required for the delineation of critical habitat.

			Habitat Attributes		
Life Stage	**Function**	**Feature(s)**	**Scientific Literature**	**Current Records**	**For Identification of Critical Habitat**
Adult (Age 2+ [onset of sexual maturity])	Feeding Cover	Nearshore areas with deep water	• Depth of capture ranged from 18–89 m with the majority captured from 55–70 m (Scott and Crossman 1973); • Most individuals from Keweenaw Bay found at depths ranging from 46–71 m, but individuals were caught at all depths sampled (11–101 m; Eschmeyer and Bailey 1955); • Waters with temperatures less than 10 °C (COSEWIC 2016); • Dissolved oxygen levels greater than 5 mg/L (COSEWIC 2016)	• There is > 50% probability of catch at depths ranging from 50–110 m (Figure 9; van der Lee and Koops 2020; USGS unpublished data). Peak biomass is predicted to occur from 80–95 m (Figure 10; van der Lee and Koops 2020; USGS unpublished data). • USGS data from bottom trawls conducted between 1963 and 2018 show that ~ 75% of individuals in Lake Superior inhabited waters ranging from 2.5 to 5.5 °C (USGS unpublished data) • The majority of individuals were found in waters with dissolved oxygen levels ranging from 12.5– 13 mg/L (USGS unpublished data)	• Depths ranging from 50 to 110 m
Spawn to hatch	Spawning	Shallow nearshore waters with coarse gravel substrate, hypothetically	• Spawning has not been observed	• No records	• Unknown
Young of the Year (YOY) and juvenile	Nursery Feeding Cover	Nearshore areas with deep water	• May occupy shallower depths than adults (Gorman et al. 2012)	• Same as adults	• Presumed to be the same as adults

Element 5: *Provide information on the spatial extent of the areas in Pygmy Whitefish (DU5) distribution that are likely to have these habitat properties.*

The spatial extent of areas likely to have the habitat properties outlined in Table 1 has been estimated for adults. Habitat for the adult life stage does not appear to be limiting as vast areas of Lake Superior have sufficient depth for Pygmy Whitefish. Using depth as the sole predictor of occurrence, van der Lee and Koops (2021) estimated 9,871 km^2 (CI: 1,142–24,798 km^2) of suitable habitat in Lake Superior. Despite this projection, Pygmy Whitefish adults have not been detected in many of these areas indicating a need to better understand the processes that influence Pygmy Whitefish occupancy. However, important habitat attributes for early life stages (spawn to hatch, juvenile) are currently unknown, thereby preventing similar spatial estimates of available habitat for those life stages.

Element 6: *Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.*

Pygmy Whitefish is found in the vast deep water habitats in nearshore and offshore areas of Lake Superior. Given that the species does not utilize tributary streams, there are no known spatial configuration constraints that would limit connectivity. Non-zero densities of the species exist throughout suitable depth ranges. Populations structure is not well resolved.

Element 7: *Evaluate to what extent the concept of residence applies to the species, and if so, describe the species' residence*

Residence is defined in SARA as a "dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating". Residence is interpreted by DFO as being constructed by the organism. In the context of the above narrative description of habitat requirements for YOY, juvenile, and adult life stages, Pygmy Whitefish (DU5) individuals do not construct residences during their life cycle.

THREATS AND LIMITING FACTORS TO THE SURVIVAL AND RECOVERY

Element 8: *Assess and prioritize the threats to the survival and recovery of the Pygmy Whitefish DU5*

THREAT CATEGORIES

A paucity of information exists about threats to Pygmy Whitefish in DU5. COSEWIC (2016) noted the potential importance of invasive species, pollution, and climate change. However, the impact of these factors on Pygmy Whitefish is poorly understood. Factors such as predation from native fishes may be limiting population growth. Threat classes presented below follow the IUCN threat classification framework (Salafsky et al. 2008) as used by (COSEWIC 2016). Threats identified as negligible by COSEWIC (2016) are not included in this research document. Owing to the lack of definitive information about population structure, threats to Pygmy Whitefish have been summarized across the entirety of the DU5 range.

Pollution

Degradation of the preferred habitat of Pygmy Whitefish may result from household sewage and urban waste water, industrial effluents, and airborne pollutants (e.g., mercury), the majority of which are confined to shoreline areas (COSEWIC 2016). Point sources of pollution include sewage treatment plant releases, primarily in the Thunder Bay area, and effluents from industries such as paper mills and mining operations. Relevant industrial sources of pollutants include gold mining near Michipicoten Bay and a pulp and paper industry in Terrace Bay. However, given the large lake area to watershed ratio of Lake Superior, as well as the depth preference of Pygmy Whitefish, the impact of industrial pollutants may be lessened relative to other fishes experiencing contaminant effects in the Great Lakes basin (COSEWIC 2016). Airborne pollutants are of greater concern with the majority of contaminant loadings in Lake Superior a result of atmospheric deposition (Eisenreich and Strachan 1992). Airborne pollutants include chemicals and heavy metals such as mercury, PCBs (polychlorinated biphenyls), dioxins (polychlorinated dibenzodioxins), PCDFs (polychlorinated dibenzofurans), and toxaphene. These contaminants can negatively impact fish through bioaccumulation in their diet or by direct absorption. Mercury's highly toxic form, methylmercury, can bioaccumulate in fishes and may impair life history processes including increased mortality, reduced growth rates and fecundity, and changes in age at maturation (Weis 2009, Amundsen et al. 2011). Mercury in Cisco has increased in Lake Superior since the early 2000s (Visha et al. 2018). However, the presence of contaminants (including mercury) has not been investigated for Pygmy Whitefish.

The concentration of PCBs in the water column tend to increase with depth in Lake Superior (Jurado et al. 2007, Ruge et al. 2018) but these contaminants have been declining in Lake Superior sediments and biota annually (Smith 2000). However, PCBs have the potential to bioaccumulate in Pygmy Whitefish as the most dominant prey item in the profundal zone, *Diporeia hoyi*, feed on surficial particulate matter that contain higher concentrations of contaminants (Nalepa and Landrum 1988). *Diporeia* spp. is an important component of the diet of Pygmy Whitefish. This prey item has recently been identified as decreasing in abundance in Lake Superior (Mehler et al. 2018). Although it is unlikely that pollution has contributed to lake-wide decline in this amphipod, *Diporeia* has decreased in abundance in areas contaminated by copper and pulp mill effluent in Lake Superior in the past (Wal 1977, Kraft 1979). Current densities of *Diporeia* in deep water habitat are believed not to be limiting to Pygmy Whitefish.

Despite knowledge of contaminants within related species (e.g., Cisco) and potential bioaccumulation within prey items (e.g., *Diporeia*), it is unlikely that current levels of contaminants (if any) within Pygmy Whitefish are contributing to reproduction failure or other meaningful changes in vital rates given the short opportunity for bioaccumulation in Pygmy Whitefish.

Invasive and other problematic species and genes

There are a total of 20 introduced fish species that are established in the Lake Superior basin (Roth et al. 2013). This includes, but is not limited to, Rainbow Smelt (*Osmerus mordax*), Ruffe (*Gymnocephalus cernuus*), Alewife (*Alosa pseudoharengus*), four Pacific salmon species (*Oncorhynchus* spp.), Brown Trout (*Salmo trutta*), and Round Goby (*Neogobius melanostomus*). Of these introduced fishes, only the first four were detected in USGS nearshore bottom trawl surveys in 2017 with Rainbow Smelt being the most common, by number, of any fish species in those trawls (USGS 2018).

A list of non-native fishes present in Lake Superior is given in Table 2 along with depth and diet preference. The impact of introduced fishes on Pygmy Whitefish is unknown but negative effects could occur through multiple direct and indirect pathways. For instance, species likely to be found at depths occupied by Pygmy Whitefish, such as Rainbow Smelt and Ruffe, could impact Pygmy Whitefish directly through competitive or predatory interactions. Predation by Rainbow Smelt on eggs/larvae has been implicated in the decline and extirpation of fishes in other lakes in the Great Lakes region (Evans and Waring 1987, Hrabik et al. 1998, Hrabik et al. 2001). However, limited co-occurrence at depth between Rainbow Smelt, Ruffe and adult Pygmy Whitefish may minimize direct negative impacts. Recruitment of Cisco has been negatively correlated with the biomass of Rainbow Smelt in Lake Superior (Rook et al. 2013) but the mechanism underlying this relationship is poorly known. Predation or direct competition by Pacific salmonids with Pygmy Whitefish is likely not substantial given the lack of shared habitat use. Indirect effects, whereby the collective presence of introduced fishes lead to lake-wide changes in food supply or energy transfer, may be more relevant for Pygmy Whitefish.

In addition to fishes, the invasive spiny water flea (*Bythotrephes longimanus*) has contributed to food web changes in Lake Superior which may directly or indirectly affect Pygmy Whitefish. For instance, *B. longimanus* has been implicated in top-down effects on cladoceran biomass in Lake Superior (Pawlowski et al. 2017). However, cladocerans appear to comprise a very small portion of the Pygmy Whitefish diet (Eschmeyer and Bailey 1955) indicating that direct impacts from *B. longimanus* are likely minimal. *B. longimanus* has not been implicated in changes in biomass of other crustaceans such as copepods, an important food source for juvenile Pygmy Whitefish.

Invasive Dreissenid mussels (*Dreissena bugensis* and *Dreissena polymorpha*) are not widespread throughout Lake Superior. However, localized populations of Dreissenid mussels exist in western portions of the lake such as the St. Louis River estuary and near the Apostle Islands (Trebitz et al. 2019). Dreissenid mussels have been implicated in the decline of *Diporeia* spp. in Lake Michigan with competition for food resources and/or a foreign agent associated with Dreissenid biodeposits hypothesized as potential causes for this decline (Nalepa et al. 2009). As Dreissenid populations tend to be localized in Lake Superior, the recent lake-wide decline in *Diporeia* spp. is likely due to other factors. However, if Dreissenid populations increase in Lake Superior in the future there may be increased impacts for *Diporeia* spp. Significant future declines in the abundance of *Diporeia* spp. would undoubtedly have measurable effects in the offshore and nearshore fish communities of Lake Superior including Pygmy Whitefish.

Although the potential exists for introduced fishes and invertebrates to impact Pygmy Whitefish through multiple direct or indirect mechanisms, there is insufficient evidence to suggest that the current low density of Pygmy Whitefish within DU5 is the result of these interactions.

Table 2. Depth use and diet of introduced fish species present in Lake Superior. Depth and diet have been summarized based on current literature.

Species	Depth Preference (m)	Diet	Reference
Alewife	< 75	Crustaceans	Bronte et al. 1991, Coker et al. 2001
Atlantic Salmon	2–18	Fishes/Crustaceans	Lane et al. 1996, Lackey 1970, Coker et al. 2001
Brown Trout	0–47	Molluscs/Other/Insects/ Fishes/Crustaceans	Nettles 1983, Coker et al. 2001
Chinook Salmon	15–60	Fishes	Eakins 2019, Coker et al. 2001
Coho Salmon	16–60	Crustaceans/Insects/Fishes	Eakins 2019, Coker et al. 2001
Common Carp	0–5	Macrophytes/Crustaceans/ Annelids/Molluscs/Insects	Lane et al. 1996, Coker et al. 2001
Fourspine Stickleback	0–4	Phytoplankton/Crustaceans	Blouw and Hagen 1981, Coker et al. 2001
Freshwater Drum	< 18	Fishes/Molluscs/Insects/ Crustaceans	Lane et al. 1996, Coker et al. 2001
Goldfish	0–2	Annelids/Macrophytes/ Crustaceans/Molluscs/ Insects	Lane et al. 1996, Coker et al. 2001
Margined Madtom	0–1	Fishes/Insects/Crustaceans	COSEWIC 2002, Coker et al. 2001
Pink Salmon	6–36	Crustaceans	Eakins 2019, Coker et al. 2001
Rainbow Smelt	< 50	Fishes/Insects/Annelids/ Crustaceans/Fish eggs	Heist and Swenson 1983, Rasmussen 1974, Coker et al. 2001
Rainbow Trout	2–10	Fishes/Molluscs/Annelids/ Crustaceans/Insects	Lane et al. 1996, Coker et al. 2001
Round Goby	0–73	Fish eggs/ Fishes/Insects/Annelids/ Molluscs/Crustaceans	Lane et al. 1996, Schaeffer et al. 2005, Coker et al. 2001
Ruffe	0.2–205	Fish eggs/ Molluscs/Annelids/ Insects/Crustaceans	Gutsch 2017, Coker et al. 2001
Sea Lamprey	60–150; any depth	Fishes	Applegate 1950, Johnson 1969 Morman et al. 1980, Coker et al. 2001
Threespine Stickleback	0–55	Fishes/Fish Eggs/Annelids/ Crustaceans/Molluscs/ Insects	Stedman and Bowen II 1985, Lane et al. 1996, Coker et al. 2001
Tubenose Goby	0–7	Crustaceans/Insects	Lane et al. 1996, Kocovsky et al. 2011, Coker et al. 2001
White Perch	0–40	Molluscs/Annelids/Insects/ Fishes/Crustaceans	Stanley and Danie 1983, Lane et al. 1996, Coker et al. 2001

Climate change and severe weather

A changing climate can negatively impact fishes through increases in water and air temperature, changes (decreases) in water level, shortened duration of ice cover, increases in the frequency of extreme weather events, emergence of disease, and shifts in predator-prey dynamics (Lemmen et al. 2004). This includes food web changes that are occurring in lower trophic levels. For instance, Bramburger et al. (2017) demonstrated that mean cell size of phytoplankton has decreased in Lake Superior and the Great Lakes in general which is reflective of increasing water surface temperatures. Size decreases could impact the availability and quality of food for fishes in higher trophic levels (Bramburger et al. 2017). No studies have directly evaluated the impacts of climate change to Pygmy Whitefish in Lake Superior but insights can be gained from studies of other designatable units and other fishes in Lake Superior. Surface water temperatures are increasing rapidly for Lake Superior and have reduced preferred habitat for deep cold water species such as Siscowet Lake Trout (*Salvelinus namaycush*; Austin and Colman 2007, Cline et al. 2013). The decrease in preferred habitat is primarily due to a reduction in the extent and duration of winter ice cover and increasing length of summer stratification (Austin and Colman 2007). Warming waters have also been implicated in the decreased body condition of two species of coregonines in Northwestern Ontario (Rennie et al. 2010). Future warming is likely to exclude cold water fishes from nearshore habitats in Lake Superior which is consistent with climate forecasting for cool water and cold water fishes in Lake Michigan (Magnuson et al. 1990, Cline et al. 2013). Exclusion, however, is likely to be influenced by species-specific tolerances to temperature as well as other biotic and abiotic factors such as dissolved oxygen, prey availability, and predation.

A study on Pygmy Whitefish in Washington State found that high flow events in spawning rivers could negatively affect reproductive success due to scour (Barnett and Paige 2012). Reproductive success of Pygmy Whitefish in Lake Superior may also be impacted by lack of ice cover and the resulting increase of storm events which would increase egg mortality. Although spawning in Lake Superior has not been observed, there are multiple ways in which the effects of climate change could be impacting egg survival. The specific tolerance to changing water temperatures and oxygen levels is unknown for Pygmy Whitefish in Lake Superior. However, one Pygmy Whitefish population in British Columbia appears to tolerate warmer temperatures and low oxygen levels for short durations. This population is unique to that particular watershed as the lake is small and shallow with other whitefish species absent (Zemlak and McPhail 2006). Despite the apparent short-term tolerance to warm waters by one population in western Canada, further research is required to evaluate whether such responses are also expected within DU5.

THREAT ASSESSMENT

The threat assessment was completed at a lake-wide scale following guidelines provided in DFO (2014). Each threat was ranked in terms of the threat Likelihood of Occurrence (LO), threat Level of Impact (LI) and Causal Certainty (CC). The Likelihood of Occurrence was assigned as Known, Likely, Unlikely, Remote, or Unknown, and refers to the probability of a specific threat occurring for a given population over 10 years or 3 generations, whichever is shorter. The Level of Impact was assigned as Extreme, High, Medium, Low, or Unknown and refers to the magnitude of the impact caused by a given threat and the level to which it affects the survival or recovery of the population (Table 3). The level of certainty associated with each threat was assessed and classified as: 1 = very high, 2 = high, 3 = medium, 4 = low, and 5 = very low. The Population-Level Threat Occurrence (PTO), Threat Frequency (PTF), and Threat Extent (PTE) were also evaluated and assigned a status based on the definitions outlined in Table 3 (Table 4). The Likelihood of Occurrence and Level of Impact for each population were subsequently combined in the Threat Risk Matrix (Table 5) resulting in the DU-Level Threat Risk (Table 6). As insufficient information exists about population structure in Lake Superior, threats were assessed at the lake-wide level; therefore, the population-level threat evaluation is similar to the DU-level threat risk.

Table 3. Definition and terms used to describe likelihood of occurrence (LO), level of impact (LI), causal certainty (CC), population level threat occurrence (PTO), threat frequency (PTF), and threat extent (PTE) reproduced from DFO (2014).

Term	Definition
Likelihood of Occurrence (LO)	
Known or very likely to occur (K)	This threat has been recorded to occur 91–100%.
Likely to occur (L)	There is 51–90% chance that this threat is or will be occurring.
Unlikely (UL)	There is 11–50% chance that this threat is or will be occurring.
Remote (R)	There is 1–10% or less chance that this threat is or will be occurring.
Unknown (U)	There are no data or prior knowledge of this threat occurring or known to occur in the future.
Level of Impact (LI)	
Extreme (E)	Severe population decline (e.g. 71–100%) with the potential for extirpation.
High (H)	Substantial loss of population (31–70%) or threat would jeopardize the survival or recovery of the population.
Medium (M)	Moderate loss of population (11–30%) or threat is likely to jeopardize the survival or recovery of the population.
Low (L)	Little change in population (1–10%) or threat is unlikely to jeopardize the survival or recovery of the population.
Unknown (U)	No prior knowledge, literature or data to guide the assessment of threat severity on population.
Causal Certainty (CC)	
Very high (1)	Very strong evidence that threat is occurring and the magnitude of the impact to the population can be quantified.
High (2)	Substantial evidence of a causal link between threat and population decline or jeopardy to survival or recovery.
Medium (3)	There is some evidence linking the threat to population decline or jeopardy to survival or recovery.
Low (4)	There is a theoretical link with limited evidence that threat is leading to a population decline or jeopardy to survival or recovery.
Very low (5)	There is a plausible link with no evidence that the threat is leading to a population decline or jeopardy to survival or recovery.
Population-Level Threat Occurrence (PTO)	
Historical (H)	A threat that is known to have occurred in the past and negatively impacted the population.
Current (C)	A threat that is ongoing, and is currently negatively impacting the population.
Anticipatory (A)	A threat that is anticipated to occur in the future, and will negatively impact the population.
Population-Level Threat Frequency (PTF)	
Single (S)	The threat occurs once.
Recurrent (R)	The threat occurs periodically, or repeatedly.
Continuous (C)	The threat occurs without interruption.
Population- Level Threat Extent (PTE)	
Extensive (E)	71–100% of the population is affected by the threat.
Broad (B)	31–70% of the population is affected by the threat.
Narrow (NA)	11–30% of the population is affected by the threat.
Restricted (R)	1–10% of the population is affected by the threat.

Table 4. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-Level Threat Occurrence (PTO), Population- Level Threat Frequency (PTF) and Population-Level Threat Extent (PTE) for Pygmy Whitefish, Great Lakes – Upper St. Lawrence populations (DU5).

	Lake Superior						
	LO	LI	CC	PTO	PTF	PTE	Ref
Pollution	K	U	5	H,C,A	C	E	-
Invasive and other problematic species and genes	K	U	5	H,C,A	C	E	-
Climate change and severe weather	K	U	5	C, A	C	E	-

Table 5. The Threat Level Matrix combines the Likelihood of Occurrence and Level of Impact rankings to establish the Threat Level for Pygmy Whitefish, Great Lakes – Upper St. Lawrence populations (DU5). The resulting Threat Level has been categorized low, medium, high or unknown.

		Level of Impact				
		Low	Medium	High	Extreme	Unknown
Likelihood of Occurrence	Known or very likely	Low	Medium	High	High	Unknown
	Likely	Low	Medium	High	High	Unknown
	Unlikely	Low	Medium	Medium	Medium	Unknown
	Remote	Low	Low	Low	Low	Unknown
	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

Table 6. Threat Level Assessment for Pygmy Whitefish, Great Lakes – Upper St. Lawrence populations (DU5), resulting from an analysis of both the Threat Likelihood and Threat Impact. The number in brackets refers to the level of certainty associated with the threat impact (1 = Very High; 2 = High; 3 = Medium; 4 = Low; 5 = Very Low).

Threat	Threat Risk
Pollution	Unknown (5)
Invasive and other problematic species and genes	Unknown (5)
Climate change and severe weather	Unknown (5)

LIMITING FACTORS

Pygmy Whitefish is found in cold deep waters and has likely always existed at low population density. However, predation by native predators such as Lean and Siscowet Lake Trout and Burbot (*Lota lota*) likely play a role in the low density of Pygmy Whitefish in DU5. The relationship between current population declines in Pygmy Whitefish and predation by native species is not well resolved. The recent decline in Pygmy Whitefish has coincided with a decline in lake-wide Lean Lake Trout biomass from nearshore bottom trawls while Siscowet Lake Trout biomass has remained stable since 1990 (USGS 2018). These trends, however, should include the caveat that bottom trawls are not the ideal gear type to assess Lake Trout abundance (Mark Vinson, USGS, pers. comm.). As a result, Lake Trout abundance trends from gill nets does not always correspond with trends observed in bottom trawls. Several authors have hypothesized that the recovery of Lake Trout from historical lows and recent evidence of a decline in prey fish biomass suggests that top predators may be food-limited in Lake Superior (Negus et al. 2008) which is supported by the decline in the commercial CPUE of deep water ciscoes as well as declines in Rainbow Smelt biomass (Gorman 2007, 2012). This hypothesis may also suggest increasing predation on Pygmy Whitefish by native predatory species but there is currently little direct evidence that Lake Trout populations have contributed to recent declines in Pygmy Whitefish abundance.

Element 9: *Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4-5 and provide information on the extent and consequences of these activities.*

The threats most relevant to Pygmy Whitefish (DU5) habitat are pollution and climate change, although the level of impact of these two threats is unknown. Heavy metals and other contaminants from airborne sources are lake-wide and are the primary sources of contaminants in Lake Superior. Effluents from urban waste water systems and industrial sources such as gold mining and pulp and paper mills also contribute to contaminant loads in the system. Point sources of pollution include sewage treatment plant releases in the Thunder Bay area and effluents from industries such as paper mills and mines near Michipicoten and Terrace bays. Impacts to Pygmy Whitefish have not been documented as a result of pollution in Lake Superior but the potential exists for negative direct and indirect effects to Pygmy Whitefish populations.

Element 10: *Assess any natural factors that will limit the survival and recovery of the Pygmy Whitefish DU5.*

Pygmy Whitefish populations may be limited by predation in Lake Superior due to the increase in population abundance of Lake Trout, concordant with a decline in other prey fishes (e.g., deep water ciscoes). Recent evidence suggests that top predators in Lake Superior may be at carrying capacity (Negus et al. 2008) which is supported by declines in deep water ciscoes and Rainbow Smelt. Bottom-up effects on Pygmy Whitefish have not been discussed in the literature. However, it is feasible that prey densities could influence survival and population growth. *Diporeia* spp. are the dominant benthic macroinvertebrate in Lake Superior and declines in nearshore abundance of this amphipod (Mehler et al. 2018) coincides with a decrease in Pygmy Whitefish over the last five years (USGS unpublished data).

Element 11: *Discuss the potential ecological impacts of the threats identified in element 8 to Pygmy Whitefish DU5 and other co-occurring species. List the possible benefits and disadvantages to the target species and other co-occurring species that may occur if the threats are abated. Identify existing monitoring efforts for the target species and other co-occurring species associated with each of the threats, and identify any knowledge gaps.*

The greatest threats to Pygmy Whitefish in Lake Superior are pollution, invasive species, and climate change, yet the impact of each of these threats on the species is unknown. Pollutants such as heavy metals can cause neurological damage and chemicals like dioxins are endocrine disruptors that can impede the production of hormones for vital life processes. Indirect effects of pollutants include impacts to preferred prey such as *Diporeia* spp. Food webs can also be disrupted through the introduction of invasive species such as Dreissenid mussels and *Bythotrephes* which can indirectly impact Pygmy Whitefish. Furthermore, climate change can affect environmental variables such as water temperature and dissolved oxygen levels which can impact Pygmy Whitefish both directly and indirectly. For instance, climate change can exclude organisms from a particular area when environmental variables exceed the physiological tolerances. Indirect effects include shifting food webs as a result of changes to water quality variables. These three threats could be impacting Pygmy Whitefish populations but the magnitude of these threats is unknown.

SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

Element 16: *Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in element 8 and 10).*

Threats to species survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects that could result from works or undertakings associated with projects or activities in Pygmy Whitefish DU5 habitat. In previous RPAs, the DFO Program Activity Tracking for Habitat (PATH) database was queried for a variety of works, undertakings, and activities that occurred within a species known distribution during the previous five years that could harm or destroy its habitat. In the case of Pygmy Whitefish, this review of activities was not provided as only a handful of projects would result and these activities would be limited almost entirely to shoreline areas and whose impacts would be largely negligible to this deep water species. In a case where an activity threatens Pygmy Whitefish (DU5) habitat, habitat-related threats can be linked to the Pathways of Effects developed by DFO's Fish and Fish Habitat Protection Program (FFHPP) in Coker et al. (2010). The document provides guidance on mitigation measures for 19 Pathways of Effects for the protection of aquatic species at risk in the Central and Arctic Region (Coker et al. 2010). Coker et al. (2010) should be referred to when considering mitigation and alternative strategies for habitat-related threats. Additional mitigation and alternative measures related to non-habitat related threats such as invasive species are listed below.

Invasive and other problematic species and genes

As discussed in the Threats and Limiting Factors section, Rainbow Smelt, Ruffe, and *Bythotrephes* may be negatively impacting Pygmy Whitefish populations in Lake Superior.

Mitigation

- Monitor for invasive species that may negatively affect Pygmy Whitefish populations directly, or negatively affect Pygmy Whitefish preferred habitat.
- Develop a plan to address potential risks, impacts, and proposed actions if monitoring detects the arrival or establishment of an invasive species.
- Establish "Safe Harbours" in areas known to have suitable Pygmy Whitefish habitat. Safe Harbours work to minimize the impact or prevent the introduction of invasive species through best management practices.
- Implement a rapid response plan if invasive species are detected to eradicate or control them.
- Introduction of a public awareness campaign and encourage the use of existing invasive species reporting systems.

Alternatives

- Unauthorized introductions
  - There are no alternatives for unauthorized introduction because unauthorized introductions should not occur.
- Authorized introductions
  - Use only native species.
  - Follow the National Code on Introductions and Transfers of Aquatic Organisms for all aquatic organism introductions (DFO 2017).

Element 17: *Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 15).*

The mitigation measures outlined above are consistent with the goal of increasing survivorship by reducing threats to Pygmy Whitefish from invasive species. Mitigation measures for habitat-related threats such as waste water effluents are outlined in Coker et al. (2010) and provide a means to increase survivorship, provided such threats are causing mortality. However, current knowledge on how threats to Pygmy Whitefish impact their survival and habitat is limited. Further research is required to identify why Pygmy Whitefish populations in Lake Superior may be declining.

Element 18: *If current habitat supply may be insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets.*

Deep water habitat for Pygmy Whitefish in Lake Superior is not limiting at this time. Refer to van der Lee and Koops (2020) for estimated projections of habitat availability as a function of the depth preference of the species.

SOURCES OF UNCERTAINTY

Few targeted studies have been conducted on Pygmy Whitefish in Lake Superior (DU5) due to its low population abundance and relatively recent discovery in the Great Lakes basin. Although the species is widespread in Lake Superior, occurrence and biomass are not fully explained by habitat variables such as depth, dissolved oxygen, and water temperature. Further research is required to determine the potential abiotic and biotic variables that influence occurrence and biomass patterns including limnological factors that could influence recruitment and population dynamics. Lack of knowledge on life history including spawning behaviour (timing, site selection), fecundity, maturity, sex ratio, age-length relationships, and the habitat features necessary for egg and juvenile development, are key gaps in the current understanding of this species. Knowledge gaps on habitat use necessitated the inference of habitat requirements for larvae and juveniles from the adult life stage in this document. Given the small physical size of this species, the potential for multiple reproductively isolated populations of Pygmy Whitefish exists within Lake Superior. However, targeted research about dispersal and genetic exchange within DU5 has not been conducted. The factors that influence population growth, whether top-down effects of predators or bottom-up effects of prey availability, require further study. Threats such as pollution, invasive species, and climate change have the potential to impact population growth of Pygmy Whitefish but very little empirical information exists about how these threats are currently influencing Pygmy Whitefish in Lake Superior.

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