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Science Response 2023/038

INFORMATION FOR IDENTIFICATION OF CANDIDATE CRITICAL HABITAT OF LITTLE QUARRY LAKE BENTHIC AND LIMNETIC THREESPINE STICKLEBACKS (*GASTEROSTEUS ACULEATUS*)

Context

Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks (*Gasterosteus aculeatus*) are endemic to Little Quarry Lake on Nelson Island, British Columbia (BC). This benthic-limnetic species pair is one of three known extant and genetically distinct pairs found in BC. The benthic and limnetic forms differ genetically and in body morphology, habitat use, and feeding ecology (McPhail 1984; Ridgway and McPhail 1984; Bentzen and McPhail 1984; Bentzen et al. 1984). The pair are kept genetically distinct by low levels of hybridization attributed to a combination of morphological, behavioural, and ecological differences (Bentzen et al. 1984; Ridgway and McPhail 1984; Gow et al. 2008). The major potential threat to the two species is the introduction of invasive species, which can alter the habitat in such a way that could dissolve reproductive barriers and the ability of these two fish species to recognize mates, resulting in increased hybridization (cf. Taylor and Piercey 2018).

In 2015, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed both Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks as Threatened. The species are under consideration for listing under Schedule 1 of the *Species at Risk Act* (SARA; 2002). If listed, critical habitat (CH) must be identified as a part of the recovery strategy. Critical habitat is defined in the *Species at Risk Act* as "…*the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species*" [s. 2(1)]. Under SARA S.41.1(c) a species' critical habitat must be identified "to the greatest extent possible, based on the best available information, including the information provided by COSEWIC, and examples of activities that are likely to result in its destruction."

Fisheries and Ocean Canada (DFO) Species at Risk Program has requested science advice in support of the identification of candidate critical habitat necessary for the survival or recovery of Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks, which will be used to inform the identification of critical habitat under SARA. The specific objectives of this review are to:

Objective 1: Review information available on the habitat necessary for survival and recovery of Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks and identify the function, features, and attributes of this habitat across life stages.

Objective 2: Present candidate critical habitat spatial attributes.

This Science Response Report results from the May 30, 2023 regional peer review on the Information for identification of candidate critical habitat of Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks (*Gasterosteus aculeatus*).

Background

Little Quarry Lake Threespine Sticklebacks consist of two genetically distinct forms, a benthic and limnetic form, endemic to Little Quarry Lake on Nelson Island, southwestern BC (Gow et al. 2008). Little Quarry Lake is a small lake with a surface area of 22 ha with a small inlet stream and an artificially dammed outlet (Gow et al. 2008). Threespine Sticklebacks are the only fish species present in Little Quarry Lake (Gow et al. 2008). The absence of other fish species is considered important to the persistence of this sympatric species pair (DFO 2018).

Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks are genetically discrete (Gow et al. 2008; COSEWIC 2015), reproductively isolated from each other (Gow et al. 2008; COSEWIC 2015), and likely use different trophic niches as in other species pair lakes (Bentzen and McPhail 1984; Bentzen et al. 1984). The Little Quarry Lake Benthic and Limnetic Sticklebacks are likely similar to other benthic-limnetic stickleback pairs, where the limnetic form feeds on pelagic plankton and the benthic form feeds on invertebrates at the lake bottom (benthic) and close to shore (littoral) (Bentzen 1982; McPhail 1989). The limnetic form resides near the lake surface in the summer, moving to deeper water in the winter, while the benthic form resides in the littoral zone in the summer and occupies the lake bottom in the winter (McPhail 1989). There is, however, overlap in May-June when both limnetic and benthic males nest in the littoral zone (Bentzen et al. 1984; McPhail 1989). For spawning, the benthic form needs a vegetated littoral habitat, while the limnetic form needs a littoral region with a beach that has gently sloping bottom with substrate grain size from silt to gravel (COSEWIC 2015). Additionally, adequate and continued littoral, benthic, and pelagic productivity is necessary to enable feeding and growth of the benthic-limnetic stickleback pair.

The benthic and limnetic populations maintain their genetic uniqueness through reproductive barriers reducing hybridization. Adequate light transmission enabling visual mate recognition is considered necessary to reduce the threat of hybridization (COSEWIC 2015; DFO 2018). Further, to ensure segregated nest and juvenile rearing habitat, maintenance of gently sloping sediment (e.g., silt, sand, gravel) beaches and natural littoral macrophyte cover is needed (COSEWIC 2015; DFO 2018). Hybrid incompatibility in benthic-limnetic stickleback pairs is dependent on extrinsic/environmental factors; maintaining current environmental parameters contributes to the preservation of the sympatric stickleback species pairs (Hatfield and Schluter 1999; Thompson et al. 2022). Changes to these habitat variables can cause a breakdown in the benthic-limnetic stickleback pair's isolating mechanisms and increase the risk of hybridization (COSEWIC 2015; DFO 2018). Consequences of hybridization include mixing of these two populations causing a rapid collapse into a hybrid swarm as has been documented for the Enos Lake stickleback pair, and potential extinction of the species pair, as was the case for the Hadley Lake stickleback pair (COSEWIC 2015; DFO 2018; Taylor and Piercey 2018).

Analysis and Response

If an aquatic species is listed on Schedule 1 of SARA as *Threatened*, *Endangered* or *Extirpated*, DFO is required to identify and protect the species' critical habitat, to the extent possible based on the best available information. Critical habitat is defined under SARA as "*the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species*". Further, habitat of aquatic species is defined as "*spawning grounds and nursery, rearing, food supply, migration, and any other areas on which aquatic species depend directly or indirectly to carry out their life processes, or areas on which aquatic species formerly occurred and have the potential to be reintroduced.*" Critical habitat is typically identified in the species' recovery strategy and linked to the species' population and distribution objectives.

Scientific information on candidate critical habitat necessary for the survival or recovery of Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks should include the geographic location (e.g., coordinates); functions, features, and attributes; and a summary of habitat identification relative to population and distribution objectives (DFO 2015). This Science Response provides a review of available information that supports the identification of important habitat necessary for the survival and recovery of Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks, on Nelson Island, which will be used to inform the identification of critical habitat under SARA.

Information and Methods Used to Identify Candidate Critical Habitat

The intent of this Science Response is to provide information on important habitat in support of the identification of critical habitat. The information was derived from the COSEWIC Status Report (COSEWIC 2015), the Recovery Potential Assessment (RPA; DFO 2018), guidance for critical habitat identification (DFO 2015), the updated recovery strategy for similar populations (DFO 2019), and primary publications.

The approach used to delineate the candidate critical habitat for Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks is the bounding box approach (BBA). The BBA defines an area within which candidate critical habitat is found (DFO 2015). The BBA is applied when habitat features and attributes that support the species' life cycle functions can be described but their exact location may vary or specific locations may be unknown (DFO 2015). The BBA is also an appropriate method to use when the features and attributes shift from time to time, but are mostly stationary. In order for a site to be considered candidate critical habitat, it must be within the bounding box and represent the described functions, features, and attributes necessary for the survival or recovery of the species (DFO 2015).

Response to Objective 1: Review Information on Critical Habitat

Table 1 summarizes the best available knowledge of the functions, features, and attributes for each life stage of Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks. If the features as described in Table 1 are present and capable of supporting the associated life-cycle function(s), the feature(s) is considered candidate critical habitat for the species, even though some of the associated attributes may be present or might be outside of the range indicated in the table (DFO 2015).

Table 1. Summary of the biophysical features and attributes of important habitat for Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks that support one or more life-cycle functions necessary for the species' survival or recovery (modified from DFO 2018).

Life Stage	Function	Features	Attributes
Benthic and Limnetic eggs/embryos, and adults	Mate selection, spawning, nest creation and protection	• Littoral zone	• Low slope (e.g., silt, sand, gravel beaches) - Limnetic • Macrophyte cover - Benthic • Adequate light transmission (low turbidity, limit suspended solids) • Maintenance of lake chemistry values (e.g., temperature, pH, turbidity, total dissolved solids, dissolved oxygen, dissolved inorganic carbon, conductivity, nutrients) within current/historical range • Stable faunal community, free of aquatic invasive species
Benthic and Limnetic eggs/embryos, juveniles, and adults	Foraging, growth, and rearing	• Littoral zone	• Maintenance of lake chemistry values (e.g., temperature, pH, turbidity, total dissolved solids, dissolved oxygen, dissolved inorganic carbon, conductivity, nutrients) within current/historical range • Sufficient productivity and food supply; including plankton for Limnetics and benthic invertebrates for Benthics • Stable faunal community, free of aquatic invasive species
Limnetic juveniles and adults	Foraging, growth, and overwintering	• Lake pelagic zone	• Maintenance of lake chemistry values (e.g., temperature, pH, turbidity, total dissolved solids, dissolved oxygen, dissolved inorganic carbon, conductivity, nutrients) within current/historical range • Sufficient productivity and food supply, including plankton • Stable faunal community, free of aquatic invasive species
Benthic juveniles and adults	Foraging, growth, and overwintering	• Lake benthic and pelagic zones	• Maintenance of lake chemistry values (e.g., temperature, pH, turbidity, total dissolved solids, dissolved oxygen, dissolved inorganic carbon, conductivity, nutrients) within current/historical range • Sufficient productivity and food supply, including benthic invertebrates • Stable faunal community, free of aquatic invasive species
Benthic and Limnetic all life stages	Mate selection, spawning, nest construction, protection, foraging, rearing, growth, overwintering	• Riparian zone	• Intact and sufficient riparian vegetation for maintenance of lake chemistry values (e.g., temperature, pH, turbidity, total dissolved solids, dissolved oxygen, dissolved inorganic carbon, conductivity, nutrients) within current/historical range, through adequate filtration, infiltration, isolation, erosion, and subsidization processes • Adequate light transmission (low turbidity, limit suspended solids) through erosion and filtration processes

Life Stage	Function	Features	Attributes
		• Inlet stream habitat	• Maintenance of lake chemistry values (e.g. temperature, pH, turbidity, total dissolved solids, dissolved oxygen, dissolved inorganic carbon, conductivity, nutrients) within current/historical range • Sufficient productivity to support stable lake water levels and water quality parameters

Benthic and Limnetic Threespine Sticklebacks have unique morphological adaptations to their habitat and feeding style (Ridgway and McPhail 1984; COSEWIC 2015), and require access to their preferred lake habitat for their continued survival. Further, healthy functioning pelagic, benthic and littoral zones of the lake are necessary to maintain genetic distinction. The maintenance of the habitat features is believed to help constrain hybridization and therefore the maintenance of Benthic and Limnetic Threespine Sticklebacks (DFO 2018).

Visual mate recognition is necessary to ensure that reproduction only occurs among limnetic forms and only among benthic forms. Sufficient light transmission is necessary and required for both forms to successfully recognize mates and spawn (Boughman 2001). Hence, macrophyte beds and minimal alterations to the riparian zone to limit turbidity fluctuations and suspended solids in the water column, and maintain water quality is required (Hatfield 2009; Ormond et al. 2011; Richardson et al. 2010; DFO 2020). Additionally, an experimental study of pond- and aquarium-born and raised hybrid crosses showed that hybrid incompatibilities are environment-dependent (Thompson et al. 2022). Thus, maintaining current environmental parameters is necessary for the survival of the sympatric stickleback species.

The benthic-limnetic stickleback pair have considerable overlap in spawning time but differ in spawning habitat. Both macrophyte-covered and open, gently sloping littoral zones are required for segregated nesting and rearing habitats (Hatfield and Schluter 1996; DFO 2018). Limnetic males build nests and mate in unvegetated, open nesting locations (McPhail 1992; Hatfield and Schluter 1996), often in less than 1 m of water on submerged logs, in shallow bays with gravel or rocky substrates and, on firm muddy substrate (Hatfield 2001b). Benthic males prefer densely vegetated nesting locations, usually among *Chara* algae (McPhail 1992; Hatfield and Schluter 1996). They nest in deeper water than the limnetic form but usually in water less than 2 m deep (Hatfield 2001b). Depending on temperature, eggs take about a week to hatch and another 3-5 days until the larvae are free swimming (McPhail 1992). Males of both forms protect their nests until fry are about a week old, hence both need the littoral zone for foraging.

Current water quality, water levels, nutrient availability, and productivity in the littoral, benthic, and pelagic zones maintain foraging, growth, rearing, and overwintering of the benthic-limnetic species pair. Although there are no direct studies of the effects of changes in productivity on the survival or growth of Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks, changes to the environmental parameters may be detrimental to stickleback species pairs as these changes may reduce the type and/or supply of food resources (Ormond et al. 2011). Thus, the precautionary approach should be taken recommending limited fluctuations or changes in water level, chemistry and productivity for the whole lake. Such data specific to Little Quarry Lake have been published by Ormond et al. (2011). Furthermore, water from the inlet stream could support and contribute to water levels, water quality parameters, and productivity of, and transfer of nutrients to, the whole lake.

The lack of predation and competition, by either fish or invertebrates, likely enabled the diversification and persistence of this species pair. Introductions of non-native species have disrupted other stickleback species pairs; by example, the introduction of Signal Crayfish

(*Pacifastacus leniusculus*) resulted in the collapse of the Enos Lake Sticklebacks into a hybrid swarm (Kraak et al. 2005; Taylor et al. 2006; Velema et al. 2012). The presence of Signal Crayfish has been experimentally shown to reduce male limnetic stickleback's reproductive behaviour (Velema et al. 2012). Further, the introduction of Brown Bullhead (*Ameirus nebulosus*) likely caused the extinction of the Hadley Lake stickleback pair through nocturnal nest predation (Hatfield 2001a). Therefore, the current lake faunal composition should be maintained for the continued survival of both the benthic and limnetic forms in Little Quarry Lake.

Critical habitat for aquatic species often includes riparian areas that surround a waterbody as they provide important processes that are necessary for the survival or recovery of a species (DFO 2020). The amount of riparian area included in the identification of candidate critical habitat depends on the number of processes required by the species, i.e., critical habitat size increases with the number of processes (DFO 2020). There are five riparian processes necessary for this stickleback pair: filtration (i.e., the removal of matter from water), erosion (i.e., the wearing of soil from terrestrial sources by wind, water or gravity), subsidization (i.e., the transfer of energy, food, and structural components from the terrestrial zone to the aquatic habitat), infiltration (i.e., entry of surface water in soil), and isolation (i.e., spatial distancing of a place or thing from a disturbance; DFO 2020). These processes are required to maintain current and stable water quality parameters and productivity of the lake littoral, benthic, pelagic area and photic environment, which are essential for the survival of the stickleback pair.

Response to Objective 2: Candidate Critical Habitat Spatial Attributes

For Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks, candidate critical habitat is identified to the extent possible, using the best available information, including proxy information, and provides the functions and features necessary to support the species' life cycle processes. Based on the multitude of functions, features, and attributes, in various zones in the lake (Table 1), candidate critical habitat is therefore defined as the entirety of Little Quarry Lake as well as a minimum of 100 m of the inlet stream. Because of the lack of direct studies on Little Quarry Lake and the stickleback pair, it is unclear how much of the inlet stream is required (if any) to maintain water levels and water quality parameter, and whether the pair use or occupy part of the inlet stream. Using the precautionary approach, and until further studies are completed in the lake, a minimum of 100 m of the inlet stream is included in the candidate critical habitat, which aligns with advice for other freshwater species at risk (e.g., MacConnachie and Wade 2016). Additionally, given the high number of riparian processes necessary for the benthic-limnetic stickleback pair's survival (Table 1), candidate critical habitat is recommended to include a 30 m riparian zone buffer (DFO 2020) from the wetted perimeter surrounding the lake, along 100 m of the inlet stream, and on the unnamed island within Little Quarry Lake (Figure 1). As in recovery documents for other stickleback pairs (DFO 2019), the wetted perimeter is to be interpreted on the ground as the high water mark for the lake, stream, and wetland, respectively, as defined in the *Riparian Areas Protection Regulation* (BC Reg. 178/2019). The 30 m width of the recommended riparian zone is precautionary, as the direct and indirect roles of the riparian zone around the lake and inlet stream, and on the unnamed island, are not yet fully understood. To use the BBA and to facilitate mapping of the riparian zone, 18 locations were randomly selected along Little Quarry Lake and the inlet stream (Table 2; Figure 1).

Table 2. Markers and coordinates used to create the candidate critical habitat maps.

Location IDs	Latitude	Longitude
S1	49.66060	-124.1150559
S2	49.66191	-124.1132437
S3	49.66301	-124.1117990
S4	49.66448	-124.1095327
S5	49.66523	-124.1062787
S6	49.66447	-124.1047515
S7	49.66528	-124.1021633
S8	49.66509	-124.1012028
S9	49.66449	-124.1015355
S10	49.66395	-124.1026040
S11	49.66349	-124.1042587
S12	49.66217	-124.1066939
S13	49.66139	-124.1072174
S14	49.66101	-124.1079570
S15	49.66049	-124.1092895
S16	49.66015	-124.1103194
S17	49.66101	-124.1111166
S18	49.66075	-124.1121633

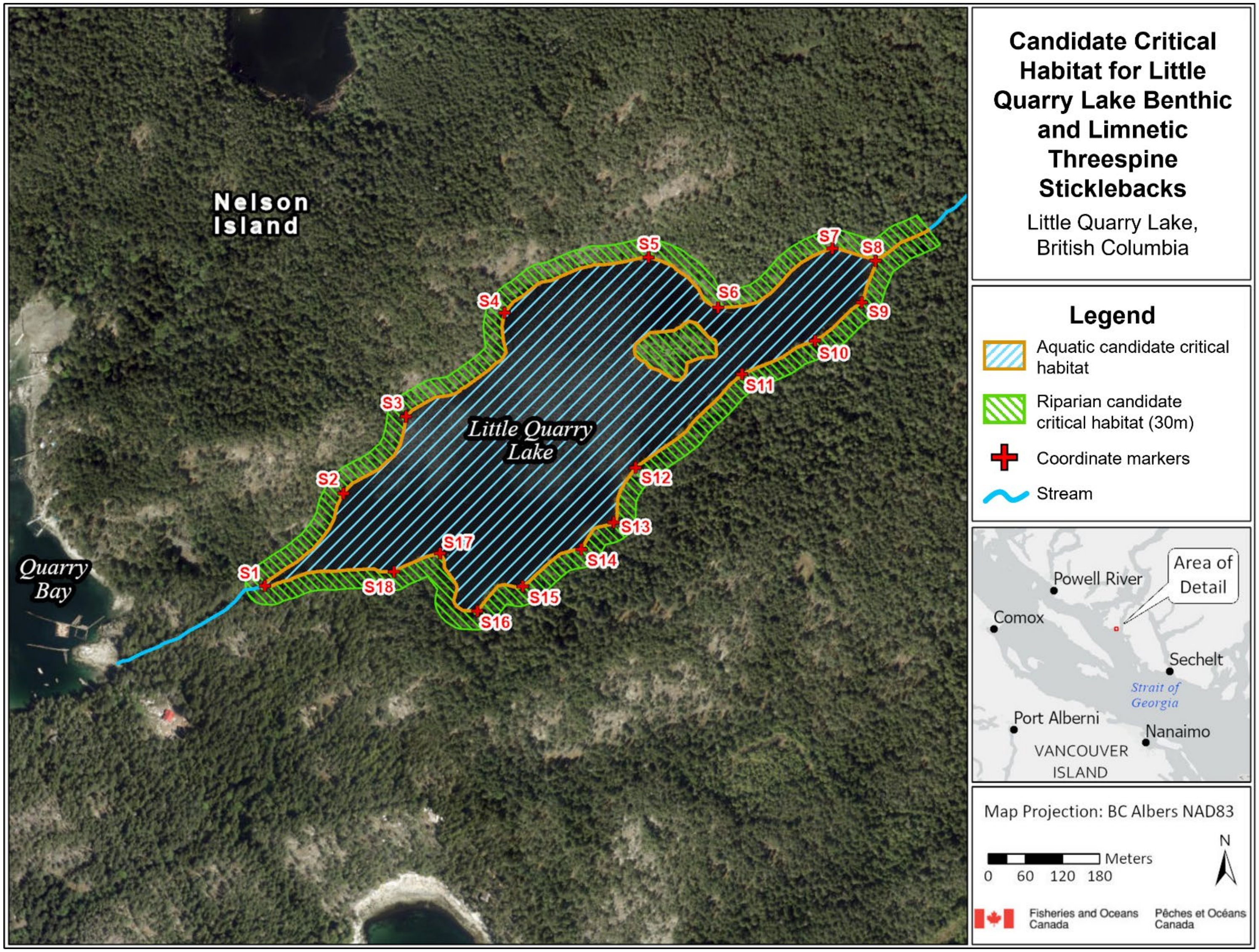

Figure 1. Candidate critical habitat for Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks on Nelson Island, British Columbia.

Conclusions

Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks are genetically distinct and endemic to Little Quarry Lake, BC. Due to their restricted distribution, and susceptibility to extinction from aquatic invasive species, the pair was assessed by COSEWIC as Threatened in 2015. Based on the best available information, the BBA outlining the functions, features, and attributes, including those of riparian zones, was used to identify candidate critical habitat (habitat necessary for the survival or recovery of the species) to the greatest extent possible.

Because there have been very few studies directly on Little Quarry Lake Benthic and Limnetic Threespine Sticklebacks, inferences based on the biology and habitat requirements of other similar benthic-limnetic stickleback pairs were made to identify candidate critical habitat. Therefore, it is recommended that future targeted studies on the Little Quarry Lake stickleback pair be undertaken, specifically their microhabitat use in the lake, the inlet stream, and around the unnamed island and how these habitats help maintain sympatry. It is also suggested that further research be conducted on riparian zones and function in relation to widths required for maintaining quality of aquatic habitats in addition to mate selection of species pairs. Furthermore, uncertainties remain around the functions, features, and attributes of the inlet stream as well as the riparian area around the lake, inlet stream, and of the unnamed island; further studies are recommended.

Contributors

Contributor	Affiliation
Rowshyra Castañeda	DFO Science, Pacific Region
Paul Grant	DFO Science, Pacific Region
Jocelyn Nelson	DFO Science, Pacific Region
Faith Yu	DFO Science, Pacific Region
Joy Wade	DFO Science, Pacific Region
Shannan May-McNally (reviewer)	DFO Science, National
Eric B. Taylor (reviewer)	University of British Columbia

Approved by

Andrew Thomson
Regional Director
Science Branch, Pacific Region
Fisheries and Oceans Canada

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Sources of Information

BC Reg. 178/2019. Riparian Areas Protection Regulation. Retrieved on 2023-07-10.

Bentzen, P. 1982. Specializations for alternate trophic niches by two forms of threespine stickleback *Gasterosteus*, co-existing in Enos Lake, Vancouver Island. M .Sc. thesis, Department of Zoology, University of British Columbia, Vancouver, B.C.

Bentzen, P., and McPhail, J.D. 1984. Ecology and evolution of sympatric sticklebacks (*Gasterosteus*): specialization for alternative trophic niches in the Enos Lake species pair. Can. J. Zool. 62: 2280-2286.

Bentzen, P., Ridgway, M.S., and McPhail, J.D. 1984. Ecology and evolution of sympatric sticklebacks (*Gasterosteus*): spatial segregation and seasonal habitat shifts in the Enos Lake species pair. Can. J. Zool. 62: 2436–2439.

Boughman, J.W. 2001. Divergent sexual selection enhances reproductive isolation in sticklebacks. Nature 411: 944–948.

COSEWIC. 2015. COSEWIC assessment and status report on the Little Quarry Lake Benthic Threespine Stickleback and the Little Quarry Lake Limnetic Threespine Stickleback *Gasterosteus aculeatus* in Canada. Comm. Status End. Wild. Can. xiii + 37pp.

DFO. 2015. Guidelines for the Identification of Critical Habitat for Aquatic Species at Risk. Unpubl. Report, Ecosystem Management Branch, Ottawa, Canada, 43 p.

DFO. 2018. Recovery potential assessment for the Little Quarry Lake Stickleback species pair (*Gasterosteus aculeatus*). Can. Sci. Advis. Sec. Sci. Resp. 2018/006.

DFO. 2019. Recovery strategy for the Paxton Lake, Enos Lake, and Venanda Creek stickleback species pairs (*Gasterosteus aculeatus*) in Canada. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. ix + 45pp.

DFO. 2020. Guidance on the identification of Critical Habitat in the riparian zone for freshwater species at risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/040.

Gow, J.L, Rogers, S.M., Jackson, M., and Schluter, D. 2008. Ecological predictions lead to the discovery of a benthic-limnetic sympatric species pair of threespine stickleback in Little Quarry Lake, British Columbia. Can. J. Zool. 86: 564–571.

Hatfield, T. 2001a. Status of the stickleback species pair, *Gasterosteus* spp., in Hadley Lake, Lasqueti Island, British Columbia. Can. Field-Nat. 115(4): 579–583.

Hatfield, T., 2001b. Status of the stickleback pair, *Gasterosteus* spp., in the Venanda Creek watershed of Texada Island, British Columbia. Can. Field-Nat. 115(4): 584–590

Hatfield, T. 2009. Identification of Critical Habitat for Sympatric Stickleback Species Pairs and the Misty Lake Parapatric Strickleback Species Pair. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/056. vi + 35 p.

Hatfield, T., and Schluter, D. 1996. A test for sexual selection on hybrids of two sympatric sticklebacks. Evol. 50(6): 2429–2434.

Hatfield, T., and Schluter, D. 1999. Ecological speciation in sticklebacks: Environment-dependent fitness. Evol. 53(3): 866–873.

Kraak, S.B.M., Mundwiler, B., and Hart, P.J.B. 2001. Increased number of hybrids between benthic and limnetic three-spined sticklebacks in Enos Lake, Canada; the collapse of a species pair? J. Fish Biol. 58: 1458–1464.

MacConnachie, S., and Wade, J. 2016. Information in support of the identification of critical habitat for the Cowichan (Vancouver) Lamprey (*Entosphenus macrostomus*). DFO Can. Sci. Advis. Sec. Res. Doc. 2016/109. vi + 17 p.

McPhail, J.D. 1984. Ecology and evolution of sympatric sticklebacks (*Gasterosteus*): morphological and genetic evidence or a species pair in Enos Lake, British Columbia. Can. J. Zool. 62: 1402–1408.

McPhail, J.D. 1989. Status of the Enos Lake stickleback species pair, *Gasterosteus* spp. Can. Field-Nat. 103(2): 216–219.

McPhail, J.D. 1992. Ecology and evolution of sympatric sticklebacks *(Gasterosteus):* evidence for a species-pair in Paxton Lake, Texada Island, British Columbia. Can. J. Zool. 70: 361 – 369.

Ormond, C.I., Rosenfeld, J.S., and Taylor, E.B. 2011. Environmental determinants of threespine stickleback species pair evolution and persistence. Can. J. Fish. Aquat. Sci. 68: 1983–1997.

Richardson, J.S., Taylor, E., Schluter, D., Pearson, M., and Hatfield, T. 2010. Do riparian zones qualify as critical habitat for endangered freshwater fishes? Can J. Fish. Aquat. Sci. 67: 1197–1204.

Ridgway, M.S., and McPhail, J.D. 1984. Ecology and evolution of sympatric sticklebacks (*Gasterosteus*): mate choice and reproductive isolation in the Enos Lake species pair. Can. J. Zool. 62: 1813–1818.

SARA. 2002. *Species at Risk Act* (S.C. 2002, c. 29).

Taylor, E.B., and Piercey, R.S. 2018. Going, going, gone: evidence for loss of an endemic species pair of threespine sticklebacks (*Gasterosteus aculeatus*) with implications for protection under species-at-risk legislation Conserv. Genet. 19: 297–308.

Taylor, E.B., Boughman, J.W., Groenenboom, M., Sniatynski, M., Schluter, D., and Gow, J.L. 2006. Speciation in reverse: morphological and genetic evidence of the collapse of a three-spined stickleback (*Gasterosteus aculeatus*) species pair. Mol. Ecol. 15: 343–355.

Thompson, K.A., Peichel, C.L., Rennison, D.J., McGee, M.D., Albert, A.Y.K, Vines, T.H., Greenwood, A.K., Wark, A.R., Brandvain, Y., Schumer, M. and Schluter, D. 2022. Analysis of ancestry heterozygosity suggests that hybrid incompatibilities in threespine stickleback are environment dependent. PLoS Biol 20(1): e3001469.

Velema, G.J., Rosenfeld, J.S., and Taylor, E.B., 2012. Effects of invasive American signal crayfish (*Pacifastacus leniusculus*) on the reproductive behaviour of threespine stickleback (*Gasterosteus aculeatus*) sympatric species pairs. Can. J. Zool. 90: 1328–1338.

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Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

E-Mail: DFO.PacificCSA-CASPacifique.MPO@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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