Species at Risk Act
Recovery Strategy Series

Recovery Strategy for Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs (*Gasterosteus aculeatus*) in Canada

Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs

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For copies of the recovery strategy, or for additional information on species at risk, including Committee on the Status of Endangered Wildlife in Canada (COSEWIC) Status Reports, residence descriptions, action plans, and other related recovery documents, please visit the SAR Public Registry.

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Preface

The federal, provincial, and territorial government signatories under the Accord for the Protection of Species at Risk (1996) agreed to establish complementary legislation and programs that provide for effective protection of species at risk throughout Canada. Under the *Species at Risk Act* (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of a recovery strategy for species listed as extirpated, endangered, or threatened and are required to report on progress five years after the publication of the final document on the Species at Risk Public Registry.

The Minister of Fisheries and Oceans is the competent minister under SARA for the Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs and has prepared this strategy, as per section 37 of SARA. A recovery strategy was completed for Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs and posted on the Species at Risk Registry in 2007. This 2019 recovery strategy amends the 2007 recovery strategy. It updates species' biology, recovery feasibility assessments, population abundance information, threats, and population and distribution objectives. It also includes the identification of critical habitat and residence description, which were initially published in the action plan (DFO 2016a).

In preparing this recovery strategy, the competent minister has considered, as per section 38 of SARA, the commitment of the Government of Canada to conserving biological diversity and to the principle that, if there are threats of serious or irreversible damage to the listed species, cost-effective measures to prevent the reduction or loss of the species should not be postponed for a lack of full scientific certainty. To the extent possible, this recovery strategy has been prepared in cooperation with the province of British Columbia as per section 39(1) of SARA.

As stated in the preamble to SARA, success in the recovery of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy and will not be achieved by Fisheries and Oceans Canada, or any other jurisdiction alone. The cost of conserving species at risk is shared amongst different constituencies. All Canadians are invited to join in supporting and implementing this strategy for the benefit of the Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs and Canadian society as a whole.

The action plan (DFO 2018) provides information on recovery measures to be taken by Fisheries and Oceans Canada and other jurisdictions and/or organizations involved in the conservation of the species. Implementation of this strategy is subject to appropriations, priorities, and budgetary constraints of the participating jurisdictions and organizations.

Acknowledgments

Fisheries and Oceans Canada (DFO) and the Province of British Columbia (B.C.) cooperated in the development of this amended recovery strategy (2019). They acknowledge the efforts of Jennifer Gow, who authored the amended recovery strategy, with contributions from Erin Gertzen, Ahdia Hassan, Andrew Baylis, Martin Nantel and Sean MacConnachie from DFO.

DFO and the Province of B.C. extend their appreciation to the members of the former Stickleback Species Pairs Recovery Team, who authored the 2007 recovery strategy. Members include Jordan Rosenfeld, B.C. Ministry of Environment (MOE), co-chair; Dan Sneep, DFO, co-chair; Todd Hatfield, Solander Ecological Research, coordinator; Don McPhail, University of British Columbia (UBC), retired; John Richardson, UBC; Dolph Schluter, UBC; Eric Taylor, UBC; Paul Wood, UBC. Development of the 2007 recovery strategy was partially funded by the Habitat Conservation Trust Fund of British Columbia.

Executive summary

The Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs (*Gasterosteus aculeatus*) were listed as endangered under the *Species at Risk Act* (SARA) in 2003, 2005 and 2003, respectively. This amended recovery strategy is considered one in a series of documents for these species that are linked and should be taken into consideration together; including the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status reports (2010a, 2010b, 2012), and the proposed Action Plan for Paxton Lake and Vananda Creek Stickleback Species Pairs (DFO 2018). Recovery for the Paxton Lake and Vananda Creek Stickleback Species Pairs has been determined to be biologically and technically feasible. Recovery for the Enos Lake Stickleback Species Pair has been determined to not be biologically or technically feasible. A proposed joint Paxton Lake and Vananda Creek Stickleback Species Pair action plan was posted on the Species at Risk Public Registry in 2016 and an amended version was posted in 2018 to reflect changes in this amended recovery strategy.

A recovery strategy was completed for Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs and posted on the Species at Risk Registry in 2007. This 2019 recovery strategy amends the 2007 recovery strategy. It updates species' biology, recovery feasibility assessments, population abundance information, threats, and population and distribution objectives. It also includes the identification of critical habitat and residence description, which were initially published in the proposed action plan (DFO 2016a).

The Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs are endemic to watersheds in British Columbia. These sympatric (co-occurring) species pairs have been found in just a few lakes on islands in the Strait of Georgia in south-western British Columbia. Each pair consists of an open water-feeding "limnetic" species adapted to feeding on zooplankton and a bottom-feeding "benthic" species adapted to feeding on benthic invertebrates in the littoral zone. Each species pair evolved independently from their marine ancestors following the end of the last glaciation. As well as being ecologically divergent, benthic and limnetic species are morphologically and genetically distinct from one another, and do not usually interbreed. An exception to this is the Enos Lake Stickleback Species Pair, which collapsed into a single genetic and morphological hybrid group following the appearance of the American Signal Crayfish (*Pacifastacus leniusculus*; Taylor and Piercey 2016). Distinct limnetic and benthic species in Enos Lake are no longer discernible.

Section 33 of SARA prohibits the damage or destruction of a species' residence. A detailed description of the Paxton Lake and Vananda Creek Stickleback Species Pairs' residence is provided in section 4.4 and is also available on the Species at Risk Public Registry.

The threats facing the Paxton Lake and Vananda Creek Stickleback Species Pairs are described in section 5 and include: the introduction of aquatic invasive species; water management; land use, including forest harvest as well as other uses; and scientific collections and *in situ* research.

The population and distribution objectives (section 6) for the Paxton Lake and Vananda Creek Stickleback Species Pairs are:

- Maintain, or where possible increase, abundance relative to the 2016 observed population sizes of each species pair. The 2016 abundances are thought to be near historical levels and self-sustaining (detailed in section 4.2).
- Maintain the current spatial distribution of each species pair.

A description of the broad strategies to be taken to address threats to the species' survival and recovery, as well as research and management approaches needed to meet the population and distribution objectives are included in section 7. These will help inform the development of specific recovery measures in one or more action plans.

For the Paxton Lake and Vananda Creek Stickleback Species Pairs, critical habitat is identified to the extent possible, using the best available information, and provides the functions and features necessary to support the species' life-cycle processes and to achieve the species' population and distribution objectives. This recovery strategy identifies critical habitat for Paxton Lake and Vananda Creek Stickleback Species Pairs as the entirety of Paxton, Spectacle, Priest and Emily Lakes (each with a 15 m riparian width surrounding their wetted perimeters), as well as the stream and marsh between Emily and Priest Lakes, and the shallow marsh between Spectacle and Priest Lakes (each with a 30 m riparian width surrounding their wetted perimeters; section 8). Critical habitat is not identified for the Enos Lake Stickleback Species Pair because its survival and recovery is not considered feasible based on current knowledge.

Recovery feasibility summary

The purposes of the *Species at Risk Act* (SARA) are to prevent wildlife species from being extirpated or becoming extinct, to provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity and to manage species of special concern to prevent them from becoming endangered or threatened.

DFO determined that the endangered Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs are historically precarious species because they were never widespread or abundant within Canada. For historically precarious species, recovery is considered feasible if the extent of irreversible biological or ecological change is such that it is technically and biologically feasible to improve the condition[1] of the species to approach its historic condition.

Using criteria outlined in table 1 below, DFO determined that the survival and recovery of the Paxton Lake Stickleback Species Pair are feasible based on species' characteristics and thresholds required to approach the historical condition of the species pair.

Using criteria outlined in table 2 below, DFO determined that the survival and recovery of the Enos Lake Stickleback Species Pair are not feasible based on species' characteristics and thresholds required to approach the historical condition of the species pair. The extent of irreversible biological and ecological change is too great to recover the species pair.

Using criteria outlined in table 3 below, DFO determined that the survival and recovery of the Vananda Creek Stickleback Species Pair are feasible based on species' characteristics and thresholds required to approach the historical condition of the species pair.

[1] Condition of the species: combination of the level of redundancy, resilience, representation, population and distribution, trend, threats, ecological role and any other factors that together determine the risk of extinction or extirpation of the species in Canada.

Table 1: Recovery feasibility evaluation of historically precarious Paxton Lake Stickleback Species Pair.

Fundamental species characteristic	**Survival or recovery threshold** (precarious species)	**Technically and biologically feasible to achieve threshold before opportunity lost? (Y/N/unknown)**
Survival threshold		
Species trend	Stable or increasing over 10 years or 3 generations whichever is longer (up to 100 years)	Yes: although trends are unknown, expert opinion suggests they are stable (COSEWIC 2010a)
Resilience (population size)	Approximating historical condition	Yes: although population sizes are unknown, expert opinion suggests current sizes approximate historical sizes (COSEWIC 2010a)
Redundancy (population # / distribution)	Approximating historical condition	n/a: restricted to a single lake (COSEWIC 2010a)
Population connectivity	Approximating historical condition	n/a: restricted to a single lake (COSEWIC 2010a)
Mitigation of anthropogenic threats	Significant threats avoided or mitigated to the extent that they no longer threaten the species	Yes: significant threats avoided to date (National Recovery Team for Stickleback Species Pairs 2007, COSEWIC 2010a)
Result	*If all above conditions met, species is above the survival threshold*	☒ ***Survival threshold met*** ☐ ***Survival threshold not met***
Minimum recovery threshold		
Species condition	Improved over when first assessed as at risk or approximating historical condition	Yes: although conditions are unknown, expert opinion suggests they approximate historical conditions (COSEWIC 2010a)
Representation (species presence in appropriate ecological communities)	Approximating historical condition at a coarse scale	Yes: representation approximates historical condition (COSEWIC 2010a)
Independent of connectivity with populations outside of Canada	Connectivity okay if necessary	n/a: restricted to a single lake (COSEWIC 2010a)
Independent of human intervention (in perpetuity)	Yes	Yes: this species continues to persist without intervention (COSEWIC 2010a)
Result	*If survival threshold and all above conditions are met, recovery is feasible*	☒ ***Recovery feasible*** ☐ ***Recovery not feasible***

Table 2: Recovery feasibility evaluation of historically precarious Enos Lake Stickleback Species Pair.

Fundamental species characteristic	**Survival or recovery threshold** (precarious species)	**Technically and biologically feasible to achieve threshold before opportunity lost? (Y/N/unknown)**
Survival threshold		
Species trend	Stable or increasing over 10 years or 3 generations whichever is longer (up to 100 years)	No: species pair has collapsed into a hybrid swarm (Taylor and Piercey 2016)
Resilience (population size)	Approximating historical condition	No: species pair has collapsed into a hybrid swarm (Taylor and Piercey 2016)
Redundancy (population # / distribution)	Approximating historical condition	n/a: restricted to a single lake (COSEWIC 2012)
Population connectivity	Approximating historical condition	n/a: restricted to a single lake (COSEWIC 2012)
Mitigation of anthropogenic threats	Significant threats avoided or mitigated to the extent that they no longer threaten the species	No: following American Signal Crayfish appearance, species pair has collapsed into a hybrid swarm (Kraak *et al.* 2001; Gow *et al.* 2006; Taylor *et al.* 2006; Behm *et al.* 2010)
Result	*If all above conditions met, species is above the survival threshold*	☐***Survival threshold met*** ☒ ***Survival threshold not met***
Minimum recovery threshold		
Species condition	Improved over when first assessed as at risk or approximating historical condition	No: species pair has collapsed into a hybrid swarm (Taylor and Piercey 2016)
Representation (species presence in appropriate ecological communities)	Approximating historical condition at a coarse scale	No: species pair has collapsed into a hybrid swarm (Taylor and Piercey 2016)
Independent of connectivity with populations outside of Canada	Connectivity okay if necessary	n/a: restricted to a single lake (COSEWIC 2012)
Independent of human intervention (in perpetuity)	Yes	n/a: species pair has collapsed into a hybrid swarm that is morphologically and genetically indistinct (Taylor and Piercey 2016) such that recovery through species intervention is not feasible
Result	*If survival threshold and all above conditions are met, recovery is feasible*	☐ ***Recovery feasible*** ☒ ***Recovery not feasible***

Table 3: Recovery feasibility evaluation of historically precarious Vananda Creek Stickleback Species Pair.

Fundamental species characteristic	**Survival or recovery threshold** (precarious species)	**Technically and biologically feasible to achieve threshold before opportunity lost? (Y/N/unknown)**
Survival threshold		
Species trend	Stable or increasing over 10 years or 3 generations whichever is longer (up to 100 years)	Yes: although trends are unknown, expert opinion suggests they are stable (COSEWIC 2010b)
Resilience (population size)	Approximating historical condition	Yes: although population sizes are unknown, expert opinion suggests current sizes approximate historical sizes (COSEWIC 2010b)
Redundancy (population # / distribution)	Approximating historical condition	n/a: restricted to a single watershed (COSEWIC 2010b)
Population connectivity	Approximating historical condition	n/a: restricted to a single watershed (COSEWIC 2010b)
Mitigation of anthropogenic threats	Significant threats avoided or mitigated to the extent that they no longer threaten the species	Yes: significant threats avoided to date (National Recovery Team for Stickleback Species Pairs 2007, COSEWIC 2010b)
Result	*If all above conditions met, species is above the survival threshold*	☒ ***Survival threshold met*** ☐ ***Survival threshold not met***
Minimum recovery threshold		
Species condition	Improved over when first assessed as at risk or approximating historical condition	Yes: although conditions are unknown, expert opinion suggests they approximate historical conditions (COSEWIC 2010b)
Representation (species presence in appropriate ecological communities)	Approximating historical condition at a coarse scale	Yes: representation approximates historical condition (COSEWIC 2010b)
Independent of connectivity with populations outside of Canada	Connectivity okay if necessary	n/a: restricted to a single watershed (COSEWIC 2010b)
Independent of human intervention (in perpetuity)	Yes	Yes: this species continues to persist without intervention (COSEWIC 2010b)
Result	*If survival threshold and all above conditions are met, recovery is feasible*	☒ ***Recovery feasible*** ☐ ***Recovery not feasible***

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Background

1. Introduction

The Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs (*Gasterosteus aculeatus*) were listed as endangered under the *Species at Risk Act* (SARA) in 2003, 2005 and 2003, respectively.

This recovery strategy is part of a series of documents regarding Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs that should be taken into consideration together, including the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status reports (COSEWIC 2010a, 2010b, 2012), and the Action Plan for Paxton Lake and Vananda Creek Stickleback Species Pairs (DFO 2018). A recovery strategy is a planning document that identifies what needs to be done to arrest or reverse the decline of a species. It sets objectives and identifies the main areas of activities to be undertaken. Detailed planning is done at the subsequent action plan stage.

2. COSEWIC[2] species assessment information

Assessment summary – April 2010

Common name: Paxton Lake Benthic and Limnetic Threespine Stickleback

Scientific name: *Gasterosteus aculeatus*

COSEWIC status: endangered

Reason for designation: These small freshwater fishes are unique Canadian endemics that are restricted to a single small lake in coastal British Columbia (B.C.). These wildlife species are highly susceptible to extinction from aquatic invasive species introductions that have been observed to cause rapid extinction of similar species in at least two other lakes. Invasive aquatic species continue to increase in lakes on adjacent Vancouver Island and the Lower Mainland of B.C., and there is, therefore, a reasonable likelihood that invasives could be introduced into the habitat of the species over the next 10 years. This species is also susceptible to habitat loss and degradation from water extraction and land use activities in the surrounding landscape.

Occurrence: British Columbia

Status history: Designated threatened in April 1998. Status re-examined and confirmed in April 1999. Status re-examined and designated endangered in May 2000. Status re-examined and confirmed in April 2010.

***Species at Risk Act* status:** Listed, endangered

[2] COSEWIC (Committee on the Status of Endangered Wildlife in Canada)

Assessment summary – May 2012

Common name: Enos Lake Benthic and Limnetic Threespine Stickleback

Scientific name: *Gasterosteus aculeatus*

COSEWIC status: endangered

Reason for designation: These small fishes occur in a single lake in south coastal British Columbia where it has now formed a hybrid swarm with a co-existing stickleback. Although it is possible that a small number of genetically pure fish still exist in the lake, the ongoing presence of an invasive crayfish, and associated habitat degradation, continue to place these species at a high risk of extinction.

Occurrence: British Columbia

Status history: Original designation (including both benthic and limnetic species) was threatened in April 1988. Split into two species when re-examined in November 2002 and the Enos Lake Benthic and Limnetic Threespine Stickleback was designated endangered. Status re-examined and confirmed in May 2012.

***Species at Risk Act* status:** Listed, endangered

Assessment summary – April 2010

Common name: Vananda Creek Benthic and Limnetic Threespine Stickleback

Scientific name: *Gasterosteus aculeatus*

COSEWIC status: endangered

Reason for designation: These small freshwater fishes are unique Canadian endemics that are restricted to three small, interconnected lakes in coastal British Columbia (B.C.). The wildlife species are highly susceptible to extinction from aquatic invasive species introductions that have been observed to cause rapid extinction of similar species in at least two other lakes. Invasive aquatic species continue to increase in lakes on adjacent Vancouver Island and the Lower Mainland of B.C., and there is, therefore, a reasonable likelihood that invasives could be introduced into the habitat of the species over the next 10 years. This species is also susceptible to habitat loss and degradation from water extraction and land use activities in the surrounding landscape.

Occurrence: British Columbia

Status history: Designated threatened in April 1999. Status re-examined and designated endangered in May 2000 and in April 2010.

***Species at Risk Act* status:** Listed, endangered

3. Species status information

Table 4. Summary of existing protection or other status designations assigned to Paxton Lake (Pa), Enos Lake (En), and Vananda Creek (Va) Stickleback Species Pairs.

Jurisdiction	Authority/organization	Year	Status/description	Designation level
Global	NatureServe (2016)	Pa: 2002 En: 2012 Va: 2002	Critically imperiled	G1*
National	*Species at Risk Act*	Pa: 2003 En: 2005 Va: 2003	Endangered	Schedule 1
National/ provincial	NatureServe (2016)	Pa: 1992 En: 2012 Va: 1992	Critically imperiled	N1/S1*
Provincial	B.C. Ministry of Environment and B.C. Conservation Data Centre (2016)	Pa: 1992 En: 2012 Va: 1992	Red listed	S1*

*G = Global Status; N = National Status; S = Subnational Status; 1= Critically imperiled

Upon listing as endangered species, the Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs became protected wherever they are found by section 32 of SARA:

> "*No person shall kill, harm, harass, capture or take an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species*." [s. 32(1)]

> "*No person shall possess, collect, buy, sell or trade an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species, or any part or derivative of such an individual*." [s. 32(2)]

Under section 73 of SARA, the competent minister may enter into an agreement or issue a permit authorizing a person to engage in an activity affecting a listed wildlife species, any part of its critical habitat or its residences.

4. Species information

4.1 Description

The fish known collectively as "Stickleback Species Pairs" are thought to have evolved from the marine Threespine Stickleback (*Gasterosteus aculeatus*). Their recent and unique evolutionary history has been of considerable scientific interest and value. They are considered to be one of the youngest species on earth; strong evidence suggests that the species pairs developed after the last glaciation, less than 13,000 years ago. They are also among the world's best examples of rapid adaptive radiation and recent parallel evolution in nature (as cited in Wood et al. 2004). These species pairs are now amongst the most extensively studied systems of ecological speciation in nature, giving insight into the processes that give rise to global biodiversity (reviewed in Rundle and Nosil 2005; Nosil and Schluter 2011; Seehausen *et al.* 2014).

Sympatric[3] Stickleback Species Pairs have only been found in few small lakes in British Columbia (B.C.). They provide a unique contribution to Canada's biodiversity as endemic species. The Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs are three such sympatric Stickleback Species Pairs. They each consist of a pair of species that are genetically and morphologically distinct from each other. Even though they live in the same lake, they are reproductively isolated. Each species pair includes a "limnetic" species adapted for a zooplankton-consuming lifestyle in open water, and a bottom-feeding "benthic" species adapted to prey on benthic invertebrates in the littoral zone (Schluter and McPhail 1992, 1993; McGee *et al.* 2013). Notable shifts in morphology from the limnetic to the benthic species include: a greater overall body depth; shorter dorsal and anal fins; a smaller eye; a shorter jaw that is more downward-oriented; and fewer and shorter gill rakers (Schluter and McPhail 1992, 1993; Gow *et al.* 2008). These differences are considered adaptations to their divergent feeding lifestyles. Comprehensive descriptions of Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs can be found in their COSEWIC Status Reports (2010a, 2010b, 2012, respectively).

In general, Stickleback Species Pairs are highly susceptible to extinction from aquatic invasive species (AIS) introductions, as well as to habitat loss and degradation from water extraction and land use in the surrounding watersheds (COSEWIC 2010a, 2010b, 2012). The Enos Lake Stickleback Species Pair collapsed into a hybrid swarm following the appearance of American Signal Crayfish (*Pacifastacus leniusculus*; Kraak *et al.* 2001; Gow *et al.* 2006; Taylor *et al.* 2006; Behm *et al.* 2010). Pre- and post-mating reproductive isolation broke down and interbreeding occurred, causing the species pair to become morphologically and genetically indistinct (Behm *et al.* 2010; Lackey and Boughman 2013). The first evidence of an increasing proportion of hybrids was observed in 1999 (Kraak et al. 2001; COSEWIC 2012). Recent extensive morphological and genetic analyses of Enos Lake Sticklebacks show no evidence of any "genetically pure" benthic or limnetic species remaining in the lake (McPhail 1984; Taylor and Piercey 2016). This provides strong evidence that Enos Lake now consists entirely of a single breeding population of sticklebacks that constitutes a hybrid population of the former benthic and limnetic species.

4.2 Population abundance and distribution

The Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs are endemic to just one or a few interconnected lakes on islands in south-western B.C., Canada. The Paxton Lake Stickleback Species Pair is restricted to a single lake (Paxton Lake) on Texada Island (figure 1; McPhail 1992, 1993), while the Vananda Creek Stickleback Species Pair is found in Spectacle[4], Priest and Emily[5] Lakes, and their interconnecting marshes and streams in the Vananda Creek Watershed, on Texada Island (figure 3; Taylor and McPhail 2000; COSEWIC 2010b). Prior to its

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[3] The spatial distribution of the two species is entirely or mostly overlapping.
[4] Spectacle Lake is sometimes referred to as Balkwill Lake.
[5] Emily Lake is sometimes referred to as Turtle Lake.

collapse into a single breeding population, the Enos Lake Stickleback Species Pair was restricted to Enos Lake on southeastern Vancouver Island (figure 2).

Prior to the collapse of the Enos Lake Stickleback Species Pair, a population of Enos Lake limnetic species was established in a pond in Murdo-Frazer Park in North Vancouver in 1988 and 1989 (Taylor and Piercey 2016). Morphological analyses of subsequent generations of these pond fishes found they quickly became more similar to the benthic species (Taylor and Piercey 2016); therefore, the Murdo-Frazer population does not represent the Enos Lake limnetic species, and cannot be considered for use as a rescue population. A captive breeding program was started at the University of British Columbia but was discontinued in 2015 because genetic evidence suggested too much hybridization had occurred prior to capturing individuals; genetic marker data and morphological measurements indicated that none of the crosses were close to the pure benthic or limnetic species (D. Schluter pers. comm.). The population size of the non-SARA listed hybrid population in Enos Lake is less than 26,000 (Matthews et al. 2001; R. Taylor pers. comm).

A 2005 mark-recapture study estimated abundance in Paxton Lake to be approximately 3,300 mature benthic males and 45,800 mature limnetic males (Nomura 2005). Low capture success of limnetic species contributed to relatively poor confidence in estimate of limnetic species abundance (see Hatfield 2009 and COSEWIC 2010a). A 2016 mark-recapture study estimated total population abundance (males, females and juveniles) to be 22,191 (95% confidence intervals: 17,544, 28,991) for the benthic species and 368,885 (95% confidence intervals: 236,137, 842,518) for the limnetic species (Schluter et al. 2017). The estimates used all trap data but the limnetic species population estimate may be artificially high due to schooling behaviour (Schluter et al. 2017). If all mark-recapture traps containing more than 60 individuals are excluded from the analysis to reduce the influence of schooling behaviour, the limnetic species population estimate becomes 194,257 (95% confidence intervals: 132,784, 361,711; D. Schluter, unpub. data). Given the effects of schooling behaviour and the relatively poor confidence in estimates from limnetic species sampling, the actual limnetic species population size may be closer to 100,000 (D. Schluter pers. comm.).

Total population estimates of the Vananda Creek Stickleback Species Pair within Priest Lake were 118,058 (95% confidence intervals: 101,351, 141,358) for the benthic species and 110,612 (95% confidence intervals: 78,068, 189,684) for the limnetic species (Schluter et al. 2017). There have been no direct population estimates of benthic and limnetic species from other parts of the Vananda Creek range. Using data extrapolated from other populations (Paxton Lake; Nomura 2005), COSEWIC (2010b) estimates total Vananda Creek population sizes to be 10,500 mature benthic males and 516,000 mature limnetic males. Caution must be taken, however, when considering the accuracy of these preliminary estimates (Hatfield 2009; COSEWIC 2010b; Ormond *et al.* 2011).

There has been no systematic monitoring of abundance in Paxton Lake or Vananda Creek so population trends are unknown (COSEWIC 2010a, 2010b). Qualitatively, researchers have continued to easily trap the sticklebacks from Paxton and Priest Lakes, while sampling from Spectacle and Emily Lakes has been more sporadic (COSEWIC 2010a, 2010b).

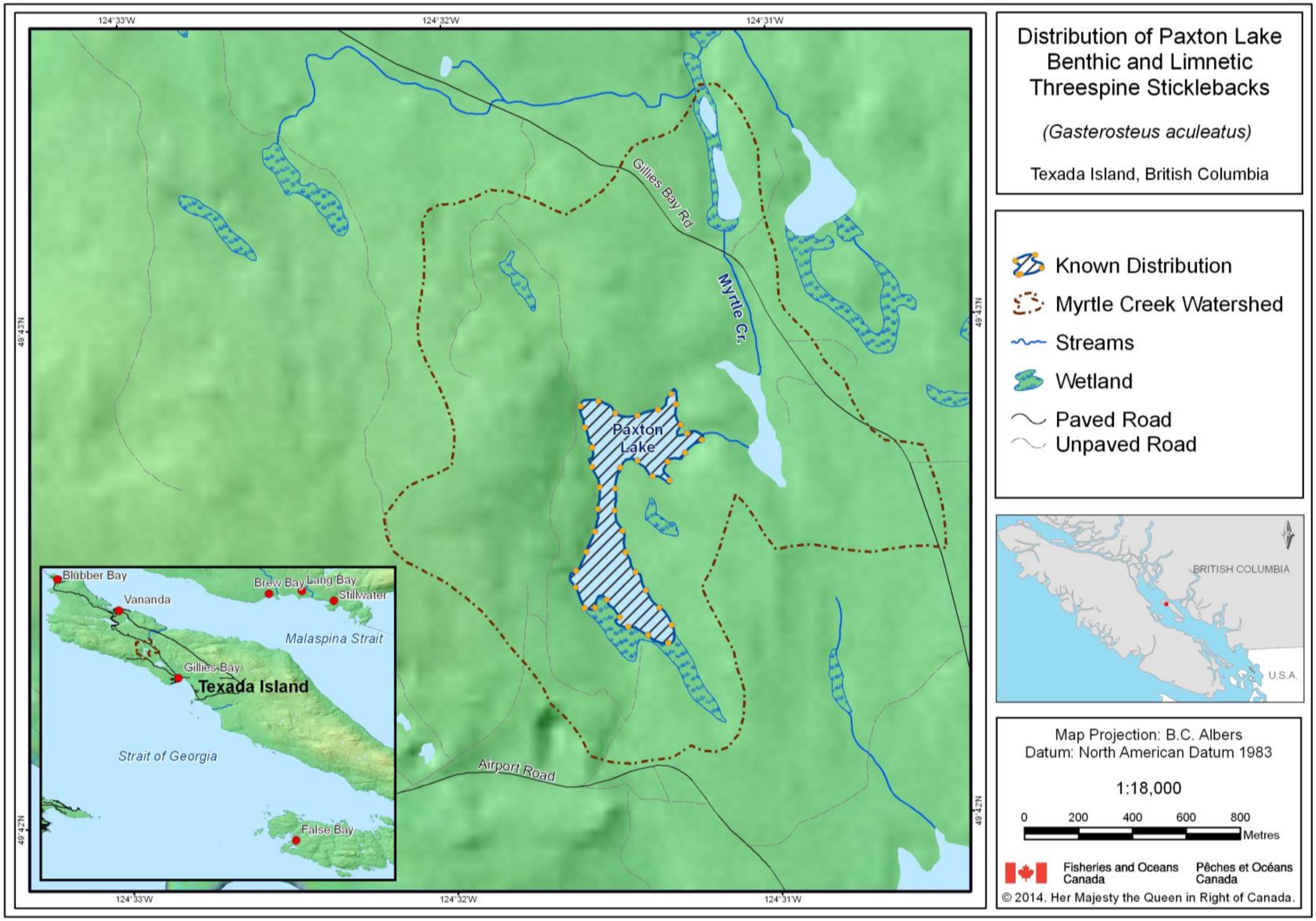

Figure 1. Distribution of the Paxton Lake Benthic and Limnetic Threespine Sticklebacks.

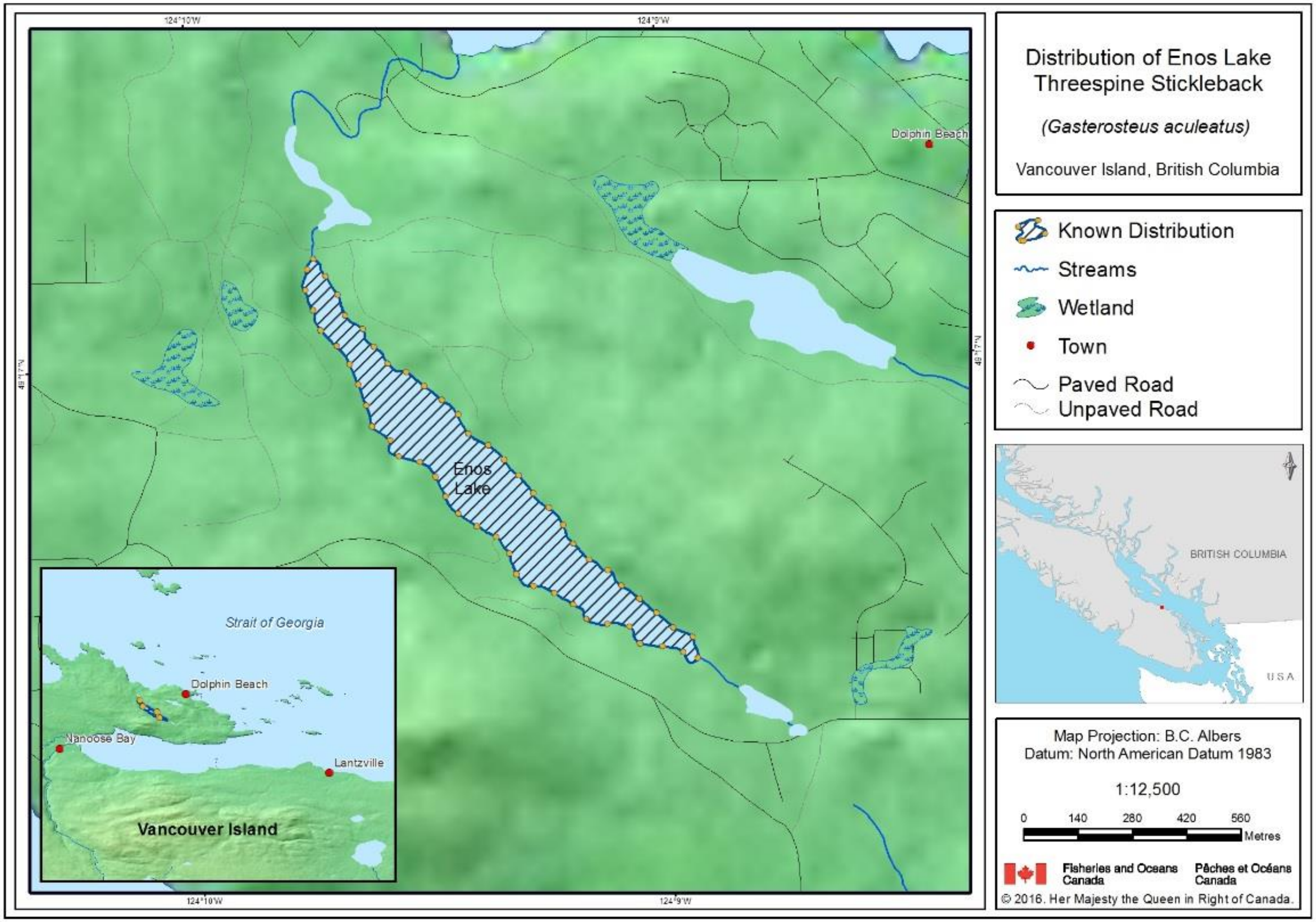

Figure 2. Distribution of the Enos Lake Threespine Stickleback.

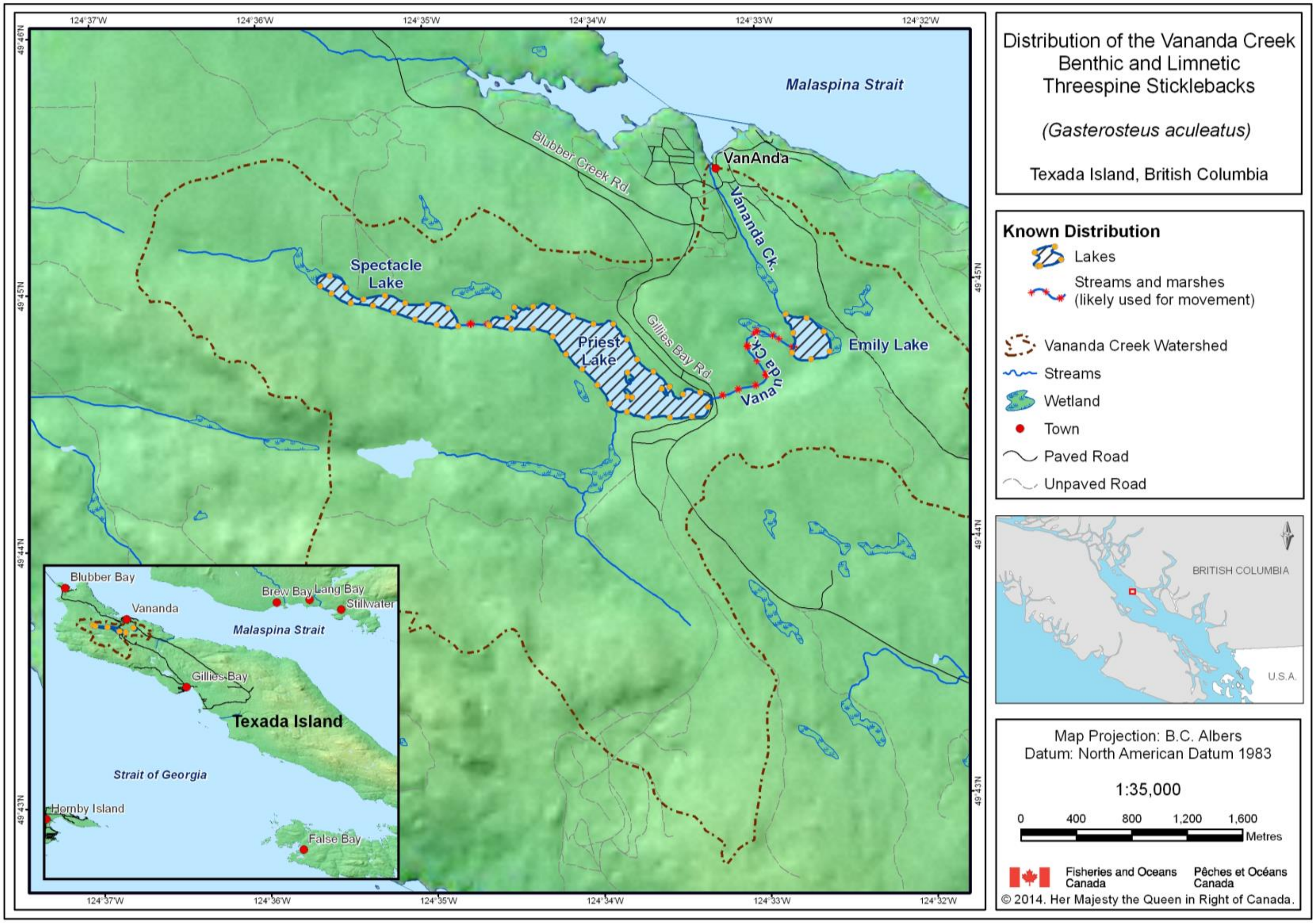

Figure 3. Distribution of the Vananda Creek Benthic and Limnetic Threespine Sticklebacks.

4.3 Needs of the species

Marine Threespine Stickleback are generally tolerant of a wide range of water quality conditions, can adapt readily to change, and are resilient to environmental perturbations (Scholz and Mayer 2008; Candolin 2009; Hatfield 2009). In contrast, sympatric Stickleback Species Pair populations such as the Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs, are sensitive to habitat changes. In addition to the habitat features needed to maintain a viable population, species pairs require habitat features that prevent hybridization (that is, maintain mate recognition and reproductive barriers) and maintain selection against hybrids (Hatfield 2009; Velema *et al.* 2012). Since they have the capacity to interbreed when reproductive barriers are removed, they are extremely vulnerable to environmental changes that disrupt these barriers and increase hybridization (McPhail 1992). The Enos Lake Stickleback Species Pair demonstrates the significance of this; it collapsed into a hybrid swarm (see section 4.1 ‘Description’) following altered lake conditions that accompanied the appearance of the American Signal Crayfish (Kraak *et al.* 2001; Gow *et al.* 2006; Taylor *et al.* 2006; Behm *et al.* 2010).

The specific habitat features that are essential to the persistence of Stickleback Species Pairs such as the Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs as well as the historical forces that created these pairs in some lakes but not others are not fully understood (Ormond *et al.* 2011). What is known about their habitat requirements has been gleaned from studies of the species pairs in Paxton Lake and Enos Lake (prior to its collapse). A brief summary is provided here. Please refer to 'Habitat', 'Biology' and 'Interspecific Interactions' sections of their respective COSEWIC Status Reports for detailed descriptions and full references (COSEWIC 2010a, 2012). There has been less direct study of the biology of the Vananda Creek Stickleback Species Pair (see COSEWIC 2010b); they may be ecologically and behaviourally similar to the other species pairs but differences in abiotic and biotic attributes between lakes could give rise to differences in habitat use (Ormond *et al.* 2011).

Limnetic adults feed on zooplankton in the pelagic zone and benthic adults feed on benthic invertebrates in the littoral zone. During the spring breeding season, shallow littoral areas of the lakes form the spawning habitat for both benthic and limnetic species; however, there is microspatial segregation of nesting sites. The limnetic species requires open nesting sites on gravel, rock or submerged logs while the benthic species requires the cover of aquatic vegetation or other structures (see section 4.4, ‘Residence’). Indeed, habitat isolation plays a role in their reproductive isolation (Southcott *et al.* 2013; Lackey and Boughman 2014).

Little is known about the habitat requirements of early life stages, although both limnetic and benthic fry are known to utilize the littoral zone, where macrophyte[6] beds provide food and refuge from predators. Habitat partitioning between the two species increases in later life stages, and the limnetic species eventually moves offshore to feed in pelagic areas. During the fall and winter, both benthic and limnetic species overwinter in deep water habitats.

Based on this current knowledge, the habitat needs of the Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs likely include the following (National Recovery Team for Stickleback Species Pairs 2007; Hatfield 2009):

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[6] Macrophyte: an aquatic plant that is visible to the naked eye

- Sustained littoral and pelagic productivity to support both benthic and limnetic species
- Natural light transmissivity to enable mate recognition
- Maintenance of gently-sloping sediment (for example, silt, sand, gravel) beaches and natural littoral macrophytes to provide segregated nesting and juvenile rearing habitats

Changes to natural littoral macrophyte cover and water clarity are thought to have contributed to the collapse of the Enos Lake Stickleback Species Pair (Behm *et al.* 2010). Submerged macrophytes are key to maintaining spatial isolation between limnetic and benthic spawners, thus mediating reproductive isolation and limiting hybridization (Hatfield 2009). Macrophyte cover declined drastically in Enos Lake following the appearance of the American Signal Crayfish, dropping to 0.1% cover (Behm *et al.* 2010; Ormond *et al.* 2011). This habitat destruction is thought to have contributed to the breakdown of reproductive barriers between benthic and limnetic species, and the collapse of the species pair into a hybrid swarm (Taylor *et al.* 2006; Rosenfeld *et al.* 2008a; Behm *et al.* 2010; Velema *et al.* 2012). In addition, changes in water quality that alter the transmission of light may disrupt mate recognition, and result in increased hybridization (Behm *et al.* 2010). Indeed, increased turbidity associated with the appearance of the American Signal Crayfish is thought to have interfered with mate discrimination within Enos Lake, and is considered a key mechanism that led to the collapse of the species pair (Taylor *et al.* 2006; Behm *et al.* 2010; Malek *et al.* 2012; Velema *et al.* 2012; Lackey and Boughman 2013). Lab research has shown that American Signal Crayfish cause a greater disruption of normal nesting behavior of male Limnetic sticklebacks than of male benthic sticklebacks; this may have contributed to the collapse of the Enos Lake Stickleback Species Pair because hybridization between two species often increases when the abundance of one of them is greatly reduced (Velema *et al.* 2012, D. Schluter pers. comm.).

The specific limiting factors[7] for the Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs remain poorly understood but it appears that the Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs are sensitive to habitat changes. Therefore, maintaining current abiotic and biotic conditions is likely important (baseline documented in Ormond *et al.* 2011). Effects of climate change that alter habitat conditions beyond the current range could adversely impact the Paxton Lake, Enos Lake and Vananda Creek Stickleback Species Pairs. Additionally, persistence of Stickleback Species Pairs in general seems to depend on the absence of other fish species in their lakes, with the exception Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*; Hatfield 2009; COSEWIC 2010a, 2010b, 2012; Ormond *et al.* 2011), as evidenced by the rapid extinction of the Hadley Lake Stickleback Species Pair following the introduction of Brown Bullhead (*Ameiurus nebulosus*; Hatfield 2001).

4.4 Residence of the species

Residence of Paxton Lake and Vananda Creek Stickleback Species Pairs was originally described in section 2.4 of the action plan (DFO 2016a). It has been moved unchanged to section 4.4 of this recovery strategy.

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[7] Limiting factor: a non-anthropogenic factor that, within a range of natural variation, limits the abundance and distribution of a wildlife species or a population (for example, age at first reproduction, fecundity, age at senescence, prey abundance, mortality rate) (Fisheries and Oceans Canada 2014).

4.4.1 Location of the species' residence

SARA states that "*No person shall damage or destroy the residence of one or more individuals of a wildlife species that is listed as an endangered species or a threatened species, or that is listed as an extirpated species if a recovery strategy has recommended the reintroduction of the species into the wild in Canada*." [s. 33]

Also, SARA defines "residence" 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.*" [s. 2(1)]

The following statement (the residence statement) is a description of a residence for Paxton Lake and Vananda Creek Stickleback Species Pairs.

Paxton Lake and Vananda Creek Benthic and Limnetic Sticklebacks build nests within the littoral zone of the lakes in which they are found. These nests are considered residences as defined by SARA.

4.4.2 Structure, form and investment

The nests created, modified, used and defended by Paxton Lake and Vananda Creek Stickleback Species Pairs for spawning and early stages of rearing represent discrete dwelling places requiring significant investment in their creation and maintenance by the male sticklebacks.

4.4.3 Occupancy and life-cycle function

Stickleback Species Pairs, including Paxton Lake and Vananda Creek Stickleback Species Pairs, spawn in the shallow littoral areas of lakes (McPhail 1994). The limnetic species spawns from early April to early June in open-nesting sites on gravel or rock substrates, or on submerged logs, and at depths of no more than one metre. The benthic species spawns from mid-March to mid-May and chooses sites under the cover of aquatic vegetation or other structures in slightly deeper water, up to two metres (McPhail 1994; Hatfield and Schluter 1996, as cited in Hatfield 2009). The males of the species build nests in which a female lays her eggs. Males may mate with several females over a one to four day period. The males guard and defend the nests throughout nest construction, mating and a 'parental care' phase until fry are about one week old (Wood *et al*. 2004). Defended territories are related to the size of the individual male (Wood *et al*. 2004).

The nests have the functional capacity to support successful spawning and hatching and are occupied during the life stages of adult, egg and juvenile hatch. As such, nests are considered a residence for the Paxton Lake and Vananda Creek Stickleback Species Pairs during the time they are occupied by the male through the spawning period, while incubating the eggs and protecting the juveniles after they have hatched and left the nest, and until the male has finished all its nesting cycles.

5. Threats

5.1 Threat assessment

Threats to Paxton Lake and Vananda Creek Stickleback Species Pairs described in National Recovery Team for Stickleback Species Pairs (2007) and COSEWIC (2010a) and (2010b) are based largely on expert opinion and observations. Since the survival and recovery of the Enos Lake Stickleback Species Pair is not considered feasible (see section 'recovery feasibility summary'), this species pair is not included in the Threats Assessment.

For more details on the threat assessment process, refer to the [Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk] (DFO 2014). Assessment category definitions are provided in footnotes to table 5.

Table 5: Threats Assessment for Paxton Lake and Vananda Creek Stickleback Species Pairs.

Threat	Level of concern[8]	Extent [9]	Likelihood of occurrence[10]	Frequency[11]	Severity[12]	Causal certainty[13]
Aquatic invasive species	High	Extensive	Unlikely	One-time or continuous	Extreme	Very high
Water management (including water pollution and/or sedimentation)	Medium	Extensive	Known to have occurred	Recurrent	Medium-high	Medium
Land use (including habitat loss or degradation)	Medium	Extensive	Unlikely	Recurrent	Medium-high	Medium
Scientific collections / *in situ* research	Medium	Extensive	Known to have occurred	Recurrent	Low	Medium
Recreation	Low	Extensive	Remote	Recurrent	Low	Very low
Disease	Unknown	Extensive	Unknown	Continuous	Unknown	Very low

[8] Level of concern: signifies that managing the threat is of High, Medium or Low concern for the recovery of the species, consistent with the population and distribution objectives. This criterion considers the assessment of all the information in the table.
[9] Extent: proportion of the species affected by the threat.
[10] Likelihood of occurrence: the probability of a specific threat occurring for a given population over 10 years or 3 generations, whichever is shorter.
[11] Frequency: reflects how often a threat, if it occurs, is predicted to impact the species (one-time, seasonal, recurrent, continuous or unknown).
[12] Severity: reflects the population-level effect (High; Moderate; Low; Unknown).
[13] Causal certainty: reflects the degree of evidence that is known for the threat (High: available evidence strongly links the threat to stresses on population viability; Medium: there is a correlation between the threat and population viability for example, expert opinion; Low: the threat is assumed or plausible).

5.2 Description of threats

Aquatic invasive species (AIS)

The primary threat to Paxton Lake and Vananda Creek Stickleback Species Pairs comes from the introduction of AIS. AIS refers to all species that are not native to these watersheds. Examples include Brown Bullhead, American Signal Crayfish, Bullfrog (*Rana catesbeiana*), Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*M. dolomieu*), Pumpkinseed (*Lepomis gibbosus*), Yellow Perch (*Perca flavescens*), Eurasian Milfoil (*Myriophyllum spicatum*), and Purple Loosestrife (*Lythrum salicaria*).

The persistence of Paxton Lake and Vananda Creek Stickleback Species Pairs appears to depend on the maintenance of several ecological factors, including a simple fish community (an environment where there is little to no interspecific competition and predation). Given the growing number of AIS in nearby areas (Hatfield and Pollard 2009), the threat of introduction of AIS is likely high. Risk assessments concluded that for most regions of B.C., the probability of invasive fish species becoming established after release is high or very high, and the likely magnitude of ecological impact in small water bodies is very high (Bradford *et al.* 2008a, 2008b). Indeed, the devastating impact of invasive species has been demonstrated in two Stickleback Species Pairs in recent decades: the collapse of Enos Lake Stickleback Species Pair into a morphologically and genetically indistinct hybrid swarm followed the appearance of American Signal Crayfish and the extinction of Hadley Lake Stickleback Species Pair followed the introduction of Brown Bullhead (Hatfield 2001; Taylor *et al.* 2006).

Water management (including water pollution and/or sedimentation)

Severe drawdowns have occurred in the past as part of mining operations (Larson 1976), and existing water licenses for both Paxton Lake and Vananda Creek remain large relative to the volume of the lakes and size of the catchments (Government of British Columbia 2016). Although the impact of historical and current use of water on Paxton Lake and Vananda Creek Stickleback Species Pairs is not known, large fluctuations in water levels should be avoided to minimize changes to lake water volume, water pollution, sedimentation rates, and the littoral zone habitat required by these species pairs for foraging, spawning and juvenile rearing.

Land use (including habitat loss, or degradation)

There have been numerous historical land-based development activities in the watersheds of Paxton Lake (forestry, mining, road building; COSEWIC 2010a) and Vananda Creek (forestry, mining, road building, pipeline construction, and housing development; COSEWIC 2010b). The main concerns from such activities include cumulative impacts of sedimentation and pollution on water quality (especially turbidity and water clarity) and habitat (for example, smothering of nesting areas). The threat from current land-based activities is unknown (COSEWIC 2010a, 2010b).

Scientific research

Research collection activities have likely been a leading source of non-natural mortality of adult fish in the Paxton Lake and Vananda Creek Stickleback Species Pairs (Rosenfeld *et al.* 2008b). Abundance estimates of the Paxton Lake benthic species from mark-recapture studies in 2005 (Nomura) and 2017 (Schluter *et al.*) have differed and suggest some uncertainty, and have therefore led to a precautionary approach towards sampling from Paxton Lake and Vananda Creek and other Stickleback Species Pairs. Guidelines now prohibit the use of hybrids or AIS in any *in situ* studies, recommend limits for lethal and non-lethal sampling of the Paxton Lake and Vananda Creek Stickleback Species Pairs, and restrict the sampling area within each lake; approximately half of each lake is recommended as a no-take area (Rosenfeld *et al.* 2008b).

Recreation

Recreation activities such as boating are believed to present a low risk to Paxton Lake and Vananda Creek Stickleback Species Pairs. Boating activity may contribute to other threats, one example being the introduction of AIS.

Disease

Introduction of disease organisms is poorly understood but is believed to present a low risk to Paxton Lake and Vananda Creek Stickleback Species Pairs.

Recovery

6. Population and distribution objectives

Population and distribution objectives establish, to the extent possible, the number of individuals and/or populations, and the geographic distribution that is necessary for the recovery of the species. The population and distribution objectives for Paxton Lake and Vananda Creek Stickleback Species Pairs are:

Population objective:
Maintain, and where possible increase, abundance relative to the 2016 observed population sizes of each species pair. The 2016 abundances are thought to be near historical levels and self-sustaining (table 6).

Table 6. Population objectives for Paxton Lake and Vananda Creek Stickleback Species Pairs.

Population	Benthic population	Limnetic population
Paxton Lake	20,000*	100,000*
Emily Lake (Vananda Creek)	**	**
Priest Lake (Vananda Creek)	118,058***	110,612***
Spectacle Lake (Vananda Creek)	**	**

* population objectives are based on expert opinion and are conservative given large confidence intervals in a mark-recapture study (Schluter et al. 2017; D. Schluter pers. comm.)
** population abundance has not been estimated for these locations and the population objective has not been quantified
*** population objectives are based on population estimates from a mark-recapture study (Schluter et al. 2017)

Distribution objective:
Maintain the current spatial distribution of each species pair.

Since Paxton Lake and Vananda Creek Stickleback Species Pairs are historically precarious and their endangered status is largely a reflection of the limited geographic range and natural rarity of these species pairs (COSEWIC 2010a, 2010b), meeting population and distribution objectives may not result in a status reassessment to threatened, special concern or not at risk.

The survival and recovery of Enos Lake Stickleback Species Pair is not feasible (see section 'Recovery Feasibility Summary') because evidence suggests the Enos Lake Stickleback Species Pair has collapsed into a single hybrid population. Therefore, setting population and distribution objectives for the benthic and limnetic species is not appropriate and no objectives have been set.

7. Broad strategies and general approaches to meet objectives

7.1 Actions already completed

For information on actions already completed or underway, refer to the Report on the Progress of Recovery Strategy Implementation for the Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs (*Gasterosteus aculeatus*) in Canada for the Period 2007 – 2015 (DFO 2016b).

7.2 Strategic direction for recovery

A description of the research and management approaches are presented under broad strategies intended to address the identified threats (table 7). These will help inform the development of specific recovery measures in one or more action plans for Paxton Lake and Vananda Creek Stickleback Species Pairs. The survival and recovery of the Enos Lake Stickleback Species Pair is not feasible (see section 'Recovery Feasibility Summary'), and not included in table 7.

Table 7. Recovery planning table for Paxton Lake and Vananda Creek Stickleback Species Pairs.

Broad strategy	General description of research and management approaches	Priority[14]	Threat or concern addressed
Develop and implement monitoring programs	Develop and implement an ongoing long-term program to monitor population and distribution of Paxton and Vananda Stickleback Species Pairs.	High	Aquatic invasive species; Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation); Scientific collections / *in situ* research
Conduct research on the Paxton Lake and Vananda Creek Stickleback Species Pairs	Conduct scientific research that contributes to recovery and/or addresses knowledge gaps affecting management of the Paxton Lake and Vananda Creek Stickleback Species Pairs. These include studies exploring basic biology and threat clarification.	High	Aquatic invasive species; Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)
Conduct research on the Paxton Lake and Vananda Creek Stickleback Species Pairs	Investigate potential water quality implications and effects on the species pairs from the use of explosives for mining activities within the species pairs' watersheds.	Medium	Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)
Develop an Aquatic Invasive Species management plan	Develop and implement an Aquatic Invasive Species (AIS) management plan to prevent aquatic invasive species from entering and becoming established in lakes containing these species pairs.	High	Aquatic invasive species; Land use (including habitat loss or degradation)
Develop an Aquatic Invasive Species management plan	Research potential impacts of recreational lake usage on Paxton Lake and Vananda Creek Stickleback Species Pairs and develop mitigation measures to address impacts.	Low	Aquatic invasive species; Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)

[14] Priority" reflects the degree to which the approach contributes directly to the recovery of the species or is an essential precursor to an approach that contributes to the recovery of the species:

- "High" priority approaches are considered likely to have an immediate and/or direct influence on the recovery of the species.
- "Medium" priority approaches are important but considered to have an indirect or less immediate influence on the recovery of the species.
- "Low" priority approaches are considered important contributions to the knowledge base about the species and mitigation of threats.

Broad strategy	General description of research and management approaches	Priority[14]	Threat or concern addressed
Establish baseline water quality parameters for the Paxton Lake and Vananda Creek Stickleback Species Pairs	Establish baseline parameters for turbidity, temperature, pH, and dissolved oxygen for all lakes and streams containing the Paxton Lake and Vananda Creek Stickleback Species Pairs to better understand the species' biological needs and the parameters that affect habitat quality.	High	Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)
Develop a comprehensive water management plan for each basin	Identify and evaluate water management options to satisfy both conservation and stakeholder needs. This may include developing and implementing projects to promote water conservation and the adoption of best practices for water use in the Paxton Lake and Vananda Creek Stickleback Species Pairs' watersheds.	High	Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)
Develop land management strategies	Develop land management strategies, including assessing current strategies (for example, Wildlife Habitat Areas), identifying and evaluating land use planning and management options, and developing best management practices and mitigation measures for land use in the species pairs' watersheds.	High	Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)
Develop protocols for scientific investigations of the Paxton Lake and Vananda Creek Stickleback Species Pairs	Update the protocols for scientific investigations that include the collection and use of *in situ* studies to increase scientific understanding of Paxton Lake and Vananda Creek Stickleback Species Pairs (Rosenfeld 2008b).	Medium	Aquatic invasive species; Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation); Scientific collections / *in situ* research
Develop and implement outreach and stewardship projects for the Paxton Lake and Vananda Creek Stickleback Species Pairs	Develop outreach and stewardship projects in support of recovery measures and foster awareness of the Paxton Lake and Vananda Creek Stickleback Species Pairs. Target audiences should include local community members, landowners, industry, recreational groups, and local schools.	High	Aquatic invasive species; Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)
Develop and implement outreach and stewardship projects for the Paxton Lake and Vananda Creek Stickleback Species Pairs	Establish and support a group that undertakes stewardship initiatives that increase understanding and awareness of the Paxton Lake and Vananda Creek Stickleback Species Pairs.	High	Aquatic invasive species; Water management (including water pollution and/or sedimentation); Land use (including habitat loss or degradation)

8. Critical habitat

Critical habitat for Paxton Lake and Vananda Creek Stickleback Species Pairs was originally described in section 2 of the action plan (DFO 2016a). It has been moved with only minor editorial updates to section 8 of this recovery strategy.

8.1 Identification of the species' critical Habitat

8.1.1 General description of the species' critical habitat

Critical habitat is defined in 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*." [s. 2(1)]

Also, SARA defines habitat for aquatic species as "… *spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced*." [s. 2(1)]

For the Paxton Lake and Vananda Creek Stickleback Species Pairs, critical habitat is identified to the extent possible, using the best available information, and provides the functions and features necessary to support the species' life-cycle processes and to achieve the species' population and distribution objectives.

This recovery strategy identifies critical habitat for Paxton Lake and Vananda Creek Stickleback Species Pairs as the entirety of Paxton, Spectacle, Priest and Emily Lakes (each with a 15 m riparian width surrounding their wetted perimeters), as well as the stream and marsh between Emily and Priest Lakes, and the shallow marsh between Spectacle and Priest Lakes (each with a 30 m riparian width surrounding their wetted perimeters). In contrast, critical habitat is not identified for the Enos Lake Stickleback Species Pair because its survival and recovery are not considered feasible with current knowledge.

The critical habitat identified in this recovery strategy for the Paxton Lake and Vananda Creek Stickleback Species Pairs is sufficient to achieve the species' population and distribution objectives.

8.1.2 Information and methods used to identify critical habitat

Critical habitat identification for Paxton Lake and Vananda Creek Stickleback Species Pairs has been informed by the publicly available research document *Identification of Critical Habitat for Sympatric Stickleback Species Pairs and the Misty Lake Parapatric Stickleback Species Pair* (Hatfield 2009), which reflects the outcomes of the related peer review process undertaken through DFO's Canadian Science Advisory Secretariat.

In Hatfield (2009), critical habitat was recommended by applying a three-step framework as suggested in Rosenfeld and Hatfield (2006):

(1) Identification of a population recovery target

Hatfield (2009) considered several different possible population recovery targets for Paxton Lake and Vananda Creek Stickleback Species Pairs; each generated using a different method of analysis or approach to determining the population necessary to ensure genetic viability over the long term.

(2) Determination of a quantitative relationship between habitat and population size

Little information was available to compare habitat availability and abundance for the Paxton Lake and Vananda Creek Stickleback Species Pairs, so a linear relationship between habitat availability and population size was assumed (Hatfield 2009).

(3) Determination of sufficient habitat to meet the recovery target based on the habitat-population relationship.

The results of the analysis of the proportion of existing lake habitat that should be considered critical for each of the different abundance targets identified in step one indicates that the majority or, in some cases, all of the lake habitat is required (Hatfield 2009). Therefore, Hatfield (2009) recommended that the entire lake and a riparian buffer of 15 to 30 m around the lakes be identified as critical habitat for the Paxton Lake and Vananda Creek Stickleback Species Pairs (Hatfield 2009).

Concerns over potential sediment inputs from activities in areas upstream from the lakes and the risk of hybridization of the two forms of stickleback in the lakes led Hatfield (2009) to recommend the inclusion of a riparian buffer of 15 to 30 m in width around all ephemeral and perennial streams flowing into the lakes occupied by the Paxton Lake and Vananda Creek Stickleback Species Pairs.

Recent DFO guidance on critical habitat identification using the bounding box approach, which is described in more detail below, has clarified that critical habitat includes the biophysical features and attributes within an area frequented by the species that provide the functional capacity for the species to carry out its life-cycle processes (DFO 2015). The critical habitat area recommended by Hatfield (2009) was thus adjusted to reflect this new departmental guidance.

8.1.3 Identification of critical habitat

Geographic information

In summary, for the Paxton Lake and Vananda Creek Stickleback Species Pairs, critical habitat is identified as the entirety of Paxton, Spectacle, Priest and Emily Lakes (each with a 15 m riparian width surrounding their wetted perimeters), as well as the stream and marsh between Emily and Priest Lakes, and the shallow marsh between Spectacle and Priest Lakes (each with a 30 m riparian width surrounding their wetted perimeters; figures 4 & 5).

The location(s) of the critical habitat’s functions, features and attributes have been identified using the Bounding Box approach. This means that the critical habitat is not comprised of the entire area within the identified boundaries but only those areas within the identified geographical boundaries where the described biophysical feature and the function it supports occur, as described in table 8.

Figures 4 and 5 show the boundaries and coordinates of the bounding boxes that contain critical habitat features, functions and attributes for the Paxton Lake and Vananda Creek Stickleback Species Pairs. These critical habitat maps are produced based on best available information and are only meant to provide geographical information related to critical habitat.

The geospatial extent of critical habitat for the Paxton Lake and Vananda Creek Stickleback Species Pairs includes the entirety of Paxton, Spectacle, Priest and Emily Lakes and an associated riparian area. Hatfield (2009) recommended that critical habitat for the Paxton Lake and Vananda Creek Stickleback Species Pairs include “a riparian buffer of 15 to 30 m width surrounding the wetted perimeter of [the lakes]”. A 15 m riparian buffer is important for bank stability, woody debris supply, and for food and nutrient inputs from litter fall and insect drop into the lake and streams. The larger 30 m riparian buffer is suggested for areas where shade provides a specific function to the habitat. Shade is not as important for the lakes due to their larger surface area which results in most of the lake receiving sunlight regardless if the riparian buffer is 15 meters or 30 meters. Also, woody debris supply and insect drops are likely more important than shade for the Paxton Lake and Vananda Creek Stickleback Species Pairs (Hatfield 2009). Therefore, the width of the riparian area surrounding the lakes included in the critical habitat bounding box area for the Paxton Lake and Vananda Creek Stickleback Species Pairs is 15 m measured from the wetted perimeter of each lake.

In 2009, Hatfield recommended that a “riparian buffer of 15 to 30 m width surrounding […] all ephemeral and perennial streams flowing into the [species pair] lakes” be included in critical habitat, due to concerns over sediment inputs from upstream activities. Individual sticklebacks are not present in these streams. Subsequent DFO guidance on critical habitat identification using the bounding box approach clarified that critical habitat includes the biophysical features and attributes within an area frequented by the species that provide the functional capacity for the species to carry out its life cycle processes (DFO 2015). Therefore, streams that the Paxton Lake and Vananda Creek Stickleback Species Pairs do not frequent have not been included in critical habitat. The need of the Paxton Lake and Vananda Creek Stickleback Species Pairs for lake habitat that has attributes such as stable light transmission levels (that is, little or no turbidity) in order to successfully spawn and not hybridize has been addressed by identifying these critical habitat attributes as being necessary for the survival and recovery of these two Stickleback Species Pairs in ‘Biophysical Functions, Features and Attributes‘ section below.

Streams that may support movement of benthic and limnetic sticklebacks between lakes in the Vananda Creek watershed are also included in the area containing critical habitat for the Vananda Creek Stickleback Species Pair, along with an associated riparian area of 30 m. This includes the shallow marsh between Spectacle and Priest Lakes, which Sticklebacks move through in both directions, and the stream and marsh between Emily and Priest Lakes, which are also potentially navigable to the Vananda Creek Stickleback Species Pair (COSEWIC 2010a; Taylor and McPhail 2000).

Overall, the geographic extent of critical habitat for the Paxton Lake Stickleback Species Pair includes:

1. The entire Paxton Lake and a riparian area of 15 m width surrounding the wetted perimeter of the lake. The wetted perimeter is to be interpreted on the ground as the high water mark

for ungauged lakes as defined in the *Riparian Areas Regulation*'s Schedule of Assessment Methods (B.C. Reg. 376/2004).[15]

The geographic extent of critical habitat for the Vananda Creek Stickleback Species Pair includes:

1. The entire lakes (Spectacle, Priest and Emily Lakes) and a riparian area of 15 m width surrounding the wetted perimeter of the lakes. The wetted perimeter is to be interpreted on the ground as the high water mark for ungauged lakes as defined in the *Riparian Areas Regulation*'s Schedule of Assessment Methods (B.C. Reg. 376/2004).

2. The shallow marsh between Spectacle and Priest Lakes and a riparian area of 30 m width surrounding the wetted perimeter of the marsh. The wetted perimeter of the marsh is to be interpreted on the ground as the high water mark for streams and wetlands, respectively, as defined in the *Riparian Areas Regulation*'s Schedule of Assessment Methods (B.C. Reg. 376/2004).[16]

3. The stream and marsh between Emily and Priest Lakes and a riparian area of 30 m width surrounding the wetted perimeter of both sides of the stream and surrounding the wetted perimeter of the marsh. The wetted perimeter of the stream and marsh is to be interpreted on the ground as the high water mark for streams and wetlands, respectively, as defined in the *Riparian Areas Regulation*'s Schedule of Assessment Methods (B.C. Reg. 376/2004).

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[15] The *Riparian Areas Regulation*'s Schedule of Assessment Methods defines the high water mark for ungauged lakes as "*where the presence and action of annual flood waters area is so common and usual and so long continued in all ordinary years, as to mark on the soil of the bed of the body of water a character distinct from that of its banks, in vegetation, as well as in the nature of the soil itself and includes areas that are seasonally inundated by floodwaters."*

[16] The *Riparian Areas Regulation*'s Schedule of Assessment Methods defines the high water mark for streams as "*the visible high water mark of a stream where the presence and action of the water are so common and usual, and so long continued in all ordinary years, as to mark on the soil of the bed of the stream a character distinct from that of its banks, in vegetation, as well as the nature of the soil itself, and includes the active floodplain"*. The *Riparian Areas Regulation*'s Schedule of Assessment Methods defines the outer edge of wetlands as "*from an ecological perspective, either an abundance of hydrophytes or hydric soil conditions is generally sufficient to indicate a wetland ecosystem. The boundary or high water mark of the wetland is identified by changes in vegetation structure, loss of obligate hydrophytes, and absence of wetland soil characteristics.*"

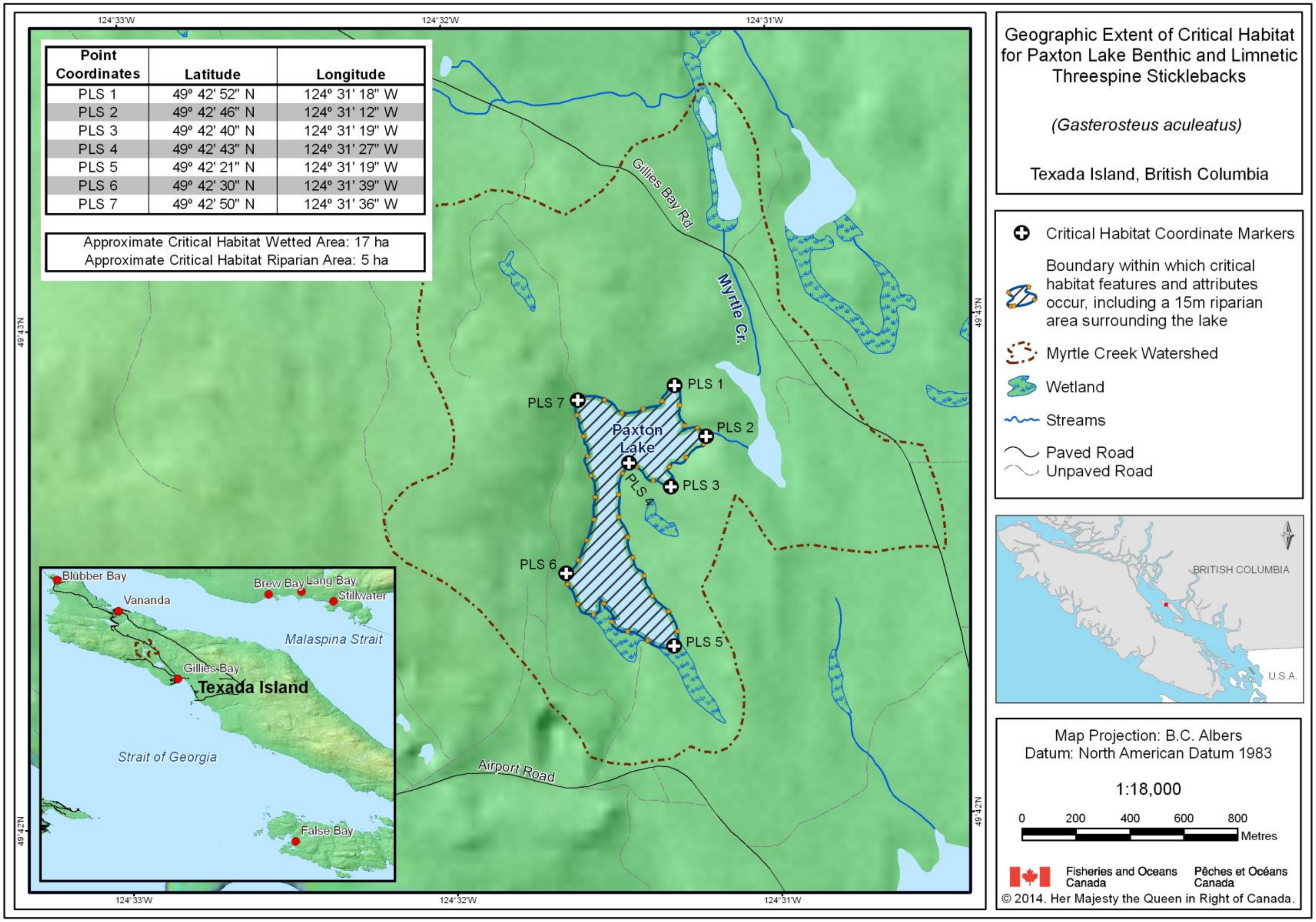
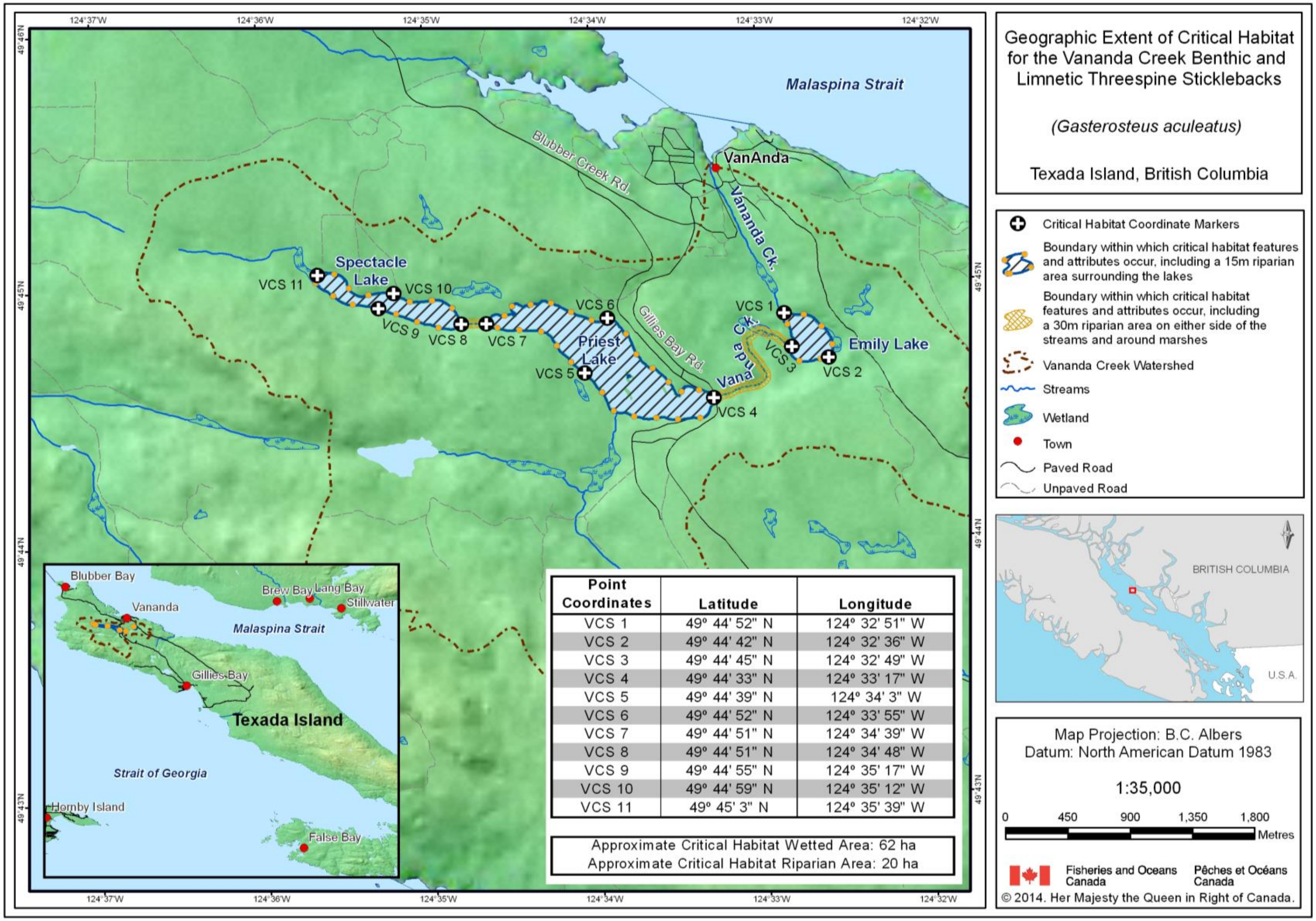


Figure 4. Geographic Extent of Critical Habitat for the Paxton Lake Benthic and Limnetic Threespine Sticklebacks.



Point Coordinates	Latitude	Longitude
VCS 1	49° 44' 52" N	124° 32' 51" W
VCS 2	49° 44' 42" N	124° 32' 36" W
VCS 3	49° 44' 45" N	124° 32' 49" W
VCS 4	49° 44' 33" N	124° 33' 17" W
VCS 5	49° 44' 39" N	124° 34' 3" W
VCS 6	49° 44' 52" N	124° 33' 55" W
VCS 7	49° 44' 51" N	124° 34' 39" W
VCS 8	49° 44' 51" N	124° 34' 48" W
VCS 9	49° 44' 55" N	124° 35' 17" W
VCS 10	49° 44' 59" N	124° 35' 12" W
VCS 11	49° 45' 3" N	124° 35' 39" W

Figure 5. Geographic Extent of Critical Habitat for the Vananda Creek Benthic and Limnetic Threespine Sticklebacks.

Biophysical functions, features and attributes

Table 8 summarizes the best available knowledge of the functions, features and attributes for each life stage and for each geographic location of the Paxton Lake and Vananda Creek Stickleback Species Pairs (refer to section 4.3 'needs of the species' for full references). Note that not all attributes in table 8 must be present in order for a feature to be identified as critical habitat. If the features as described in table 8 are present and capable of supporting the associated function(s), the feature is considered critical habitat for the species, even though some of the associated attributes might be outside of the range indicated in the table.

A key function of critical habitat features and attributes for the Paxton Lake and Vananda Creek Stickleback Species Pairs is to provide reproductive separation and prevent hybridization. Achieving the population and distribution objectives of the species pairs and preventing an increase in hybridization between the benthic and limnetic species, depend on:

1) Critical habitat features and attributes that control the abundance of the limnetic and benthic species (that is, population size), and,

2) Critical habitat features and attributes that provide reproductive separation through proper mate recognition.

As a group, Sticklebacks are relatively hardy species tolerant to a fairly large range of water quality conditions. Until more information becomes available, the B.C. *Water Quality Guidelines* serve as a general guideline for water quality parameters for lake critical habitat features and attributes (Hatfield 2009).

Table 8. General summary of the biophysical functions, features, attributes and location of critical habitat critical for the survival or recovery of Paxton Lake and Vananda Creek Stickleback Species Pairs.

Geographic location	Life stage (if more than one)	Function(s)[17]	Feature(s)[18]	Attribute(s)[19]
Paxton, Spectacle, Priest and Emily Lakes	Benthic eggs, fry, juveniles and adults Limnetic eggs, fry, juveniles and adults	Nursery, rearing, foraging (except for limnetic adults) and resting	Lake littoral habitat	• Stable faunal community, free of aquatic invasive species • Presence of macrophyte beds (within natural range of abundance) • Physical habitat complexity, including fallen logs • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Stable lake water levels (within the natural range of variation) • Adequate food supply, including benthic invertebrates
Paxton, Spectacle, Priest and Emily Lakes	Benthic and limnetic adults	Mating, spawning and nest creation and defense	Lake littoral habitat	• Stable water clarity and transmission of light (that is, little or no turbidity) • Suitable substrate for nest building • Stable faunal community, free of aquatic invasive species • Presence of macrophyte beds (within natural range of abundance) • Physical habitat complexity, including fallen logs • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Stable lake water levels (within the natural range of variation) • Adequate food supply, including benthic invertebrates

[17] Function: A life-cycle process of the listed species taking place in critical habitat (for example, spawning, nursery, rearing, feeding and migration).
[18] Feature: Features describe *how* the habitat is critical and they are the essential structural component that provides the requisite function(s) to meet the species' needs. Features may change over time and are usually composed of more than one part, or attribute. A change or disruption to the feature or any of its attributes may affect the function and its ability to meet the biological needs of the species.
[19] Attribute: Attributes are measurable properties or characteristics of a feature. Attributes describe how the identified features support the identified functions necessary for the species' life processes.

Geographic location	Life stage (if more than one)	Function(s)[17]	Feature(s)[18]	Attribute(s)[19]
Paxton, Spectacle, Priest and Emily Lakes	Limnetic juveniles and adults	Rearing, foraging and resting	Lake pelagic habitat	• Stable faunal community, free of aquatic invasive species • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Adequate food supply, including zooplankton
Paxton, Spectacle, Priest and Emily Lakes	Benthic and limnetic Juveniles and adults	Overwintering and winter foraging	Lake pelagic habitat	• Stable faunal community, free of aquatic invasive species • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Adequate food supply
Paxton, Spectacle, Priest and Emily Lakes	Benthic eggs, fry, juveniles and adults Limnetic eggs, fry, juveniles and adults	Mating, spawning, nest creation and defence, nursery, rearing, foraging, resting	Riparian area surrounding wetted perimeters of the lakes	• Physically stable foreshore environment (for example, stable riparian banks) • Sufficient riparian vegetation to provide food and nutrients • Adequate supply of cover (large woody debris, overhanging vegetation) • Adequate filtering and absorption of surface water run-off
Shallow marsh between Spectacle and Priest Lakes	Vananda Creek benthic and limnetic adults and juveniles	Movement and migration	Stream and marsh habitat	• Free of barriers to movement by fish • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation)
Stream and marsh between Emily and Priest Lakes	Vananda Creek benthic and limnetic adults and juveniles	Movement and migration	Riparian area surrounding wetted perimeters of the streams and marshes	• Physically stable foreshore environment (for example, stable riparian banks) • Sufficient riparian vegetation to provide food and nutrients • Adequate supply of cover (large woody debris, overhanging vegetation) • Adequate filtering and absorption of surface water run-off

Brief discussions on the habitat features and attributes are provided below, adopted from the work by Hatfield (2009) and the Status Reports (COSEWIC 2010a, 2010b).

<u>Critical habitat feature – lake littoral habitat</u>

Lake littoral habitat serves important spawning and rearing functions for the Paxton Lake and Vananda Creek Stickleback Species Pairs. During spawning season, benthic adults build their nests under cover of macrophytes or other structures, while limnetic adults tend to spawn in open habitats (McPhail 1994; Hatfield and Schluter 1996; Hatfield 2009). Both limnetic and benthic stickleback fry are reared in the littoral zone (Hatfield 2009). Littoral macrophyte beds constitute both a source of food (benthic invertebrates associated with the lake bottom and macrophyte surfaces) and refuge from predation (COSEWIC 2010a, 2010b). As juveniles, the limnetic species is common along steep, rocky, unvegetated littoral shorelines, compared to the benthic species which shelters around macrophytes in littoral areas (Gow pers. comm., as cited in Hatfield 2009). As adults, the limnetic species feeds on zooplankton in the pelagic zone of the lake, whereas benthic adults remain in the littoral zone feeding on benthic invertebrates (Schluter 1995).

<u>Critical habitat attribute</u> – *stable faunal community, free of aquatic invasive species*

Maintaining a stable faunal community, including the macrophyte community, fish, zooplankton and macroinvertebrates which all contribute to the lake ecosystem as a whole, is necessary if the Paxton Lake and Vananda Creek Stickleback Species Pairs are to be conserved (Hatfield 2009). The Paxton Lake and Vananda Creek Stickleback Species Pairs have evolved in coastal freshwater systems where only one other fish species exists - Coastal Cutthroat Trout (Vamosi 2003). A stable ecological community for the lakes containing these species pairs is crucial, as any invasive species in the lake habitat can easily upset the balance of the lake ecosystem. This is exemplified by the rapid extinction of the Hadley Lake Stickleback Species Pair following the invasion of Brown Bullhead, and the collapse of the Stickleback Species Pair at Enos Lake on Vancouver Island following the appearance of Signal Crayfish (Taylor *et al*. 2006; Behm *et al*. 2010; Rosenfeld *et al*. 2008a). A stable ecological community structure free of invasive species is critical to the survival of the Paxton Lake and Vananda Creek Stickleback Species Pairs.

<u>Critical habitat attributes</u> – *presence of macrophyte beds (within natural range of abundance); physical habitat complexity, including fallen logs*

Macrophyte beds represent an important attribute of critical habitat for the Paxton Lake and Vananda Creek Stickleback Species Pairs. Macrophyte beds in the littoral zone constitute the primary nesting and spawning locations for the benthic species as well as key rearing habitats for juveniles of both species. Due to different nest selection with respect to macrophyte coverage and its associated habitat complexity, macrophyte beds indirectly help to maintain mate recognition and reproductive isolation between the benthic and limnetic species (McPhail 1994; Hatfield and Schluter 1996). Macrophytes stabilize littoral zone substrates and significantly contribute to the production of benthic macroinvertebrates that support the benthic species. They help limit lake turbidity, which is an important factor for accurate mate recognition. As a result they also indirectly contribute to light transmission level (Hatfield 2009), another critical habitat attribute. The complex physical habitat structure that macrophyte beds provide is identified as a critical habitat attribute, since the observed hybridization and collapse of the Enos Lake Stickleback Species Pair coincides with the appearance of crayfish and the loss of macrophytes (Taylor *et al*. 2006; Behm *et al*. 2010).

The natural temporal range in distribution and abundance of macrophyte beds is unknown. The specific extent of macrophyte loss that can be sustained before hybridization rates reach a level causing the species to collapse into a hybrid swarm is also unknown. It is recommended, therefore, that macrophyte abundance and distribution be maintained within the natural range currently found in each lake (Hatfield 2009).

Other elements of physical habitat structure, such as fallen logs, are also an important source of cover for Sticklebacks.

Critical habitat attribute – *stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation)*

Stable water quality parameters in both pelagic and littoral habitats are important for healthy stickleback populations. These include chemical and physical parameters such as pH, dissolved oxygen, turbidity, suspended solids, nutrients, dissolved organic carbon and low pollutant levels.

Solitary stickleback populations exist across a broad range of lake productivities in B.C. (Lavin and McPhail 1985, 1986 and 1987). In contrast, Stickleback Species Pairs, such as the Paxton Lake and Vananda Creek Stickleback Species Pairs, are generally found in lakes with relatively high productivity, typically with calcareous bedrock present in the watershed, but may be found in watersheds characterized by other bedrock types (McPhail 1994, D. Schluter pers. comm.). The evolution of Stickleback Species Pairs is believed to have been possible only under specific levels of benthic and pelagic invertebrate production that facilitated exclusive adaptations to either a pelagic (zooplankton) or littoral (benthic invertebrate) food resource. Changes to water quality parameters, including nutrient levels that alter the relative productivity of zooplankton and benthos, could alter the selective environment in which Stickleback Species Pairs exist (Schluter 1995; Vamosi *et al*. 2000). Altered nutrient status may lead to demographic collapse or hybridization between the two species by altering the fitness of limnetic, benthic or hybrid species.

As a group, sticklebacks are tolerant of a fairly large range of water quality conditions. The precise needs of the Paxton Lake and Vananda Creek Stickleback Species Pairs are unknown but are believed to be similar to other stickleback species (Hatfield 2009). The B.C. *Water Quality Guidelines* are considered appropriate for basic water quality parameters for the Paxton Lake and Vananda Creek Stickleback Species Pairs.

Critical habitat attribute – *stable lake water levels (within the natural range of variation)*

Lake water levels can be subject to human influence through the construction of dams and the extraction of water. Water licenses currently allow substantial volumes to be extracted from several lakes that are home to Paxton Lake and Vananda Creek Stickleback Species Pairs, and, in some cases the annual extraction volume exceeds the volume of the lake (Larson 1976; Government of British Columbia 2016).

Since lake water levels can affect littoral habitat and macrophyte abundance, water level stability is important to the persistence of the Paxton Lake and Vananda Creek Stickleback Species Pairs. The relative extent of littoral habitat may affect reproductive isolation during nesting, growth and survival of juveniles of both species, adult abundance and individual size, as well as hybrid fitness (COSEWIC 2010a, 2010b). Variation in the extent of littoral habitat outside of the natural range will significantly increase the probability of species hybridization and collapse. Based on genetic evidence, historic hybridization has been considerably higher in the Paxton Lake Stickleback Species Pair than in other species pairs (Taylor and McPhail 1999, as cited in COSEWIC 2010a). This higher rate of hybridization is thought to be consistent with the higher rate of historical perturbations, including drawdowns from water extraction, in Paxton Lake (COSEWIC 2010a).

Critical habitat attributes – *stable water clarity and transmission of light (that is, little or no turbidity)*

Light transmission levels and water clarity are an important attribute of the littoral habitat feature during spawning season. Changes in these attributes can be a significant issue for the reproductive success of the Paxton Lake and Vananda Creek Stickleback Species Pairs. Differences in breeding coloration between benthic and limnetic species are key cues used in mate discrimination and reproductive isolation (Boughman 2001). Changes in concentration of suspended solids, dissolved organic carbon (for example, tannins), or other aspects of lake water quality that affect light transmission may disrupt mate recognition using visual cues, and could compromise the reproductive isolation between the benthic and limnetic species of the Paxton Lake and Vananda Creek Stickleback Species Pairs (Engström-Öst and Candolin 2007; Hatfield 2009). The possible collapse of Enos Lake Stickleback Species Pair into a hybrid swarm may also be attributed to the altered turbidity or water colour caused by invasive species (Taylor *et al*. 2006). No published data is available to quantify this attribute; however, it is reasonable to infer that a stable level of light transmission in the littoral habitat is critical in the spawning season.

Critical habitat attribute – *adequate food supply, including benthic invertebrates*

The availability of an adequate supply of food is an important attribute of littoral and pelagic critical habitat features for benthic and limnetic sticklebacks. Both benthic and limnetic fry feed in inshore areas once they leave the nest (Schluter 1995). Limnetic adults feed on zooplankton in the pelagic zone of the lake, whereas benthic adults remain in the littoral zone and feed on benthic invertebrates (Schluter 1995).

Critical habitat feature – lake pelagic habitat

Pelagic habitat is critical to the Paxton Lake and Vananda Creek Stickleback Species Pairs as it provides adult and juvenile rearing and overwintering functions. Adult limnetic stickleback, with the exception of nesting males, feed on zooplankton in the pelagic zone of the lake (Schluter 1995). By late summer individuals begin moving to deeper water habitats where they overwinter (Hatfield 2009). It is reasonable to infer that, similar to littoral habitat, overwintering populations will require pristine pelagic lake environments. As such, critical pelagic lake habitat attributes will include a stable ecological lake community structure, free of invasive species, as well as favorable water quality parameters (for example, temperature, pH, dissolved oxygen, turbidity, suspended solids and nutrients).

Critical habitat feature – riparian area surrounding wetted perimeters of lakes, streams and marshes

On riparian areas and their function as critical habitat for the Paxton Lake and Vananda Creek Stickleback Species Pairs, Hatfield (2009) states:

> "Riparian zones form a physical transition zone between aquatic and terrestrial ecosystems, and there are often strong physical and biological interactions between the two. For fish, riparian zones offer three important functions: streambank and lakeshore

> stability (for example, roots bind soils and prevent erosion or sloughing), instream cover (for example, large and small woody debris, overhanging vegetation), and food (for example, insect fall and contribution to invertebrate food sources). There are abundant data demonstrating the importance of riparian areas to physical processes, general ecology, and fish populations in lakes and streams […], though admittedly there is considerably more information available for streams than for lakes."

Based on the discussion offered by Hatfield (2009), the riparian area critical habitat feature has the following attributes:

<u>Critical habitat attribute</u> – *physically stable foreshore environment (for example, stable riparian banks) and adequate filtering and absorption of surface water run-off*

Of special significance to the Paxton Lake and Vananda Creek Stickleback Species Pairs is the role of vegetated riparian areas in preventing additional sediment from entering the lakes. Increased sedimentation could lead to increases in lake turbidity that may potentially trigger increased hybridization between the species pairs, particularly if the increased turbidity occurs during the breeding season. Vegetated riparian areas increase bank stability as plant roots bind soils, thereby reducing sedimentation. They also filter and absorb surface water run-off that could otherwise carry high sediment loads into the lakes.

<u>Critical habitat attribute</u> – *adequate supply of cover (large woody debris, overhanging vegetation)*

As described by Hatfield (2009), the provision of in-stream cover by a supply of large woody debris and overhanging vegetation is an important function of the riparian zone.

<u>Critical habitat attributes</u> – *sufficient riparian vegetation to provide food and nutrients*

Lake riparian areas contribute to the energy base of aquatic ecosystems through inputs of leaves, dissolved nutrients and insect fall; such external inputs can amount to up to half of the carbon base of lake ecosystems (Pace *et al*. 2004), particularly in small lakes with large perimeter to area ratios. Typically the contribution is less than half, but has been measurable in many studies (for example, France and Peters 1995; France *et al*. 1996; France and Steedman 1996).

Riparian areas provide inputs of terrestrial invertebrates that are directly consumed by fish; large woody debris inputs from the riparian zone also provide substrate for invertebrates and structural heterogeneity that influences fish abundance and the ecology of the littoral zone (Schindler *et al*. 2000; Christensen *et al*. 1996). Again it is difficult to quantify this critical habitat attribute. However it is reasonable to infer that integrity of riparian areas plays an important role in maintaining a stable food supply to aquatic environment.

<u>**Critical habitat feature – stream and marsh habitat**</u>

The three lakes containing a Stickleback Species Pair in the Vananda Creek watershed are connected by stream and marsh habitat. Benthic and limnetic sticklebacks move through the shallow marsh between Spectacle and Priest Lakes in both directions (COSEWIC 2010b). The stream and marsh between Emily and Priest Lakes are also potentially navigable to sticklebacks (Taylor and McPhail 2000). As well as providing for the movement of Sticklebacks between lakes and creating opportunities for gene flow between the lake populations, riparian areas beside these habitats provide sources of terrestrial invertebrates and large woody debris as described earlier.

Summary of critical habitat relative to population and distribution objectives

These are areas that the Minister of Fisheries and Oceans considers necessary to achieve the species' population and distribution objectives required for the survival and recovery of the species that are outlined in section 6.

8.2 Examples of activities likely to result in the destruction of critical habitat

Under SARA, critical habitat must be legally protected from destruction within 180 days of being identified in a final recovery strategy or action plan and included in the Species at Risk Public Registry. For the Paxton Lake and Vananda Creek Stickleback Species Pairs' critical habitat, it is anticipated that this will be accomplished through a SARA Critical Habitat Order made under subsections 58(4) and (5), which will invoke the prohibition in subsection 58(1) against the destruction of the identified critical habitat.

In addition to this prohibition, various other mechanisms are expected to aid in the protection of critical habitat. For example, the B.C. Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) established an 881 ha Wildlife Habitat Area (WHA) #2 to 250[20] on provincial Crown land for Vananda Creek Stickleback Species Pairs under the *Government Actions Regulation* (B.C. Reg. 582/2004) of the *Forest and Range Practices Act* (FRPA) in 2013. *Forest Act* and *Range Act* agreement-holders who prepare and submit plans and who conduct forest or range practices must comply with the WHA and general wildlife measures (GWMs) that apply to it.[21] MFLNRO also established a WHA (#2 to 250) in 2015 under the *Environmental Protection and Management Regulation* (EPMR; B.C. Reg. 200/2014) of the *Oil and Gas Activities Act* (OGAA) encompassing the same geographic area as FRPA's WHA #2 to 250. WHAs established under the OGAA do not include GWMs, as authority for regulating oil and gas activities in the WHA is transferred from MFLNRO to the Oil and Gas Commission (OGC) upon its establishment. WHA designations under the EPMR are considered by the OGC in adjudicating oil and gas activity permits.[22]

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[20] WHA #2 to 250 under FRPA

[21] Specifically, the WHA establishes (among others) GWMs that describe what forest or range practices may or may not be permitted within its boundaries, such as: timber harvest and salvage; development of roads, trails, landings, recreation sites, facilities and structures; use of pesticides; and, surface erosion, sediment delivery, and turbidity.

[22] This OGAA WHA would bring into effect the EPMR's "government's environmental objectives" for that area of wildlife habitat. Specifically, the OGC must be satisfied that: there is no "material adverse effect on the ability of the wildlife habitat within the wildlife habitat area to provide for the survival, within the wildlife habitat area, of the wildlife species for which the wildlife habitat area was established" and "that oil and gas activities on an operating area outside of a wildlife habitat area be carried out at a time and in a manner that does not result in physical disturbance to high priority wildlife or their habitat, including disturbance during sensitive seasons and critical life-cycle stages" (B.C. Reg. 200/2014). Depending on

The Powell River Regional District has also enacted the Texada Island Watershed Protection Bylaw No. 237, 1993. This bylaw has (among other actions) delineated zones surrounding Priest and Spectacle Lakes “to protect the Priest Lake Watershed from deleterious activity and uses which would tend to result in erosion, siltation and pollution of essential water resources” and “to permit only those uses and activities on the Lakes which are compatible with the maintenance of the water in the Lakes in a natural state.”[23]

Both the WHA #2 to 250 and the Texada Island Watershed Protection Bylaw No. 237, 1993 are considered beneficial to critical habitat protection given the current understanding of the nature and extent of the identified threats to the species.

Because the identified critical habitat is for both the limnetic and the benthic forms of the Paxton Lake and Vananda Creek Stickleback Species Pairs, which together make up the species complex for each pair, the destruction of critical habitat for one species could have significant consequences for the other species of the pair, in terms of effects on the health of individuals, their residences and their identified critical habitat. The legal protections provided by SARA apply equally to both the benthic and limnetic species of the Paxton Lake and Vananda Creek Stickleback Species Pairs.

The following examples of activities likely to result in the destruction[24] of critical habitat (table 9) are based on known human activities that are likely to occur in and around critical habitat and would result in the destruction of critical habitat if unmitigated. The list of activities is neither exhaustive nor exclusive and has been guided by the threats described in section 5. The absence of a specific human activity from this table does not preclude or restrict the Department’s ability to regulate that activity under the SARA. Furthermore, the inclusion of an activity does not result in its automatic prohibition, and does not mean the activity will inevitably result in destruction of critical habitat. Every proposed activity must be assessed on a case-by-case basis and site-specific mitigation will be applied where it is available and reliable. Where information is available, thresholds and limits have been developed for critical habitat attributes to better inform management and regulatory decision making. However, in many cases knowledge of a species and its critical habitat’s thresholds of tolerance to disturbance from human activities is lacking and must be acquired.

Table 9 contains examples of activities that are likely to destroy critical habitat for the Paxton Lake and Vananda Creek Stickleback Species Pairs. Detailed explanations follow the table.

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the OGC’s ability to answer these two questions, an oil and gas operating area in a WHA may or may not be approved.

[23] Texada Island Watershed Protection Bylaw No. 237, 1993

[24] Destruction occurs when there is a temporary or permanent loss of a function of critical habitat at a time when it is required by the species.

Table 9. Examples of activities likely to result in the destruction of critical habitat.

Threat	Activity	Effect pathway	Function affected	Feature affected	Attribute affected
Aquatic invasive species	Introduction through deliberate or inadvertent human actions potentially leading to subsequent establishment of non-native aquatic species into lakes	Alteration of water quality which could impact water clarity required for mate recognition. Change in vegetation community composition or structure which may affect reproductive isolation and nesting sites. Change in the faunal community that results in impacts to Stickleback populations, either directly through increased predation or displacement from nesting habitat leading to recruitment failure, or indirectly through competition for food and resources or reduced availability of prey.	Rearing, foraging and resting Mating, spawning and nest creation and defense Overwintering and foraging	Lake pelagic habitat Lake littoral habitat	• Stable faunal community, free of aquatic invasive species • Presence of macrophyte beds (within natural range of abundance) • Physical habitat complexity, including fallen logs • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Suitable substrate for nest building • Adequate food supply including zooplankton and benthic invertebrates

Threat	Activity	Effect pathway	Function affected	Feature affected	Attribute affected
Habitat loss and degradation	Substantial riparian vegetation removal within the defined riparian areas	Reduction in bank stability leading to an increase in sediment inputs to water, which could: - impact water clarity required for mate recognition while spawning; and/or - change aquatic vegetation cover or the food and nutrient regime in the lakes. Reduction in vegetative cover from predators and terrestrially-derived food. Increases in amount of sunlight reaching the lake(s), stream or marsh enhancing algal production and leading to temporary loss of habitat. Alteration of water quality (for example, nutrients, sediment, turbidity, etc.). See pathway for Aquatic invasive species and Water pollution.	Rearing, foraging and resting Mating, spawning and nest creation and defense Overwintering and foraging	Lake pelagic habitat Lake littoral habitat Riparian area surrounding wetted perimeters of lakes, streams and marshes	• Physically stable foreshore environment (for example, stable riparian banks) • Sufficient riparian vegetation to provide food and nutrients • Adequate supply of cover (large woody debris, overhanging vegetation) • Adequate filtering and absorption of surface water run-off • Physical habitat complexity, including fallen logs • Stable water clarity and transmission of light (that is, little or no turbidity) • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Suitable substrate for nest building

Threat	Activity	Effect pathway	Function affected	Feature affected	Attribute affected
Water pollution	Non-point source pollution and changes in water quality resulting from land use practices, for example, from road construction, and poorly maintained roads, stream crossings, and transmission routes	Increase in sediment inputs to water could impact water clarity required for mate recognition while spawning.	Mating, spawning and nest creation and defense	Lake littoral habitat	• Stable water clarity and transmission of light (that is, little or no turbidity) • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Suitable substrate for nest building
Water extraction / impoundment	Excessive water extraction and/or impoundment resulting in changes to lake levels	Impoundment and/or excessive water extraction could alter lake littoral and pelagic area ratios. This could result in changes to macrophyte beds and physical habitat structure, which would affect Stickleback nesting, foraging and spawning. Changes to lake levels could result in reduced availability of habitat for spawning and foraging.	Rearing, foraging and resting Mating, spawning and nest creation and defense	Lake pelagic habitat Lake littoral habitat	• Physical habitat complexity, including fallen logs • Stable water quality parameters, including temperature, pH, dissolved oxygen, turbidity, suspended solids, dissolved organic carbon and nutrients (within the natural range of variation) • Suitable substrate for nest building • Presence of macrophyte beds (within natural range of abundance) • Stable lake water levels (within the natural range of variation)

Aquatic invasive species (AIS)

The fish communities in the lakes that are home to the Paxton Lake and Vananda Creek Stickleback Species Pair only contain Sticklebacks and Coastal Cutthroat Trout (Larson 1976). This simple fish community is considered to be a major determinant of the existence of Stickleback Species Pairs in general (Vamosi 2003; Ormond 2010). One of the greatest threats to the Paxton Lake and Vananda Creek Stickleback Species Pairs is from the introduction of AIS through deliberate or inadvertent human activities (Hatfield 2009). Introduction pathways may include the use of live bait, unauthorized aquatic species transfer or stocking, pet and aquarium releases, unintentional species transfer from outdoor ponds or recreational boating, introduction and cultivation of live food fish (for example, crayfish), deliberate or malicious introduction, and range expansion of invasive species. AIS may threaten Stickleback populations directly (for example, predation or displacement from nesting habitat leading to recruitment failure) or indirectly (for example, competition for food resources, or alteration of the selective regime of their habitat).

The introduction of invasive species has been implicated in the loss of two of five of the known Benthic-Limnetic Stickleback Species Pairs. The Hadley Lake Benthic-Limnetic Stickleback Species Pair on Lasqueti Island, B.C. became extinct within five years following the introduction of Brown Bullhead (Hatfield 2001). The Stickleback Species Pair in Enos Lake on Vancouver Island may have collapsed due to hybridization that coincided with the appearance of Signal Crayfish (Taylor *et al.* 2006; Behm *et al*. 2010).

Habitat loss and degradation and water pollution

The lands in the Paxton Lake and Vananda Creek watersheds have had a long history of disturbances, including rock quarrying, forest harvesting and other development. Landscape alteration and riparian loss from these practices have potential to result in increased turbidity and sedimentation of the lakes from run-off over exposed lands or roads. The tolerance of the Paxton Lake and Vananda Creek Stickleback Species Pairs to changes in water quality is unknown. However, adverse changes in lake water quality can be expected to adversely affect water transparency (for example, increased turbidity or dissolved organic carbon, with resultant reduction of light transmission levels), which in turn may disrupt reproductive isolation mechanisms of Paxton Lake and Vananda Creek Stickleback Species Pairs by interfering with female mate discrimination, and subsequently elevate the hybridization rate (Engström-Öst and Candolin 2007). An increase in hybridization rate by as little as 3% is sufficient to cause the collapse of benthic and limnetic species into a hybrid swarm (Wood *et al*. 2004).

Riparian loss or alteration may also cause increased lake temperatures and reduce food and nutrient inputs to foreshore environments. Such changes in lake ecology may lead to littoral habitat changes which could alter optimum rearing and spawning conditions and affect Stickleback population dynamics.

Water extraction / impoundment:

In the Paxton Lake and Vananda Creek watersheds, lake levels are affected by the diversion and storage of water. Existing licenses are large relative to the volume of some of the lakes and size of the catchments. For example, existing water licenses on Paxton Lake allow annual diversions of more than twice the volume of the lake, yet inflows are low due to a small catchment area and limited precipitation (Government of British Columbia 2016). Severe drawdowns have occurred in the past as a result of mining operations (Larson 1976). The community of Van Anda depends on water extraction from the Vananda Creek watershed for its drinking water supply and for firefighting. Licensed annual diversion rates total around 15% of Priest Lake volume and about 82% of Emily Lake volume (Harvey and Brown 2013). Depending on the timing and duration of extractions, lake level drawdown may cause loss of the effective littoral zone available for foraging and nesting as critical habitat functions. Large drawdowns and subsequent lake impoundment can shrink lake volume and depth to such an extent that pelagic habitat essentially disappears and littoral habitat is all that remains, or can adversely impact littoral habitat growth and quality which affects habitat availability and productivity. Such modifications can also adversely affect water temperatures. Effects from water extraction and impoundment can result in direct effects on the Paxton Lake and Vananda Creek Stickleback Species Pairs by reducing available spawning and foraging habitat.

9. Measuring progress

The performance indicators presented below provide a way to define and measure progress towards achieving the population and distribution objectives:

1. Observe a stable or positive trend in Paxton Lake and Vananda Creek Stickleback Species Pairs population abundances by 2022, taking into account natural variation
2. Confirm stable spatial distribution of Paxton Lake and Vananda Creek Stickleback Species Pairs by 2022, taking into account natural variation

Progress towards meeting these objectives will be reported on in the report on the progress of recovery strategy implementation.

10. Statement on action plans

The federal government’s approach to recovery planning is a two-part approach, the first part being the recovery strategy and the second part being the action plan. An action plan contains specific recovery measures or activities required to meet the objectives outlined in the recovery strategy.

A joint Action Plan for Paxton Lake and Vananda Creek Stickleback Species Pairs was posted on the Species at Risk Public Registry in 2016 and 2018.

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Appendix A: effects on the environment and other species

In accordance with the Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals (2010), SARA recovery planning documents incorporate strategic environmental assessment (SEA) considerations throughout the document. The purpose of a SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally sound decision-making and to evaluate whether the outcomes of a recovery planning document could affect any component of the environment or achievement of any of the Federal Sustainable Development Strategy's goals and targets.

Recovery planning is intended to benefit species at risk and biodiversity in general. However, it is recognized that strategies may also inadvertently lead to environmental effects beyond the intended benefits. The planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts upon non-target species or habitats. The results of the SEA are incorporated directly into the strategy itself, but are also summarized below in this statement.

This recovery strategy will clearly benefit the environment by promoting the recovery of Paxton Lake and Vananda Creek Stickleback Species Pairs. The potential for the strategy to inadvertently lead to adverse effects on other species was considered. The broad strategies to recovery suggested in table 7 will likely benefit other species (for example, by maintaining habitat area and quality). Furthermore, the other species that are known to co-exist with these species pairs are widely distributed. For information on how the recovery strategy and these species pairs potentially link to, or interact with, other species and the ecosystem, refer to the following sections of the document: 'Species Description', 'Needs of the Species', 'Threats, Strategic Direction for Recovery', and 'Identification of the Species' Critical Habitat'. The management actions implemented to mitigate threats to the Paxton Lake and Vananda Creek Stickleback Species Pairs are, therefore, unlikely to negatively affect other indigenous species. The SEA concluded that this strategy will clearly benefit the environment and will not result in any significant adverse effects.

Appendix B: record of cooperation and consultation

Recovery strategies are to be prepared in cooperation and consultation with other jurisdictions, organizations, affected parties and others as outlined in SARA section 39.

The 2007 recovery strategy was developed by the former Stickleback Species Pairs Recovery Team, a group made up of DFO and Province of B.C. staff, as well as representation from academia and consulting. Consultation on the draft 2007 recovery strategy was provided through a series of multi-stakeholder Community Dialogue Sessions and First Nations information exchanges in B.C. communities as part of DFO Pacific Region's Fall Consultation Program. Further details on those consultations can be found in Appendix I of the Recovery Strategy for Paxton Lake, Enos Lake, and Vananda Creek Stickleback Species Pairs (*Gasterosteus spp.*) in Canada (National Recovery Team for Stickleback Species Pairs 2007).

This 2019 amended recovery strategy updates the 2007 recovery strategy. In May 2017, the draft amended recovery strategy was circulated to Indigenous organizations, local, regional and provincial governments, academia, environmental non-government organizations, and industry for a 30-day external review. Comments resulted in minor revisions to species descriptions and clarifications of critical habitat features and attributes.

Critical habitat identification and its anticipated protection mechanism were consulted on during consultations for the Action Plan for the Paxton Lake and Vananda Creek Stickleback Species Pairs (*Gasterosteus aculeatus*) in Canada. Details on those consultations can be found in Appendix B of the Action Plan for the Paxton Lake and Vananda Creek Stickleback Species Pairs (*Gasterosteus aculeatus*) in Canada (DFO 2018).

Additional stakeholder, Indigenous, and public input was sought through the publication of the proposed amended Recovery Strategy on the Species at Risk Public Registry for a 60-day public comment period (October 17 to December 16, 2018). No feedback was received.