Recovery Plan for Mexican Mosquito Fern (*Azolla mexicana*) in British Columbia

Prepared by the British Columbia Ministry of Environment

BRITISH COLUMBIA

April 2016

About the British Columbia Recovery Strategy Series

This series presents the recovery documents that are prepared as advice to the Province of British Columbia on the general approach required to recover species at risk. The Province prepares recovery documents to ensure coordinated conservation actions and to meet its commitments to recover species at risk under the *Accord for the Protection of Species at Risk in Canada* and the *Canada–British Columbia Agreement on Species at Risk*.

What is recovery?

Species at risk recovery is the process by which the decline of an endangered, threatened, or extirpated species is arrested or reversed, and threats are removed or reduced to improve the likelihood of a species' persistence in the wild.

What is a provincial recovery document?

Recovery documents summarize the best available scientific and traditional information of a species or ecosystem to identify goals, objectives, and strategic approaches that provide a coordinated direction for recovery. These documents outline what is and what is not known about a species or ecosystem, identify threats to the species or ecosystem, and explain what should be done to mitigate those threats, as well as provide information on habitat needed for survival and recovery of the species. This information may be summarized in a recovery strategy followed by one or more action plans. The purpose of an action plan is to offer more detailed information to guide implementation of the recovery of a species or ecosystem. When sufficient information to guide implementation can be included from the onset, all of the information is presented together in a recovery plan.

Information in provincial recovery documents may be adopted by Environment and Climate Change Canada for inclusion in federal recovery documents that the federal agencies prepare to meet their commitments to recover species at risk under the *Species at Risk Act*.

What's next?

The Province of British Columbia accepts the information in these documents as advice to inform implementation of recovery measures, including decisions regarding measures to protect habitat for the species.

Success in the recovery of a species depends on the commitment and cooperation of many different constituencies that may be involved in implementing the directions set out in this document. All British Columbians are encouraged to participate in these efforts.

For more information

To learn more about species at risk recovery in British Columbia, please visit the B.C. Ministry of Environment Recovery Planning webpage at:
<http://www.env.gov.bc.ca/wld/recoveryplans/rcvry1.htm>

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Additional copies can be downloaded from the B.C. Ministry of Environment Recovery Planning webpage at:

<http://www.env.gov.bc.ca/wld/recoveryplans/rcvry1.htm>

Disclaimer

This recovery plan has been prepared by the Ministry of Environment, as advice to the responsible jurisdictions and organizations that may be involved in recovering the species. The B.C. Ministry of Environment has received this advice as part of fulfilling its commitments under the *Accord for the Protection of Species at Risk in Canada* and the *Canada–British Columbia Agreement on Species at Risk*.

This document identifies the recovery strategies and actions that are deemed necessary, based on the best available scientific and traditional information, to recover Mexican mosquito fern populations in British Columbia. Recovery actions to achieve the goals and objectives identified herein are subject to the priorities and budgetary constraints of participatory agencies and organizations. These goals, objectives, and recovery approaches may be modified in the future to accommodate new findings.

The responsible jurisdictions have had an opportunity to review this document. However, this document does not necessarily represent the official positions of the agencies or the personal views of all individuals on the recovery team.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that may be involved in implementing the directions set out in this plan. The B.C. Ministry of Environment encourages all British Columbians to participate in the recovery of Mexican mosquito fern.

ACKNOWLEDGEMENTS

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This updated version of the provincial recovery plan was prepared Brenda Costanzo of the B.C. Ministry of Environment (MOE) with assistance from: Marta Donovan, Jenifer Penny, and Katrina Stipec of the B.C. Conservation Data Centre (MOE); Byron Woods (B.C. Ministry of Forests Lands and Natural Resource Operations); and Peter Fielder and Leah Westereng (MOE). Additional comments on the recovery strategy were provided by: Matthew Huntley and Kella Sadler (Environment and Climate Change Canada – Canadian Wildlife Service, Pacific-Yukon Region (ECCC-CWS-PYR) and Brian Campbell (ECCC-CWS-National Capital Region); Robyn Reudink (B.C. Ministry of Forests, Land and Natural Resource Operations); Chris Pasztor (B.C. Ministry of Natural Gas Development); Dave Trotter (B.C. Ministry of Agriculture); and Johnathan Tillie (Ministry of Transportation and Infrastructure). The threats calculator was developed by: Brenda Costanzo, Dave Fraser, Jenifer Penny, Peter Fielder, and Leah Westereng (MOE), Terry McIntosh (consultant), and Matthew Huntley (ECCC-CWS-PYR).

EXECUTIVE SUMMARY

Mexican mosquito fern (*Azolla mexicana*) is a tropical to subtropical species of floating aquatic fern that can form thick extensive mats in lakes, ponds, ditches, and quiet areas of streams. It is found globally in North, Central, and South America, and reaches the northern limit of its range in south-central British Columbia. This species is listed as Threatened on Schedule 1 of the *Species at Risk Act* (SARA). It was first discovered in British Columbia in 1889 by John Macoun, and is found today within three general locales in the province: (1) the Little Fort/North Thompson River area, (2) the Shuswap Lake area, and (3) Vernon. In these areas, 10 populations have been reported in the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report, of which two are now assumed as extirpated. Since the status report surveys, one new subpopulation of Mexican mosquito fern was discovered at Salmon Arm in 2013 on an artificially created island. As well, an unconfirmed species of *Azolla* was found in 2014, and again in 2015, near Kelowna at Michaelbrook Marsh. The species identification has proven to be problematic and this location is therefore not included in this recovery plan.

The main threat to Mexican mosquito fern in the province is transportation corridor maintenance. In these situations, maintenance activities such as winter road salting, road construction or improvement, and herbicide treatments can either directly kill plants or affect water conditions, changing water chemistry and making sites unsuitable for the species. Other potential threats include events such as chemical and oil spills, water chemistry changes, water level, turbidity, or watercourse alteration. Broad strategies to address the threats include site protection and site management, potential re-introduction and/or restoration at sites, and population monitoring to assess threats.

The recovery goal for Mexican mosquito fern is to maintain the distribution, and to maintain or (where feasible) increase the abundance, of all known extant populations of this species as well as any other populations identified and/or re-established.

The following recovery objectives will guide recovery planning in the near term:

1. to protect[1] extant and presumed extant populations of Mexican mosquito fern throughout its provincial range;
2. to monitor trends in population size and distribution for all recorded populations; and
3. to investigate the feasibility of restoring populations at extirpated sites or in suitable habitat near extirpated areas.

[1] Protection can be achieved through various mechanisms including: voluntary stewardship agreements, conservation covenants, sale by willing vendors on private lands, land use designations, protected areas, and mitigation of threats.

RECOVERY FEASIBILITY SUMMARY

The recovery of Mexican mosquito fern in British Columbia is considered technically and biologically feasible based on the following four criteria that Environment and Climate Change Canada uses to establish recovery feasibility.

1. Individuals of the wildlife species that are capable of reproduction are available now or in the foreseeable future to sustain the population or improve its abundance.
   YES. Individuals that are capable of reproduction are available. Reproduction (by spores or vegetatively) partially depends on abiotic/biotic conditions; however, this is not currently limiting to the species.

2. Sufficient suitable habitat is available to support the species or could be made available through habitat management or restoration.
   YES. The current availability of suitable habitat is considered sufficient to support the species. Additional suitable habitat may be available through restoration of historic sites and/or habitat management at new potential sites.

3. The primary threats to the species or its habitat (including threats outside Canada) can be avoided or mitigated.
   YES. The primary threat of transportation corridor maintenance can be avoided or mitigated through appropriate site management (e.g., habitat management and protection, improvement of water quality and quantity).

4. Recovery techniques exist to achieve the population and distribution objectives or can be expected to be developed within a reasonable timeframe.
   YES. Recovery techniques exist, and include methods for habitat restoration and species re-introduction. Techniques for propagation and (re-)introduction are well known as mosquito fern species are grown worldwide, both horticulturally and agriculturally as livestock feed and biofertilizer.

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1 COSEWIC* SPECIES ASSESSMENT INFORMATION

Assessment Summary – November 2008
Common name:** Mexican Mosquito-fern
Scientific name: *Azolla mexicana*
Status: Threatened
Reason for designation: This tiny floating aquatic fern of south-central British Columbia is restricted to 8 small water bodies where its populations undergo periodic fluctuations in numbers of individuals. Two populations and their habitat have been lost in recent years due to construction activities with most of the extant populations occurring adjacent to major highways or a railway where they are at potential risk from maintenance activities, including the use of chemicals such as road salt.
Occurrence: British Columbia
Status history: Designated Threatened in April 1984. Status re-examined and confirmed in April 1998, May 2000, and November 2008. Last assessment based on an update status report.

* Committee on the Status of Endangered Wildlife in Canada.
** Common and scientific names reported in this recovery plan follow the naming conventions of the British Columbia Conservation Data Centre. In this case, the species' common name reported by Conservation Data Centre is slightly different than the name reported by COSEWIC.

2 SPECIES STATUS INFORMATION

Mexican mosquito fern[a]		
Legal Designation:		
FRPA:[b] No OGAA:[b] No	B.C. *Wildlife Act*:[c] No	SARA:[d] Schedule 1 –Threatened (2003)
Conservation Status[e]		
B.C. List: Red B.C. Rank: S2 (2005) National Rank: N2 (2011) Global Rank: G5 (2011)		
Other National Ranks: United States (NNR) Other Subnational Ranks:[f] Arizona (SNR), Arkansas (SNR), California (S3.2?), Colorado (S4), Illinois (S4), Iowa (S3), Kansas (SNR), Minnesota (SNR), Missouri (SNR), Nebraska (SNR), Nevada (SNR), New Mexico (SNR), Oklahoma (SNR), Oregon (SNR), Texas (SNR), Utah (S2?), Washington (SNR), Wisconsin (SNR)		
B.C. Conservation Framework (CF)[g]		
Goal 1: Contribute to global efforts for species and ecosystem conservation.		Priority:[h] #4 (2009)
Goal 2: Prevent species and ecosystems from becoming at risk.		Priority: #6 (2009)
Goal 3: Maintain the diversity of native species and ecosystems.		Priority: #2 (2009)
CF Action Groups:[i]	Compile Status Report; List under *Wildlife Act*; Send to COSEWIC; Habitat Protection; Species and Population Management; Planning; Private Land Stewardship; Habitat Restoration	

[a] Data source: B.C. Conservation Data Centre (2015) unless otherwise noted.
[b] No = not listed in one of the categories of wildlife that requires special management attention to address the impacts of forest and range activities on Crown land under the *Forest and Range Practices Act* (FRPA; Province of British Columbia 2002) and/or the impacts of oil and gas activities on Crown land under the *Oil and Gas Activities Act* (OGAA; Province of British Columbia 2008).
[c] No = not designated as wildlife under the B.C. *Wildlife Act* (Province of British Columbia 1982).
[d] Schedule 1 = found on the List of Wildlife Species at Risk under the *Species at Risk Act* (SARA; Government of Canada 2002).
[e] S = subnational; N = national; G = global; T = refers to the subspecies level; B = breeding; X = presumed extirpated; H = possibly extirpated; 1 = critically imperiled; 2 = imperiled; 3 = special concern, vulnerable to extirpation or extinction; 4 = apparently secure; 5 = demonstrably widespread, abundant, and secure; NA = not applicable; NR = unranked; U = unrankable.
[f] Data source: NatureServe (2015).
[g] Data source: B.C. Ministry of Environment (2015).
[h] Six-level scale: Priority 1 (highest priority) through to Priority 6 (lowest priority).
[i] Data source: B.C. Conservation Framework (2015).

3 SPECIES INFORMATION

3.1 Species Description

Mexican mosquito fern is described in Brunton (1984) and by others (Svenson 1944; Gleason 1974; Lumpkin 1993; Douglas *et al*. 2002; Evrard and Van Hove 2004; Pereira *et al.* 2011). The taxonomy of the genus *Azolla* is still currently unresolved amongst taxonomists, although several taxonomic treatments of multiple *Azolla* species have been published. As well, Pereira *et al*. (2001) indicated that many previously described diagnostic vegetative and reproductive characters are environmentally variable. Therefore, for the purposes of this document, the following description has been derived from the above-noted references.

Mexican mosquito fern is a small, floating green plant (Figure 1) with simple roots; plants are often 1.0–1.5 cm wide with small, alternate, overlapping leaves and dichotomous (forked branches of equal size) branching. Leaves are divided into two lobes: (1) a smaller floating upper lobe 0.7 mm long, papillose (small rounded projections) on the upper surface, the largest hairs on upper (dorsal) leaf lobes thick, 2–3 celled; and (2) a lower lobe that is larger, and variously described as submerged or floating. Identification is based on microscopic reproductive parts and includes glochidia with two to multiple cross walls (septae), and pitted megaspores (female reproductive organs) 0.4–0.5 mm long. Plants may be green or red in colour. Sporocarps (fruiting bodies) occur in pairs in the leaf axils of older plants.

Figure 1. Mexican mosquito fern, Little Fort, B.C. (Jamie Fenneman).

3.2 Populations and Distribution

3.2.1 Distribution

Mexican mosquito fern is has a disjunct range within North, South, and Central America (Brunton 1984; Douglas 2004), and is patchily distributed in areas of suitable habitat. In the United States, it is found in several western and mid-western states (Figure 2): Arizona, Arkansas, California, Colorado, Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, Nevada, New Mexico, Oklahoma, Oregon, Texas, Utah, Washington, and Wisconsin.

Figure 2. North American distribution of Mexican mosquito fern (COSEWIC 2008).

In Canada, Mexican mosquito fern is found only in British Columbia, where it reaches the northern limits of its distribution (Brunton 1984). It was first collected at Sicamous in 1889, and reported from Salmon Arm in 1890 by John Macoun (Brunton 1984). Since then, it has been reported at an additional 10 locations, all in the south-central British Columbia areas of Little Fort/North Thompson River, Shuswap Lake, and Vernon (B.C. Conservation Data Centre 2015). Less than 2% of the global population is found in Canada (B.C. Conservation Data Centre (2015).

3.2.2 Populations

All populations in British Columbia occur in the Southern Interior Forest Region, which is situated within the Montane Cordillera Ecozone (Ogilvie 1998; Canadian Council on Ecological Areas 2005) and includes the Interior Douglas-fir moist warm subzone (IDFmw), the Interior Douglas-fir very dry hot subzone (IDFxh), and the Interior Cedar–Hemlock moist warm subzone (ICHmw) (Meidinger and Pojar 1991). These populations may be a relict from a warmer post-glacial period (Brunton 1984), although the COSEWIC (2008) speculated that it may "be a species still expanding" its range.

Mexican mosquito fern occurs in three areas in British Columbia: (1) the Little Fort/North Thompson River area (four populations[2]), (2) the Shuswap Lake area (three populations), and (3) Vernon (one population) (Figure 3; Table 1). Of the 10 recorded populations, eight are currently considered extant (as described above), whereas two populations (EO9 in the Little Fort/North Thompson River area; EO1 in the Shuswap Lake area) have been extirpated owing to infilling of the sites. At Cambie (EO3), two subpopulations[3] occur, of which one is of unknown status (and presumed extant) and was last seen in 1997, and the other is considered historical (not seen since 1954). At the Mt. Loveway (EO8) location (i.e., subpopulation 2 on the east side of the highway), no plants have been seen since 1997 with searches conducted in 2005 and 2007 (Southern Interior Rare Plants Recovery Team 2008). The subpopulation is considered extirpated by the BC Conservation Data Centre based on the last two conducted searches. G. W. Douglas considered this site extirpated in 2004 (B.C. Conservation Data Centre 2015).

Since the 2008 provincial recovery strategy and COSEWIC update status report, a new sub-population was discovered in 2013 in the Shuswap Lake area on an artificially created island (Christmas Island). An additional, potential population was reported from Michaelbrook Marsh near Kelowna in 2014 and surveyed again in 2015. However, confirmation of species identification has proven problematic owing to a lack of sporocarp production, which is necessary for identification to species (J. Symonds and T. McIntosh, pers. comm., 2015). The Kelowna record is approximately 45 km south of the Vernon population and would be the most southerly population in Canada, if verified as *Azolla mexicana*.

[2] In this report, location/population is defined following element occurrence specifications by NatureServe (2015), which defines populations as being separated by a least 1 km from one another.
[3] Subpopulations are within 1 km of one another (NatureServe 2015).

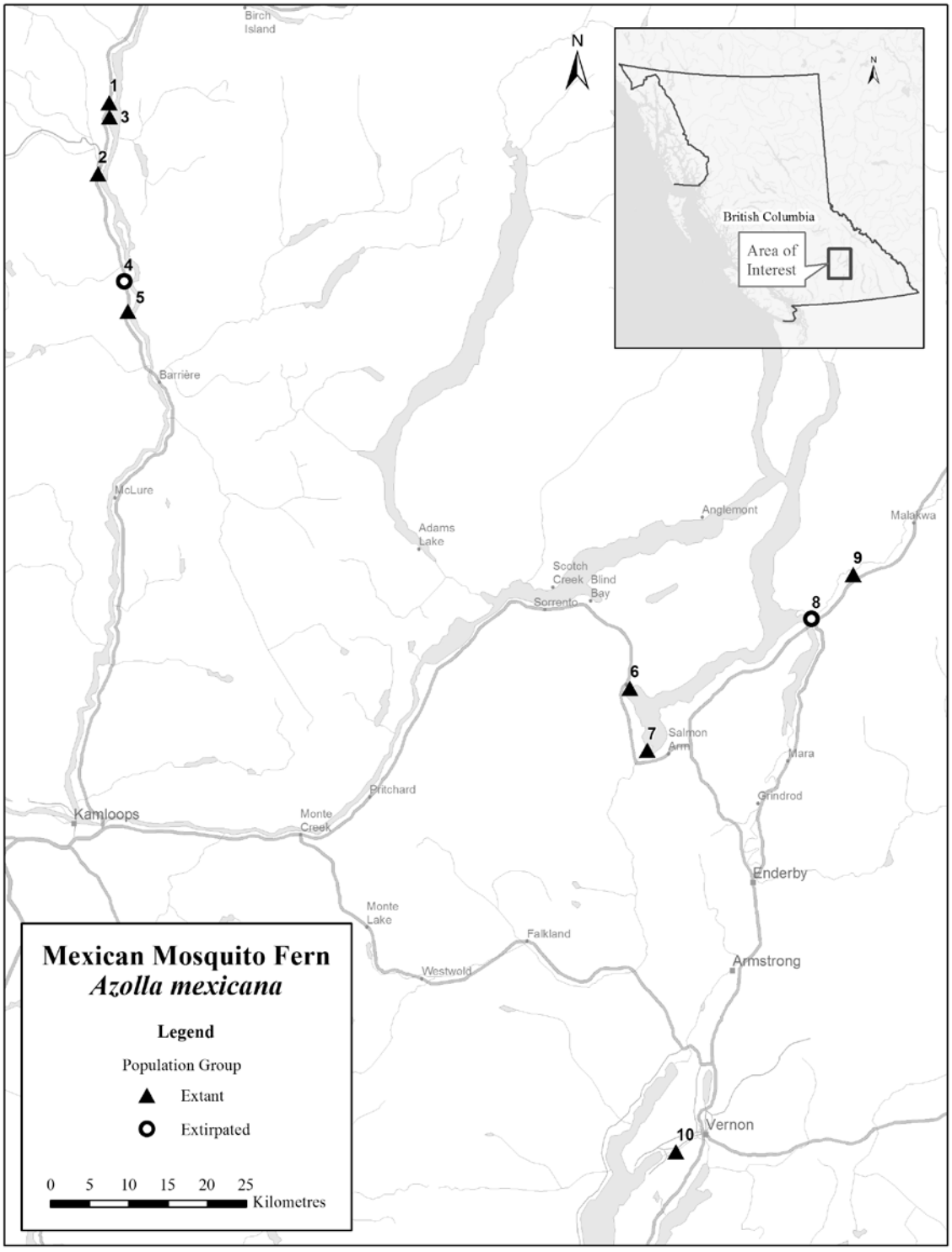

Figure 3. Distribution of Mexican mosquito fern in British Columbia. Subpopulations are grouped within the populations for ease of viewing (B.C. Conservation Data Centre 2015).

Table 1. Summary of Mexican mosquito fern populations in British Columbia (B.C. Conservation Data Centre 2015).

Geographic location	Population # on map	CDC population name	Subpopulation no.	Population/ subpopulation status[a]	B.C. CDC EO#	COSEWIC site name	COSEWIC Site #	Last Observation	Site description	No. mature individuals	Land tenure
Little Fort	1	Little Fort, N of Mount Loveway	N/A	Extant	EO10	Little Fort – Round Top Road (1)	1	2007	Covers pond (~ 10 x 5 m)	~ 500,000	Private/Provincial
	2	Little Fort, S of	Subpopn 1	Extant	EO7	Little Fort – South (3)	3	2005	Shallow pond at south end of pasture (3 x 20 m)	Not counted	Private
			Subpopn 2	Extant	EO7	Little Fort – South (3)	3	2007	Two oxbow lakes on west side of highway south of pasture (20 x 150 m)	> 1,000,000	Private
			Subpopn 3	Extant	EO7	Little Fort – South (3)	3	2007	Oxbow on east side of highway (20 x 60 m) sparsely covered	Not counted	Private
	3	Mount Loveway, 1.8 km SE of	Subpopn 1	Extant	EO8	Little Fort, N of (2)	2	2007	Covers two large oxbows on west side of highway (30 x 18 m)	> 1,000,000 (2004)	Private/Provincial
			Subpopn 2	**Extirpated**	EO8	Little Fort, N of (2)	2	1997	Oxbow on east side of highway; not observed since 1997; searched for in 2005 and 2007 but failed to find	Not counted	Private/Provincial
	4	Darfield, 1 km south of	N/A	**Extirpated**	EO9	Darfield (4)	4	1997	Douglas (2004) reported the site filled in by highway construction	N/A	Unknown
	5	Chinook Creek, 400 m south of confluence with tributary of N. Thompson	N/A	Extant	EO12	Darfield, South of (5)	5	2007	In oxbow on east side of highway only	Several 1000	Private

Geographic location	Population # on map	CDC population name	Subpopulation no.	Population/ subpopulation status[a]	B.C. CDC EO#	COSEWIC site name	COSEWIC Site #	Last Observation	Site description	No. mature individuals	Land tenure
Shuswap Lake Area	6	Tappen, Shuswap Lake	Subpopn 1	Extant	EO4	Tappen/White Creek	6	1998	Small numbers of plants among streamside vegetation along lowest stretch of the creek in 1997 (Martin 1998). No plants observed in 2004 (Douglas 2004) but habitat still intact.	Not counted	First Nations
			Subpopn 2	Extant	EO4	Tappen/White Creek[b]	6	1998	Small concentration covering 30 m^2 crescent pool at back of beach in backwater at first right-angled bend (Martin 1998). None observed in 2004 (Douglas 2004).	Not counted	First Nations
	7	Salmon Arm	Lomer 1998[c]	Extant	EO2	Salmon Arm West	7	1998	100s of plants in marsh at stream outlet (Nature Bay)	Not counted	First Nation/Crown lands?
			Subpopn B	Extant	EO2	Salmon Arm West	7 (Subpopn 1)	2004	Plants in a 5 x 30 m area in 2004 (Douglas, 2004)	Not counted	First Nation/Crown lands?
			Subpopn F	Extant	E02	Salmon Arm West	7 (Subpopn 2)	2007	Salmon Arm foreshore; 2004 several hundred plants observed in a 3 x 2 m area	None	First Nation/Crown lands?
			Symonds	Extant	EO2	Christmas Island	11	2013	Occurs on the artificially created Christmas Island in a ditch/slough between two ponds.	> 2,000,000 at Okanagan Ave.	Provincial
	8	Sicamous	N/A	**Extirpated**	EO1	Sicamous	8	1997	Douglas (2004) reported the site filled in.	N/A	Private

Geographic location	Population # on map	CDC population name	Subpopulation no.	Population/ subpopulation status[a]	B.C. CDC EO#	COSEWIC site name	COSEWIC Site #	Last Observation	Site description	No. mature individuals	Land tenure
	9	Cambie, 2.7 km west of	Subpopn 1	Unknown – presumed extant[d]	EO3	Eagle River	9	1997	Cambie along Eagle River; plants covering pond (1997). Not observed since but habitat still intact in 2007.	Not counted	Private
			Subpopn 2	Historical[e]	EO3	Eagle River	9	1954	Eagle River/ Solsqua. Not observed since but habitat intact in 2007.	Not counted	Private
Vernon	10	Vernon	Subpopn 1	Extant	EO5	Vernon Creek	10	2007	Okanagan Ave.: two 10 x 2 m patches in pasture	Not counted	Unknown
			Subpopn 2	Extant	EO5	Vernon Creek	10	2007	Marshall Fields recreation area; few plants in Sept. 2007. No plants observed in 2014 during a partial survey.	0	Municipal
			Subpopn 3[f]	Extant	EO5	Vernon Creek	10	2006	Oxbow on Vernon Creek; few plants in mud.	Not counted	Municipal

[a] Extant: occurrence has been recently verified as still existing. Extirpated: no longer present at site and site conditions have become unsuitable for the species. Historical: used when there is a lack of recent field information verifying the continued existence of the occurrence. Generally, if there is no known survey for 25 years it should be considered historical.
[b] This EO includes Lomer 1998 University of British Columbia collection accession #V234089.
[c] This EO includes Lomer 1998 University of British Columbia collection accession #V234101.
[d] The B.C. Conservation Data Centre has this occurrence as "unknown" (presumed extant) as the habitat was still intact in 2007.
[e] The B.C. Conservation Data Centre has this occurrence as "historical" as plants have not been observed since 1954 (J. Penny, pers. comm., 2016). The COSEWIC (2008) has this as an "historical site" as well.
[f] This subpopulation is in the B.C. Conservation Data Centre data but is not in the COSEWIC (2008); however, the corresponding COSEWIC site name and number would be "Vernon Creek" and "10" as for subpopulations 1 and 2.

Population trends for each population are difficult to assess for this species and additional annual surveys should be completed at all known locations. Existing data and observations indicate that this species' detectability at a site fluctuates from year to year. Lack of observation does not indicate lack of a viable population or extirpation. Extirpation for this species can only be inferred where complete and irreparable loss of the wetland/site has occurred.

3.3 Habitat and Biological Needs of the Mexican Mosquito Fern

Mexican mosquito fern can form extensive mats on the surfaces of lakes, ponds, streams, sloughs, and ditches, and less frequently in wet marshes (COSEWIC 2008). Mexican mosquito fern is primarily a still-water species usually found in non-saline ponds, lakes, and ditches, and in quiet backwaters and oxbows of rivers. Although showing preference for still or sluggish waters, it has also been found in faster-flowing waters in British Columbia and elsewhere (COSEWIC 2008).

Mexican mosquito fern grows optimally in cool, slightly acidic, partially shaded, phosphorus-rich, nutrient poor, still waters with low salinity (Brunton 1984; Douglas 2004). Existing habitat provides the slow-moving, partially shaded, protected waters needed for this species' survival—wind and wave action is reported to eventually fragment and kill Mexican mosquito ferns (Lumpkin and Plucknett 1980). Low salinity and pH values within the physiological tolerance of the species are also required (as observed by Brunton 1984). In response to stress related to poor nutrition, salinity, or high temperature, Mexican mosquito fern transforms from green to red in colour (Lumpkin 1993). Periodic annual flooding aids dispersal (COSEWIC 2008). Table 2 provides a summary of known essential features, functions, and attributes of Mexican mosquito fern habitat in the province.

Table 2. Summary of essential features, function, and attributes of Mexican mosquito fern habitat in British Columbia (compiled by Environment and Climate Change Canada 2015).

Habitat type	Feature(s)[a]	Function[b]	Life stage(s) supported	Attributes[c]
Aquatic habitat	Slow-moving, partially shaded, sheltered, shallow waters (ponds, ditches, oxbow lakes, lakeshores)	Growing, reproduction, dispersal	All life history stages	*Depth:* typically, but not exclusively, 50 cm or less; where the roots can touch the substrate in summer drawdown *Movement:* sheltered, slow-moving to still *Chemistry:* above pH 3.5, below pH 10 (optimal at pH 6.5–8.1); low salinity (≤ 1.3% salt); iron and phosphorous-rich, but otherwise nutrient-poor *Temperature:* optimal at 18–28°C (cold tolerance dependent on pH)
Shoreline habitat	Drawdown zone, band of vegetation associated with shoreline (within 30 m of highest waterline)	Growing, reproduction, dispersal	All life history stages	*Coverage:* semi-shaded (typically, but not exclusively, with intermediate canopy coverage); optimally around 50%

[a] Feature: the essential structural components of the habitat required by the species.
[b] Function: a life-cycle process of the species (e.g., include either animal or plant examples: spawning, breeding, denning, nursery, rearing, feeding/foraging and migration; flowering, fruiting, seed dispersing, germinating, seedling development).
[c] Attribute: the building blocks or *measurable* characteristics of a feature.

3.3.1 Water depth

Mexican mosquito fern is a species of relatively narrow growing requirements that is susceptible to changes in water levels and composition (Douglas 2004). Mexican mosquito fern grows well at water depths of only a few centimetres and the roots can touch the substrate (Wagner 1997; Watanabe 1997). This may correspond to summer drawdown in areas of deeper water. Sadeghi *et al*. (2012) found that optimal water depth for other mosquito fern species was 50 cm or less. Throughout its range, it grows with other, often pioneering, aquatic plant species, including *Lemna minor* (common duckweed) and *Riccia fluitans* (crystalwort) (Keddy 1976, cited by Brunton 1984).

3.3.2 Water chemistry

Mexican mosquito fern grows best in slightly acidic waters, growing most abundantly in waters with a pH ranging between 6.0 and 7.0 (Johnson 1986); this range allows greatest survival of young seedlings and greatest production of megasporocarps (Nayak and Singh 2004). Other authors report the fern's preference for "slightly" acidic conditions, with optimal growth in water with a pH ranging from 4 to 7.1 (Watanabe 1997), although it can survive in water with a pH ranging from 3.5 to 10 (Lumpkin and Plucknett 1980). Sensitivity to turbidity changes is unknown, but all sites examined in 2005 have clear water. Excessive turbidity may inhibit spore germination. Phosphorus and iron are critical elements for Mexican mosquito fern survival

(Lumpkin and Plucknett 1980, cited by Brunton 1984) and may be limiting factors for growth and population establishment.

Mexican mosquito fern and other species belonging to the genus *Azolla* live in a symbiotic relationship with a blue-green alga species (*Anabaena azollae*) (Moore 1969; Wagner 1997; Baker *et al.* 2003). This association allows for Mexican mosquito fern to fix atmospheric nitrogen at comparable rates to leguminous[4] plants. This adaptation is beneficial in nutrient-poor habitats but may allow for inhibited growth of *Azolla* species in water with high nitrogen levels (Kitoh *et al.* 1993; Wagner 1997) or outcompete under these conditions by other aquatic plants.

Most variants of Mexican mosquito fern can tolerate very low levels of salinity but are killed by high levels (Moore 1969; Johnson 1986). A 1.3% salt concentration (33% of sea water) prevents growth. Brunton (1984) reported high conductivity in the Sicamous and Salmon Arm stations (169 and 500, respectively).

Mexican mosquito fern is reported to be more tolerant of sodium chloride salinity than of other salts, including magnesium sulphate, magnesium chloride, potassium sulphate, potassium chloride, sodium sulphate, and calcium chloride (Johnson 1986).

Brunton (1984) reported that the Shuswap populations occur on glacial outwash plains with locally distributed calcareous deposits. Brunton (1984) tested the pH of the water and reported that it ranged from 6.5 (Sicamous population) to 8.1 (Salmon Arm population).

3.3.3 Water temperature

Additionally, low winter temperatures result in die-off at northern stations (Tryon and Tryon 1982, cited by Brunton 1984). Although mosquito fern species generally are reported to show resistance to cold, freezing of the water surface results in death (Tsujimura, Ikeda, and Tukamoto 1957, cited by Moore 1969). Lumpkin (1993) indicated that this species is less cold tolerant and has a narrower environmental range than eastern mosquito fern (*Azolla caroliniana*). Mexican mosquito fern is a species that is sensitive to desiccation (Watanabe 1997; Douglas 2004). It is killed by high water temperatures (Vitousek *et al.* 2002).

3.3.4 Water levels

Although Brunton (1984) described fluctuating water levels are required for the species, the COSEWIC (2008) indicated that its presence at provincial sites with flowing water "may undermine that presumption"; however, fluctuating water levels may disperse patches or individuals (COSEWIC 2008).

3.3.5 Light

Lumpkin and Plucknett (1980, cited by Brunton 1984) reported that 50% sunlight is optimal for species' growth. This fern is frequently found in partially shaded and sheltered sites, and in sites adjacent to wet meadows and other wetlands.

[4] Plants of the pea-family (Fabaceae) that house nitrogen-fixing bacteria in their roots.

3.3.6 Reproduction

Populations of Mexican mosquito fern in British Columbia show dramatic differences in size and prevalence of sporophytes that may reflect variation in water chemistry, shade versus sunlight conditions, water currents, or founder effects. Sporocarp production needs more study (Lumpkin 1993).

3.3.7 Dispersal

Dispersal may occur by wind, by flowing water, by animal transport, or by human transport (Moore 1969; Lumpkin and Plucknett 1980). Populations typically carpet areas where they occur.

3.4 Ecological Role

The ecological role for this species is not well known. As a fixer of atmospheric nitrogen, it may play in important role in nitrogen fixation in aquatic habitats where it occurs.

3.5 Limiting Factors

Mexican mosquito ferns reproduce both vegetatively and via spore production, with vegetative reproduction the more common form (Moore 1969). Nevertheless, Mexican mosquito fern spores can also lie dormant for many years (Lumpkin and Plucknett 1980) until the conditions are optimal for germination. When spore production and/or germination is limited, then the species will be restricted genetically if reproduction is mainly vegetative. As well, Brunton (1984) speculated that outbreeding may occur, though rarely, and this may be a key mechanism for population re-colonization and establishment.

Mexican mosquito fern is sensitive to cold temperatures which may account for population fluctuations from year to year. The species is also sensitive to changes in pH, salinity, and water temperatures, as well as phosphorus and iron content of the water. Changes in these levels could also account for fluctuations in populations and restrict distribution.

4 THREATS

Threats are defined as the proximate activities or processes that have caused, are causing, or may cause in the future the destruction, degradation, and/or impairment of the entity being assessed (population, species, community, or ecosystem) in the area of interest (global, national, or subnational) (adapted from Salafsky *et al.* 2008). For purposes of threat assessment, only present and future threats are considered.[5] Threats presented here do not include limiting factors,[6] which are presented in Section 3.5.

For the most part, threats are related to human activities, but they can also be natural. The impact of human activity may be direct (e.g., destruction of habitat) or indirect (e.g., introduction of invasive species). Effects of natural phenomena (e.g., fire, flooding) may be especially important when the species is concentrated in one location or has few occurrences, which may be a result of human activity (Master *et al.* 2012). As such, natural phenomena are included in the definition of a threat, though they should be considered cautiously. These stochastic events should only be considered a threat if a species or habitat is damaged from other threats and has lost its ability to recover. In such cases, the effect on the population would be disproportionately large compared to the effect experienced historically (Salafsky *et al.* 2008).

[5] Past threats may be recorded but are not used in the calculation of threat impact. Effects of past threats (if not continuing) are taken into consideration when determining long-term and/or short-term trend factors (Master *et al.* 2012).

[6] It is important to distinguish between limiting factors and threats. Limiting factors are generally not human induced and include characteristics that make the species or ecosystem less likely to respond to recovery/conservation efforts (e.g., inbreeding depression, small population size, and genetic isolation).

4.1 Threat Assessment

The threat classification below is based on the IUCN–CMP (World Conservation Union–Conservation Measures Partnership) unified threats classification system and is consistent with methods used by the B.C. Conservation Data Centre. For a detailed description of the threat classification system, see the Open Standards website (Open Standards 2015). Threats may be observed, inferred, or projected to occur in the near term. Threats are characterized here in terms of scope, severity, and timing. Threat "impact" is calculated from scope and severity. For information on how the values are assigned, see Master *et al.* (2012) and table footnotes for details. Threats for the Mexican mosquito fern were assessed for the entire province (Table 3).

Table 3. Threat classification table for Mexican mosquito fern in British Columbia.

Threat #[a]	Threat description	Impact[b]	Scope[c]	Severity[d]	Timing[e]	Population(s)
1	Residential & commercial development	Negligible	Negligible	Extreme–Serious	Moderate	
1.1	Housing & urban areas	Negligible	Negligible	Extreme–Serious	Moderate	Vernon (EO5); Chinook Creek (EO12)
4	Transportation & service corridors	Medium–Low	Large	Moderate–Slight	Moderate	
4.1	Roads & railroads	Medium–Low	Large	Moderate–Slight	Moderate	Locations near roads: Little Fort, S of (EO7) Mt. Loveway (EO8); Little Fort (EO10); Chinook Creek (EO12); Salmon Arm (EO2) near railway line
7	Natural system modifications	Not calculated	Small	Unknown	Low	
7.3	Other ecosystem modifications	Not calculated	Small	Unknown	Low	Reed canary grass at following locations: Sicamous (EO1); Salmon Arm (EO2); Tappen, Shuswap Lake (EO4); Vernon (EO5); Mt. Loveway (EO8)
9	Pollution	Unknown	Small	Unknown	High–Moderate	
9.1	Domestic & urban waste water	Unknown	Small	Unknown	High–Moderate	Salmon Arm (EO2)
11	Climate change & severe weather	Not calculated	Pervasive–Large	Unknown	Low	
11.2	Droughts	Not calculated	Pervasive–Large	Unknown	Low	All

[a] Threat numbers are provided for Level 1 threats (i.e., whole numbers) and Level 2 threats (i.e., numbers with decimals).

[b] **Impact** – The degree to which a species is observed, inferred, or suspected to be directly or indirectly threatened in the area of interest. The impact of each threat is based on severity and scope rating and considers only present and future threats. Threat impact reflects a reduction of a species population. The median rate of population reduction for each combination of scope and severity corresponds to the following classes of threat impact: Very High (75% declines), High (40%), Medium (15%), and Low (3%). Unknown: used when impact cannot be determined (e.g., if values for either scope or severity are unknown); Not Calculated: impact not calculated as threat is outside the assessment time (e.g., timing is insignificant/negligible [past threat] or low [possible threat in long term]); Negligible: when scope or severity is negligible; Not a Threat: when severity is scored as neutral or potential benefit.

[c] **Scope** – Proportion of the species that can reasonably be expected to be affected by the threat within 10 years. Usually measured as a proportion of the species' population in the area of interest. (Pervasive = 71–100%; Large = 31–70%; Restricted = 11–30%; Small = 1–10%; Negligible < 1%).

[d] **Severity** – Within the scope, the level of damage to the species from the threat that can reasonably be expected to be affected by the threat within a 10-year or 3-generation time frame. For this species a 10-year time frame was used. Usually measured as the degree of reduction of the species' population. (Extreme = 71–100%; Serious = 31–70%; Moderate = 11–30%; Slight = 1–10%; Negligible < 1%; Neutral or Potential Benefit ≥ 0%).

[e] **Timing** – High = continuing; Moderate = only in the future (could happen in the short term [< 10 years or 3 generations]) or now suspended (could come back in the short term); Low = only in the future (could happen in the long term) or now suspended (could come back in the long term); Insignificant/Negligible = only in the past and unlikely to return, or no direct effect but limiting.

4.2 Description of Threats

A summary of the threats assessment for Mexican mosquito fern is provided in Table 3. The calculated overall threat impact is Medium to Low based on the main threat of road and railroad construction/maintenance activities.

The threat classification and assessment below is based on the IUCN–CMP (International Union of Nature–Conservation Measures Partnership) unified threats classification system. This IUCN–CMP threat assessment system is currently used by the B.C. Conservation Framework and the B.C. Conservation Data Centre. For a detailed description of this classification scheme, see the Open Standards website (Open Standards 2015).

Threat 1. Residential & commercial development

1.1 Housing & urban areas
Housing and urban development is a potential threat in the Shuswap and Vernon areas. One of the subpopulations in Vernon (EO5 – subpopulation 1) occurs on land that has recently been purchased by a development company. Overall, the impact within the next 10 years is negligible. An historical population in the Shuswap Lake area (EO1) was extirpated likely related to infilling within an area of housing development.

Threat 4. Transportation & service corridors

4.1 Roads & railroads
Several populations of Mexican mosquito fern occur adjacent to roads, highways, and railroads, and proximity to these areas may pose a threat. The populations near roads or highways are Cambie (EO3), Mt. Loveway (EO8), Little Fort S of (EO7), Little Fort (EO10), and Chinook Creek (EO12). An historical population in the Darfield area (EO9) was extirpated related to infilling during road construction/road repairs (COSEWIC 2008). Additionally, salting of roadways and associated runoff leading to high salinity levels may pose a threat to individual plants or groups of plants. Chemical and oil spills would alter the water chemistry, which could cause decline of Mexican mosquito fern. The possibility of a railway spill adjacent to the Salmon Arm (EO2) population is also a threat. Although this situation is unlikely, a railway spill would nevertheless have detrimental impact (e.g., changing the pH of the water) on the adjacent wetlands and Mexican mosquito fern.

Threat 7. Natural system modifications

7.3 Other ecosystem modifications
Encroachment of reed canary grass (*Phalaris arundinacea*) is evident at several sites: Salmon Arm (EO2); Tappen, Shuswap Lake (EO4); Vernon (EO5); and Mt. Loveway (EO8) (B.C. Conservation Data Centre 2015). Reed canary grass alters the habitat by causing permanent infilling, thereby reducing the water levels (i.e., changes the habitat from aquatic to terrestrial) such that the habitat no longer supports Mexican mosquito fern. Elsewhere, the presence of another semi-aquatic introduced species, common reed (*Phragmites* spp.), has been shown to create a windbreak and shelter to other mosquito fern species (Sadeghi *et al.* 2012). Common

reed is not considered a problem (yet) at the Okanagan locations (D. Fraser and T. McIntosh, pers. comm., 2015).

Threat 9. Pollution

9.1 Household sewage & urban waste water
Eutrophication[7] is apparent at the Salmon Arm location (EO2), although the source of increased nutrient levels is unknown. Algal blooms were apparent at this site in 2005 and 2006 (COSEWIC 2008). Recent water quality assessments have also indicated increased nutrient levels (phosphorus and nitrogen) near the Salmon Arm location (EO2) (Northwest Hydraulic Consultants 2013). The actual effect of increased nutrients on Mexican mosquito fern are variable (Lumpkin and Plucknett 1980); however, increased nitrogen levels in water has been shown to inhibit growth in other *Azolla* species (Kitoh *et al.* 1993; Wagner 1997). As well, phosphorus (and iron) may be a limiting factor for growth (Brunton 1984), and therefore any change in phosphorus levels could affect Mexican mosquito fern.

Threat 11. Climate change & severe weather
Over the long term, climate change models show a decline in wetlands, but this is outside of the threats calculation time frame.

5 RECOVERY GOAL AND OBJECTIVES

5.1 Recovery (Population and Distribution) Goal

The following is the recovery (population and distribution) goal:

> To maintain the distribution, and to maintain or (where feasible) increase the abundance, of all known extant populations of this species, as well as any other populations identified and/or re-established.

5.2 Rationale for the Recovery (Population and Distribution) Goal

Abundance and distribution information of this species show nine extant populations occurring in three regions of British Columbia: (1) the Little Fort/North Thompson River area, (2) the Shuswap Lake area, and (3) Vernon. This species was previously more widespread in Canada. Two populations at Darfield (EO9) and Sicamous (EO1) have been extirpated owing to infilling of the sites, rendering the habitat unsuitable for the species.

Techniques for propagation and introduction are well known for *Azolla* species (Lumpkin and Plucknett 1982; Carrapiço and Pereira 2009); therefore, if suitable habitat is found in proximity to these two sites (at Darfield and Sicamous), re-introduction would be deemed appropriate (if feasible) to replace the two extirpated populations. The rate of change in population size for extant populations is unknown. For future monitoring and/or trend estimation purposes, note that lack of observation in a particular survey year does not indicate lack of a viable population or

[7] The enrichment of an ecosystem with nutrients, typically compounds containing nitrogen and phosphorus.

extirpation, and that the population size of this annual species may characteristically fluctuate between survey years. Where the best available information and/or long-term monitoring indicates overall population decline, deliberate attempts to improve abundance would be appropriate where feasible.

5.3 Recovery Objectives

The following recovery objectives will guide recovery planning in the near term:

1. to protect[8] extant and presumed extant populations of Mexican mosquito fern throughout the provincial range;
2. to monitor trends in population size and distribution at all sites for all recorded populations; and
3. to investigate the feasibility of restoring populations at extirpated sites or in suitable habitat near extirpated areas.

6 APPROACHES TO MEET RECOVERY OBJECTIVES

6.1 Actions Already Completed or Underway

The following actions have been categorized by the action groups of the B.C. Conservation Framework (B.C. Ministry of Environment 2015). Status of the action group for this species is given in parentheses.

Compile Status Report (complete); Send to COSEWIC (complete)

- COSEWIC report completed (COSEWIC 2008). Update due 2018.
- Mexican mosquito fern assessed as Threatened (COSEWIC 2008). Re-assessment due 2018.

Planning (in progress)

- B.C. Recovery Strategy/Plan completed (this document, 2016).

Habitat Protection and Private Land Stewardship (in progress)

- One population (EO8) is afforded protection under the *Protected Areas of British Columbia Act* in Dunn Peak Protected Area.

[8] Protection can be achieved through various mechanisms including voluntary stewardship agreements, conservation covenants, sale by willing vendors of private lands, land use designations, protected areas, and mitigation of threats.

6.2 Recovery Action Table

Table 4. Recovery actions for Mexican mosquito fern.

Objective	Conservation Framework action group	Actions to meet objectives	Threat[a] or concern addressed	Priority[b]
1	Habitat Protection and Private Land Stewardship	1. Identify and contact all landowners and land managers. 2. Pursue conservation covenants or stewardship agreements with private landowners. 3. Conduct outreach activities with targeted sectors to communicate presence of Mexican mosquito fern, particularly those populations close to agriculture lands. 4. Assess, prepare, and implement best management practices for all sites, including transportation corridors.	Habitat loss or degradation; water quality and quantity	High
2	Species and Population Management	1. Inventory extant populations to determine population distribution and population trends. 2. Develop and implement a monitoring protocol that provides reliable estimates of population size and detects threats at each known location. 3. Monitor status of population and threats at extant locations every 2 years (at minimum).	Knowledge gap	Medium
3	Habitat Restoration	1. Identify and select suitable introduction sites (if appropriate) using plant ecology data for site parameters to determine suitability. 2. Implement restoration activities.	Habitat loss or degradation	Low

[a] Threat numbers according to the IUCN–CMP classification (see Table 3 for details).
[b] Essential: urgent and important, needs to start immediately; Necessary: important but not urgent, action can start in 2–5 years; or Beneficial: action is beneficial and could start at any time that was feasible.

7 SPECIES SURVIVAL AND RECOVERY HABITAT

Survival/recovery habitat is defined as the habitat that is necessary for the survival or recovery of the species. This is the area in which the species naturally occurs or that it depends on directly or indirectly to carry out its lifecycle processes, or in which it formerly occurred and has the potential to be re-introduced.

7.1 Biophysical Description of the Species' Survival/Recovery Habitat

Section 3.3 provides a description of the known biophysical features and attributes of the species' habitat that are required to support these lifecycle processes (functions). Additional work is required to fulfill knowledge gaps in habitat requirements and distribution. These knowledge gaps are detailed in the Recovery Planning Table (Table 4).

7.2 Spatial Description of the Species' Survival/Recovery Habitat

The area of survival/recovery habitat required for a species is guided by the amount of habitat needed to meet the recovery goal. Although no survival/recovery maps are included with this document, it is recommended that the location of survival/recovery habitat is spatially described to mitigate habitat threats and to facilitate the actions outlined to meet the recovery (population and distribution) goals.

8 MEASURING PROGRESS

The following performance measures provide a way to define and measure progress toward achieving the recovery (population and distribution) goal and recovery objectives. Performance measures are listed for each objective.

Measurable(s) for Objective 1

- Habitat needed to support known populations of Mexican mosquito fern is identified and protected by 2021.[9]

Measurable(s) for Objective 2

- Population and distribution monitoring is implemented by 2021.

Measurable(s) for Objective 3

- An assessment is conducted to determine the availability of, and/or potential to restore, suitable potential habitat for Mexican mosquito fern at extirpated sites or in suitable habitat near historical areas by 2021. If deemed feasible and appropriate, attempt to restore habitat and/or re-introduce the species at sites.

[9] Protection can be achieved through various mechanisms including voluntary stewardship agreements, conservation covenants, sale by willing vendors of private lands, land use designations, protected areas, and mitigation of threats.

9 EFFECTS ON OTHER SPECIES

The recovery measures proposed are not expected to negatively affect any other species. Any efforts to conserve Mexican mosquito fern are likely to indirectly benefit other species in the area, possibly including the blue-listed Great Basin Spadefoot (*Spea intermontana*; Threatened in Canada) and Western Toad (*Bufo boreas*; Special Concern in Canada), both of which require slow-moving water bodies for part of their lifecycle. The Christmas Island subpopulation at Salmon Arm (Symonds; EO2) occurs in an area that provides habitat for the provincially red-listed American White Pelican (*Pelecanus erythrorhynchos*) and Western Grebe (*Aechmophorus occidentalis*). Recovery planning activities for Mexican mosquito fern will be implemented with consideration for all co-occurring species at risk, such that these species or their habitats experience no negative effects.

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