Fisheries and Oceans Canada | Pêches et Océans Canada
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Ontario and Prairie Region

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Science Response 2026/027

UPDATED RECOVERY POTENTIAL ASSESSMENT OF EASTERN SAND DARTER (*AMMOCRYPTA PELLUCIDA*) IN ONTARIO (SOUTHWESTERN ONTARIO AND WEST LAKE DESIGNATABLE UNITS), 2010–2022

CONTEXT

After the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses an aquatic species as Threatened, Endangered or Extirpated, Fisheries and Oceans Canada (DFO) undertakes several actions to support implementation of the *Species at Risk Act* (SARA). Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery. Formulation of this scientific advice is typically developed through a Recovery Potential Assessment (RPA) that is conducted shortly after the COSEWIC assessment. This timing allows for consideration of peer-reviewed scientific analyses into SARA processes including recovery planning.

Eastern Sand Darter (*Ammocrypta pellucida*) was first assessed by COSEWIC in April 1994 and it was recommended that the species be designated as Threatened. This status was re-assessed and confirmed in November 2000, and the species was listed as Threatened on Schedule 1 of SARA when the Act was proclaimed in June 2003. The species was re-assessed in November 2009, at which time it was recommended the species be split into two designatable units (DUs), both assessed as Threatened, one for Ontario populations and one for Quebec populations due to a large geographic separation (~500 km) between the two areas. An RPA was conducted by DFO in December 2009 (DFO 2011). In March 2013, the Ontario and Quebec DUs were listed separately as Threatened. A Recovery Strategy for the Ontario populations was developed in 2012 (DFO 2012), and in December 2017, a Critical Habitat order was enacted, triggering the prohibition in subsection 58(1) of SARA against the destruction of any part of the critical habitat of the Eastern Sand Darter that is identified in the Recovery Strategy for the species (DFO 2017). The species was re-assessed by COSEWIC in November 2021, and a new DU structure was recommended following the discovery of a new population in West Lake, Ontario (Prince Edward County) in 2013. This new DU structure included the original Quebec DU with a recommended downlisting of the status to Special Concern, a West Lake DU assessed as Threatened, and a Southwestern Ontario DU (renamed from “Ontario populations” and old DU deactivated) assessed as Threatened.

DFO Science was asked to undertake an RPA for Eastern Sand Darter – West Lake DU, and to update the RPA for the Southwestern Ontario DU. Science advice from the RPA may be used to inform the listing decision for the West Lake DU, develop the appropriate recovery document(s) for the West Lake DU (if listed), update the recovery strategy and action plan for the Southwestern Ontario DU, and support decision making with regards to the issuance of permits or agreements under SARA. Since the first RPA was undertaken in 2009, considerable research has been conducted on Eastern Sand Darter in southwestern Ontario (Drake et al. 2021). The advice generated via this process will supplement, update, or replace existing advice regarding the Southwestern Ontario DU, and is intended to accompany the original RPA documents (i.e., only new information since 2009 is presented here). Although there is no existing advice regarding the West Lake DU, there is limited DU-specific information available. As such, information presented for the Southwestern Ontario DU is assumed to apply to the West Lake DU, but DU-specific information is presented separately where possible and explicitly stated. More research is needed to better understand the unique characteristics of the West Lake DU relative to the Southwestern Ontario DU.

This document provides up-to-date information and discusses associated uncertainties of the 22 elements of the RPA process (DFO 2007, DFO unpublished) under the following categories:

- Biology, abundance, distribution, and life-history parameters;
- Habitat and residence requirements;
- Threats and limiting factors to survival and recovery;
- Recovery targets;
- Scenarios for mitigation of threats and alternatives to activities; and,
- Allowable harm.

This Science Response Report results from the regional peer review from April 26, 2023 on the Updated Recovery Potential Assessment for Eastern Sand Darter (*Ammocrypta pellucida*) in Ontario [Southwestern Ontario and West Lake Designatable Units], 2010–2022.

BACKGROUND

The Eastern Sand Darter is a small, elongate, translucent benthic percid. It has a widespread but disjunct distribution in Canada and is a habitat specialist that occupies sand and fine gravel substrates. It was historically known to occur in 11 localities in southwestern Ontario and is thought to be extirpated from three of these. In 2013, a new population was discovered in West Lake, Ontario (Reid and Dextrase 2014), and in November 2021, COSEWIC recommended a change in DU structure with West Lake representing its own DU based on evidence of genetic distinctiveness relative to all other Canadian populations, and approximately 200 km distance from either of the other two Canadian DUs (Ginson et al. 2015, COSEWIC 2022, Walter et al. 2022). West Lake is a small lacustrine habitat that is unique relative to the mostly riverine or very large lake habitats that Eastern Sand Darter occupies in southwestern Ontario and Quebec. Local adaptations to the conditions in West Lake were inferred, representing ecological significance based on COSEWIC guidelines for classification below the species level (COSEWIC 2012). The former Ontario DU was renamed Southwestern Ontario. Updated information and advice on Eastern Sand Darter, Southwestern Ontario DU from 2010–2022 and new information pertaining to the West Lake DU are presented below.

ANALYSIS AND RESPONSE

Biology, Abundance, Distribution and Life History Parameters

Element 1: *Summarize the biology of Eastern Sand Darter (Southwestern Ontario and West Lake DUs)*

Species Description and Significance: Eastern Sand Darter is a small, translucent, elongate benthic fish that is typically yellow to iridescent green, with pale yellow to silver sides and a silver to white belly, often with a metallic gold to olive-gold lateral band that is broken by 10–14 small round or oval dark spots. In Canada, it co-occurs with other darter species, but is the only species of *Ammocrypta* that occurs here, and can be easily distinguished at all ages by its translucent, slender, elongate body, and large separation between the spiny and soft dorsal fins (Holm et al. 2009, Bouvier and Mandrak 2010, COSEWIC 2022). It may also serve as a host for glochidia of the SARA-Endangered Round Hickorynut (*Obovaria subrotunda*; Shepard et al. 2021).

Biology: A detailed summary of the biology of Eastern Sand Darter is found in COSEWIC (2009); there is limited new information regarding the species life-cycle. Information that was originally presented in COSEWIC (2009) and Bouvier and Mandrak (2010) is still considered valid. Eastern Sand Darter lives to a maximum of age-4 in Ontario (Drake et al. 2008). It grows quickly but growth rates may differ by population (Finch et al. 2013). Most individuals mature in the spring one year after hatching. A larval fish survey in the Sydenham River (Southwestern Ontario DU) in 2017 detected Eastern Sand Darter eggs on June 15, and larvae from June 8 to July 26; all larval Eastern Sand Darter were measured (Figure 1; Gáspárdy et al. 2026). Based on data from 2010–2022, the median total length (TL) of individuals captured across the Southwestern Ontario DU was 54 mm (range: 16–72 mm; n = 3,254; Fish Biodiversity Database) and the median TL of the West Lake DU was 46 mm (range: 20–69 mm; n = 1,277; LeBaron et al. 2020; Figure 2). The maximum recorded TL is 84 mm (Holm et al. 2009).

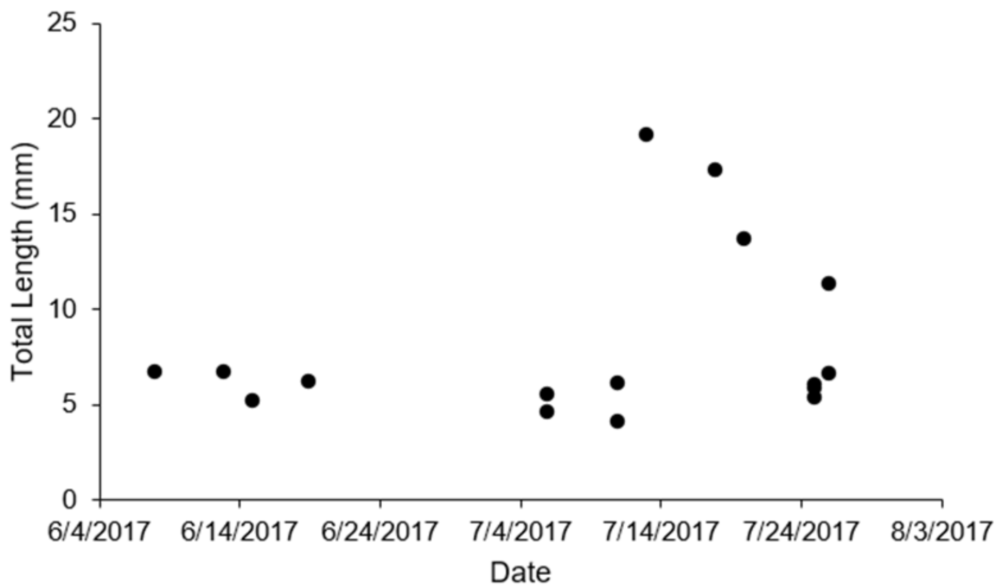

Figure 1. Total length by detection date of larval Eastern Sand Darter from the Sydenham River (Florence) in 2017. Larval fish were detected in drift nets, individually measured, and species ID was confirmed through genetic analysis (Gáspárdy et al. 2026).

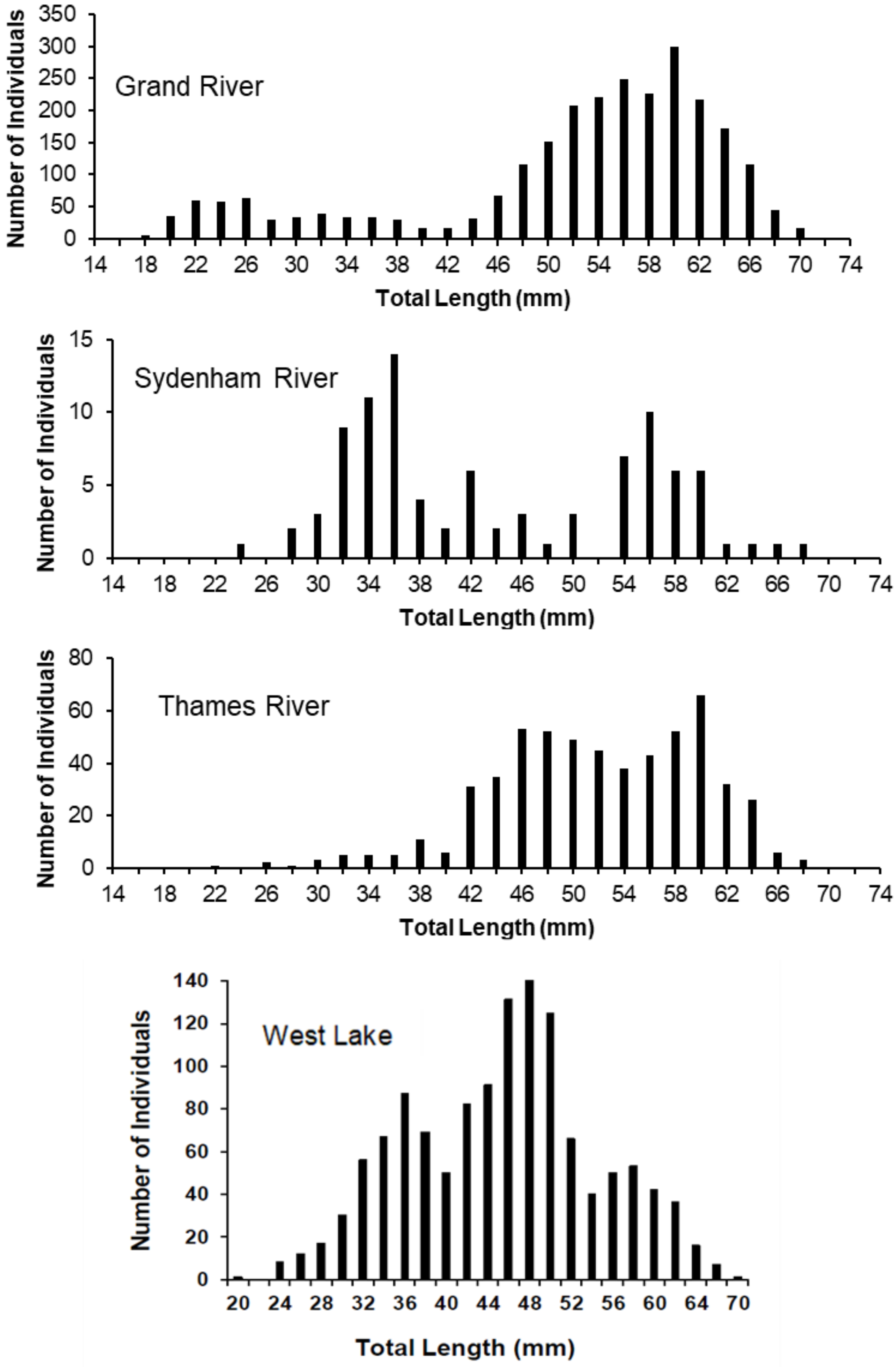

Figure 2. Length-frequency distributions from Southwestern Ontario designatable unit (DU) populations (Grand River, Sydenham River, Thames River) from specimens captured in 2010–2022 ([Fish Biodiversity Database]), and from the West Lake DU population captured in 2013–2015 (bottom panel figure reproduced from LeBaron et al. 2020). Measurements were taken from summer through fall.

Diet: Eastern Sand Darter feeds on benthic invertebrates by lunging at prey from a strike position (COSEWIC 2009). Several diet studies on the species have found that it relies predominantly on chironomid larvae, and opportunistically feeds on Ostracoda, Cladocera, Ephemeroptera, and Oligochaeta (Facey 1998, Finch 2009). Burbank et al. (2019) evaluated stomach contents and stable isotopes from specimens collected in the Thames River (Southwestern Ontario DU) to better understand the dietary niche of the species. The study confirmed that Eastern Sand Darter consumed Chironomidae frequently, but isotope analysis suggested it is more of a generalist feeder with a greater reliance on Cladocera, Ostracoda, Oligochaeta, and Ephemeroptera than previously reported. The reliance on chironomid may be seasonal (summer) and emphasis on this prey item from past studies may relate to the timing of those diet studies (Burbank et al. 2019). Despite the generalist benthic feeding, the species exhibited a relatively restricted trophic niche compared to co-occurring species, which could be related to its specialization on microhabitat features (i.e., sand and fine gravel bars). A relatively specialized diet was noted in the Sydenham River, where Eastern Sand Darter diet overlapped with few other benthic species (two species prior to the invasion of Round Goby [*Neogobius melanostomus*], and two additional species after the invasion) (Firth et al. 2021b). This narrow niche could make it more susceptible to impacts from perturbations if preferred prey become scarce (Burbank et al. 2019).

Physiology: The thermal and oxygen tolerances of adult Eastern Sand Darter were recently evaluated in field trials in southwestern Ontario. Firth et al. (2021a) evaluated two physiological thermal endpoints of Eastern Sand Darter across seasons (June through November) in the Grand River. The critical thermal maximum (CT_{max}), the temperature at which it loses the ability to escape thermal stress, ranged from 27.9–37.0 °C. The agitation temperature, the temperature at which it responds to thermal changes by attempting to flee, ranged from 23.0–33.4 °C. Both endpoints increased with acclimation temperature. A comparison with the Thames River was conducted in August and results were similar. Elevated turbidity in the Thames River did not affect either thermal endpoint relative to the Grand River. Eastern Sand Darter shows plasticity in thermal responses, affording it some protection from changing temperatures associated with climate change. A study on hypoxia tolerance of Eastern Sand Darter in the Grand River across seasons (June through October) revealed that the species is relatively hypoxia tolerant, requiring at least 1.14 mg/L of dissolved oxygen, and that it was more tolerant of hypoxia in the fall (October) compared to the summer (July) (Firth et al. 2023). Overall, it is relatively tolerant of hypoxic conditions compared to other darters (Ultsch et al. 1978). Metabolic rate increased drastically during the reproductive period; if oxygen is limited during the reproductive season, this could limit the ability of the species to increase its metabolic rate, and therefore could reduce productivity (Firth et al. 2023).

Population structure: Two studies recently evaluated the genetic structure of Eastern Sand Darter across northeastern North America. A genetic analysis was conducted using 10 polymorphic microsatellite loci from specimens in four drainages: Ohio River, Wabash River, Great Lakes, and St. Lawrence River. This analysis revealed seven distinct genetic clusters with high levels of genetic differentiation among drainages, but not necessarily among or within rivers within a drainage (Ginson et al. 2015). Notably for Eastern Sand Darter in Canada, a genetic barrier was identified separating the St. Lawrence River drainage from the Great Lakes drainage, supporting separation of the Southwestern Ontario and Quebec DUs. Within the Great Lakes drainage, samples were included from the Grand, Sydenham, and Thames rivers of the Southwestern Ontario DU. There was significant genetic differentiation between the Grand River, and the Sydenham/Thames river groups; however, there was little genetic differentiation between populations in the Sydenham and Thames rivers, suggesting some connectivity either historically through headwater connections, or presently through Lake St. Clair (Ginson et al.

2015). The species has been collected along the shoreline of Lake St. Clair between the Sydenham and Thames rivers, which may represent individuals moving between those locations, or indicate a single reproductive population in eastern Lake St. Clair and its tributaries. There was little genetic differentiation among sites within the Grand River, suggesting that some dispersal is occurring between the upstream and downstream reaches despite the presence of the Caledonia Dam; or, that the dam was built too recently for differentiation to have occurred.

The discovery of Eastern Sand Darter in West Lake prompted a re-analysis of genetic samples with West Lake specimens included. Walter et al. (2022) found similar results using nine microsatellite loci and the mitochondrial cytochrome oxidase I, and noted that West Lake was especially divergent with little admixture from other genetic clusters. It had a unique haplotype that appeared intermediate to a commonly shared haplotype, and ones that were exclusive to the Ohio River drainage. This genetic distinctiveness of West Lake relative to all other Canadian clusters provides the basis for a re-classification of the DU structure of Eastern Sand Darter in Canada based on evolutionary discreteness (COSEWIC 2022).

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

Abundance

Abundance estimates are lacking for Eastern Sand Darter in Ontario; however, some information exists to inform population size. Targeted sampling effort and captures by locality are summarized in Table 1, and incidental captures are summarized in Table 2. Density estimates from N-mixture models were developed from stratified-random sampling in the Grand River in 2022 (Gáspárdy et al. 2025), yielding an estimate of 0.075 fish/m^2 (95% Credible Interval [CI]: 0.036–0.181 fish/m^2) for the Brantford section (most upstream area sampled) and 0.019 fish/m^2 (95% CI: 0.008–0.054 fish/m^2) for the Caledonia section (most downstream area sampled). In both sections, the targeted sampling design was associated with a mean percent cover of sand and fine gravel of 82.6% and mean turbidity was 7.27 NTU. N-mixture models developed using sampling data from West Lake (2013–2015; LeBaron et al. 2020) yielded a density estimate of 0.080 fish/m^2 (95% CI: 0.049–0.136 fish/m^2) where the mean percent cover of sand was 97.9%, and mean site depth was 0.54 m (Appendix 2). Density in the Thames River was estimated using data collected in 2006 as 0.04 fish/m^2 (95% CI: 0.026–0.066) where the mean percent cover of sand and fine gravel was 45.6%, and mean water clarity (depth of light attenuation) was 26.7 cm (Dextrase 2013). Summaries of other targeted and incidental sampling efforts are presented in Table 1 and 2, respectively.

Indices of abundance were estimated for the Grand and Thames rivers based on extrapolations of the above density estimates across presumed habitat patches (Table 3 and 4; Lamothe et al. 2026). The summed mean index of abundance for the Grand River population across wadable and non-wadable habitats was estimated to be 54,869 age-1+ individuals (95% CI: 22,301–128,248), which assumes 20–25% suitable habitat in the Brantford and Caledonia sections and 5–10% suitable habitat in the Cayuga and Middleport sections. The summed mean index of abundance for the Thames River population across wadable and non-wadable habitats assuming 20–25% suitable habitat was 54,251 age-1+ individuals (95% CI: 33,607–89,357). These extrapolations assumed that fish density in non-wadable habitat was similar to fish density in wadable habitat (i.e., <1.2 m). This assumption can have a large effect on the estimated abundance of Eastern Sand Darter and is an important knowledge gap.

Trends through time are unknown given the lack of repeated standardized sampling in occupied systems.

*Table 1. Summary of targeted sampling (2010–2022) for Eastern Sand Darter (ESD) by drainage and designatable unit (DU). SN = Seine net, TRL = trawl net, CPUE = catch-per-unit-effort. Data from Fisheries and Oceans Canada (Fish Biodiversity Database) for most populations, or from Ontario Ministry of Natural Resources indicated with a * (Reid and Dextrase 2014, LeBaron et al. 2020).*

Drainage (DU)	Population	Total Targeted Effort	Gear (unit of effort)	Number of ESD	Mean CPUE
Lake Huron (Southwestern Ontario)	Ausable River	93	SN (hauls)	0	0
		42	TRL (tows)	0	0
Lake St. Clair (Southwestern Ontario)	Lake St. Clair	0	-	-	-
	Sydenham River	22	TRL (tows)	0	0
	Thames River	20	SN (hauls)	1	0.10
		69	TRL (tows)	59	0.97
Lake Erie (Southwestern Ontario)	Detroit River	0	-	-	-
	Western Basin	0	-	-	-
	Rondeau Bay*	89	SN (hauls)	4	0.04
	Catfish Creek	0	-	-	-
	Big Otter Creek	194	SN (hauls)	0	0
	Long Point Bay	0	-	-	-
	Big Creek (Norfolk County)	0	-	-	-
	Grand River	480	SN (hauls)	1,059	2.26
		60	TRL (tows)	66	1.10
Lake Ontario (West Lake)	West Lake*	500	bag SN (hauls)	262	0.52
		385	beach SN (hauls)	967	2.51

Table 2. Summary of incidental sampling by Fisheries and Oceans Canada where Eastern Sand Darter (ESD) was detected (2010–2022) by drainage and designatable unit (DU). Sampling in West Lake was conducted by Ontario Ministry of Natural Resources (Reid and Dextrase 2014). If the species was detected during non-target sampling, effort from the project was summarized, but does not represent all sampling that occurred in these areas that may have been suitable. SN = Seine net, TRL = trawl net, BEF = boat electrofishing, BPEF = backpack electrofishing, CPUE = catch-per-unit-effort.

Drainage (DU)	Population	Total Incidental Effort	Gear (unit of effort)	Number of ESD	Mean CPUE
Lake St. Clair (Southwestern Ontario)	Lake St. Clair	222	TRL (tows)	3	0.01
	Sydenham River	30,330	BPEF (seconds)	29	0.00
		243	SN (hauls)	136	0.42
		184	TRL (tows)	86	1.49
	Thames River	240	SN (hauls)	11	0.04
		297	TRL (tows)	556	3.36
Lake Erie (Southwestern Ontario)	Detroit River	15,604	BEF (seconds)	0	0.00
		112	TRL (tows)	1	0.01
	Grand River	155	SN (hauls)	80	2.00
		373	TRL (tows)	1,585	2.75
Lake Ontario (West Lake)	West Lake	15	SN (hauls)	9	0.60

Table 3. Median and mean indices of abundance for age-1+ Eastern Sand Darter in wadable, non-wadable, and combined (total) habitats in the Grand River by river section and the proportion of habitat with substrate consisting of greater than 50% sand and fine gravel. Minimum totals represent total abundance when the proportion of suitable habitat is at the minimum values considered per section and maximum totals represent total abundance when the proportion of suitable habitat is at the maximum values considered. River sections depicted in Figure 3 (Lamothe et al. 2026).

Section	Proportion of suitable habitat	Wadable (median)	Wadable (mean)	Non-wadable (median)	Non-wadable (mean)	Total (median)	Total (mean)
Brantford	0.20-0.25	9,438	10,637	22,021	24,820	**31,459**	**35,457**
Brantford	0.25-0.30	11,679	13,162	27,251	30,710	**38,930**	**43,872**
Brantford	0.30-0.35	13,832	15,399	32,276	35,932	**46,108**	**51,331**
Brantford	0.35-0.40	15,874	17,957	37,040	41,901	**52,914**	**59,858**
Brantford	0.40-0.45	18,028	20,172	42,066	47,067	**60,094**	**67,239**
Brantford	0.45-0.50	20,053	22,554	46,791	52,626	**66,844**	**75,180**
Brantford	0.50-0.55	22,402	25,297	52,271	59,026	**74,673**	**84,323**
Brantford	0.55-0.60	24,373	27,244	56,870	63,569	**81,243**	**90,813**
Brantford	0.60-0.65	26,051	29,370	60,786	68,531	**86,837**	**97,901**
Middleport	0.05-0.10	412	492	3,704	4,426	**4,116**	**4,918**
Middleport	0.10-0.15	695	816	6,257	7,343	**6,952**	**8,159**
Middleport	0.15-0.20	969	1,132	8,722	10,189	**9,691**	**11,321**
Middleport	0.20-0.25	1,266	1,488	11,395	13,393	**12,661**	**14,881**
Caledonia	0.05-0.10	1,416	1,692	1,416	1,692	**2,832**	**3,384**
Caledonia	0.10-0.15	2,392	2,808	2,392	2,808	**4,784**	**5,616**
Caledonia	0.15-0.20	3,335	3,896	3,335	3,896	**6,670**	**7,792**
Caledonia	0.20-0.25	4,357	5,121	4,357	5,121	**8,714**	**10,242**
Cayuga	0.05-0.10	356	425	3,202	3,827	**3,558**	**4,252**
Cayuga	0.10-0.15	601	705	5,410	6,349	**6,011**	**7,054**
Cayuga	0.15-0.20	838	979	7,541	8,810	**8,379**	**9,789**
Cayuga	0.20-0.25	1,095	1,287	9,852	11,580	**10,947**	**12,867**
Total (minimum)	-	**11,622**	**13,246**	**30,043**	**34,765**	**41,965**	**48,011**
Total (maximum)	-	**32,769**	**37,266**	**86,390**	**98,625**	**119,159**	**135,891**

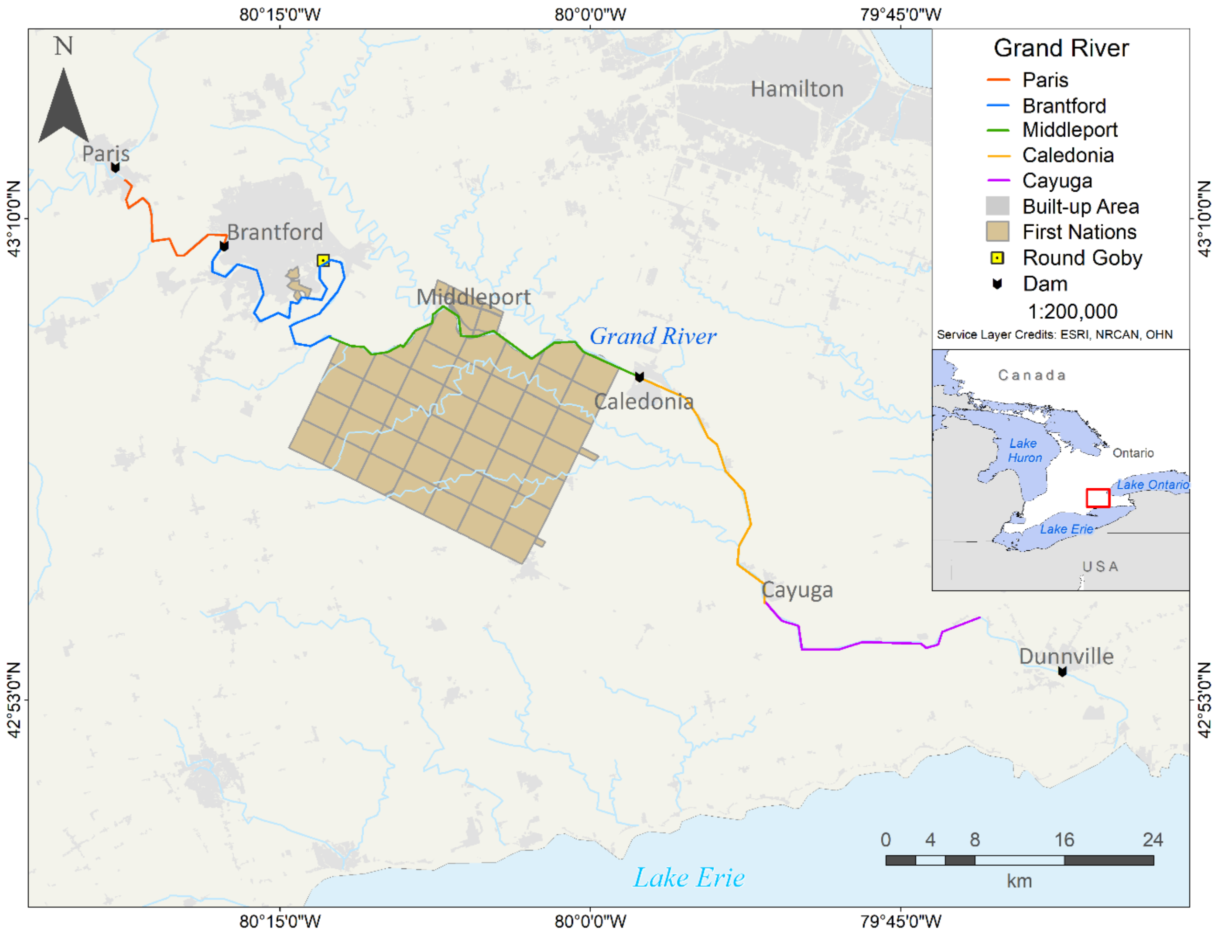

Figure 3. Map of areas containing Eastern Sand Darter critical habitat in the Grand River divided into five segments (Paris [red], Brantford [blue], Middleport [green], Caledonia [yellow], and Cayuga [purple]), as presented in Table 3. The farthest upstream detection record (2022) of Round Goby (Neogobius melanostomus) is indicated with the yellow square. Built-up area in grey and First Nation areas in tan. Figure reproduced from Lamothe et al. 2026.

Table 4. Median and mean indices of abundance for age-1+ Eastern Sand Darter in wadable, non-wadable, and combined (total) habitats in the Thames River and the proportion of habitat with substrate consisting of greater than 50% sand and fine gravel. Wadable habitat was considered to be 50% of the total habitat in the Thames River within the distribution of Eastern Sand Darter.

Proportion of suitable substrate	Wadable (median)	Wadable (mean)	Non-wadable (median)	Non-Wadable (mean)	Total (median)	Total (mean)
0.05-0.10	8,515	8,988	8,515	8,988	**17,030**	**17,976**
0.10-0.15	14,229	14,957	14,229	14,957	**28,458**	**29,914**
0.15-0.20	20,164	21,195	20,164	21,195	**40,329**	**42,390**
0.20-0.25	25,778	27,126	25,778	27,126	**51,555**	**54,251**
0.25-0.30	31,742	33,058	31,742	33,058	**63,485**	**66,116**
0.30-0.35	37,534	39,116	37,534	39,116	**75,068**	**78,232**
0.35-0.40	43,063	44,937	43,063	44,937	**86,125**	**89,874**
0.40-0.45	48,768	50,815	48,768	50,815	**97,537**	**101,630**
0.45-0.50	54,372	56,882	54,372	56,882	**108,744**	**113,765**

Distribution

Eastern Sand Darter is found in the Ohio River basin (Ohio, Indiana, Illinois, Kentucky, West Virginia, and Pennsylvania), the lower Great Lakes basin in lakes Huron, St. Clair, Erie, and Ontario (Michigan, Ohio, New York, Pennsylvania, Ontario), and the St. Lawrence River and Lake Champlain watersheds (Quebec, Vermont, New York). It is of conservation concern in 8 of 9 states and both Canadian provinces where it occurs. Two Eastern Sand Darter DUs are now recognized in Ontario (COSEWIC 2022). The Southwestern Ontario DU is found in Lake St. Clair, Sydenham River, Thames River, the Western Basin of Lake Erie (near the outlet of the Detroit and around Pelee Island; and possibly the Detroit River[1]), Rondeau Bay, Long Point Bay, Big Creek (Norfolk County), and the Grand River (Figure 4). It was historically found in the Ausable River, Catfish Creek, and Big Otter Creek, but is considered extirpated from these three localities. The West Lake DU, found only in West Lake, eastern Lake Ontario, was discovered in 2013 (Figure 5; Reid and Dextrase 2014). A brief description of records of each of the two Ontario DUs since 2010 is provided below. A complete list of records with additional suitable sampling by area was compiled in COSEWIC (2022) up to 2018.

[1] One individual was captured in 2013

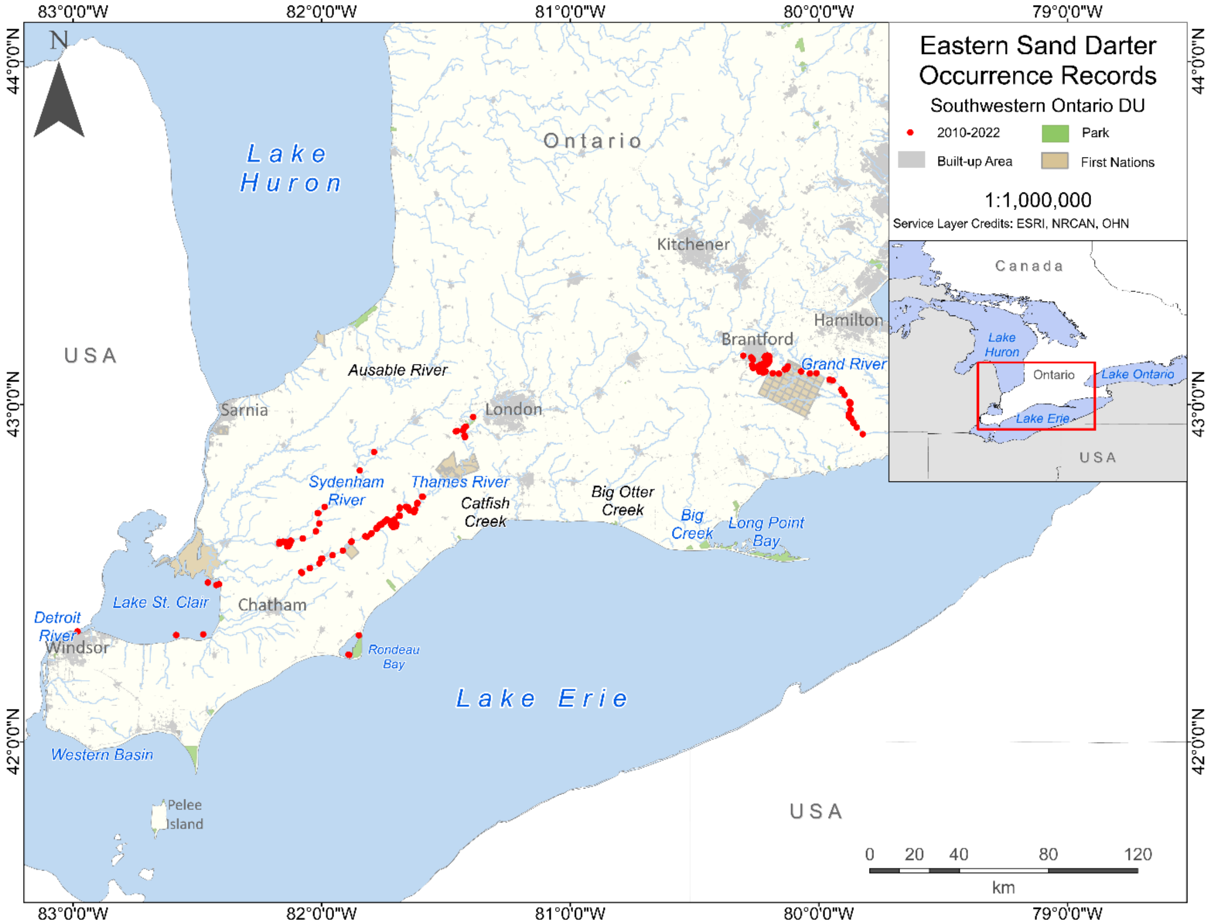

Figure 4. Distribution of Eastern Sand Darter – Southwestern Ontario Designatable Unit (DU). Red circles indicate occurrence records from 2010–2022. Localities from which the DU is thought to be extirpated are in black text. Park = green, built-up area = grey, and First Nations = tan.

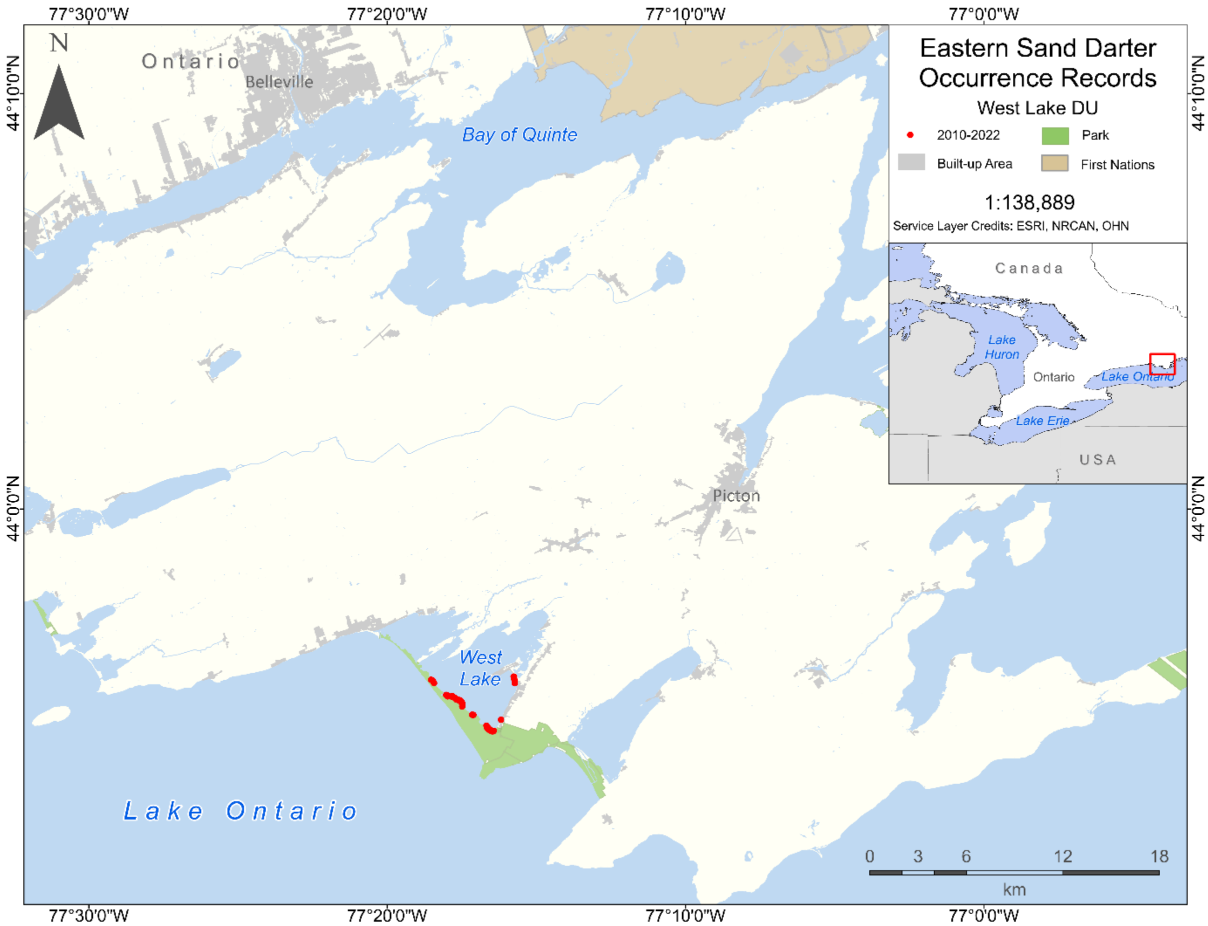

Figure 5. Distribution of Eastern Sand Darter – West Lake Designatable Unit (DU). Red circles indicate all occurrence records (note: sampling occurred in 2013–2015). Park = green, built-up area = grey, and First Nations = tan.

Current Status (2010–2022)

The historical Eastern Sand Darter records presented in Bouvier and Mandrak (2010) are considered valid and applicable; a brief summary of new information is provided below. If new information was not available, the most recent historical information is presented. There are several localities in the Southwestern Ontario DU where it is uncertain if reproduction is occurring (e.g., Rondeau Bay, Big Creek, Long Point Bay) and as such the status is uncertain.

Southwestern Ontario DU

Ausable River: There is a single historical record of Eastern Sand Darter from 1928 in the Ausable River. Despite sampling events with suitable gears (e.g., 24 sites in 2008; Dextrase 2013), including, most recently, targeted sampling at 9 sites near Exeter in 2018 (Barnucz et al. 2020), it has not been detected and is considered extirpated from this locality.

Lake St. Clair: Eastern Sand Darter has been sporadically detected in nearshore and offshore sandy locations throughout the Canadian side of Lake St. Clair. It was most recently detected in 2012 (n = 2) during targeted trawling efforts for the SARA-Endangered Northern Madtom (*Noturus stigmosus*) near Mitchell's Bay and Stoney Point, in 2013 (n = 1) just northwest of the mouth of the Thames River (Barnucz et al. 2015), and two individuals were captured in each 2016 and 2017 near Mitchell's Bay (Ontario Ministry of Natural Resources and Forestry [MNRF] unpublished data).

Sydenham River: Eastern Sand Darter was historically known to occur from Strathroy downstream to Dresden in the East Sydenham River[2]; all recent detections have been from Alvinston to Dawn Mills. Targeted sampling in 2010 yielded 12 individuals (Ginson et al. 2015). It was detected incidentally in 2010 (n = 214), 2012 during seining (n = 13) and trawling (n = 1) efforts, and during seining efforts in 2013 (n = 2) and 2015 (n = 7) (Fish Biodiversity Database). Trawling efforts targeting Round Goby captured 12 and 56 Eastern Sand Darter in 2015 and 2016, respectively (D. Raab, DFO, pers. comm.). It was detected in 2019 (n = 16; ranging 27–47 mm TL) during targeted trawling for Northern Madtom (Barnucz and Drake 2021). Ten index sites were sampled in 2020–2022 with backpack electrofishing and seining and one Eastern Sand Darter was detected in 2020 (St. Clair Region Conservation Authority [SCRCA] unpublished data; none detected in 2021 and 2022). In 2022, a single Eastern Darter (67 mm TL) was collected in the Sydenham River downstream of Napier in a seine net (DFO unpublished).

Thames River: In the Thames River, Eastern Sand Darter is known to occur from Kilworth to Kent Bridge. In 2010 and 2011, 162 individuals were captured while seining (Ginson et al. 2015). An additional 19 individuals were detected in 2010 (MNRF unpublished data). It was captured incidentally in 2011 (n = 10) and 2015 (n = 1) during seining efforts, and in 2010 (n = 78), 2012 (n = 63), 2013 (n = 103), 2014 (n = 35), 2015 (n = 264), and 2016 (n = 13) during trawling efforts (Fish Biodiversity Database). In August 2020, 59 individuals (31–64 mm TL) were captured during targeted trawling (Barnucz et al. 2022a). In 2022, six individuals were captured in a seine near the Big Bend Conservation Area (LTVCA unpublished data), and in the fall, 51 individuals (27–64 mm TL) were detected via trawling efforts from downstream of Tait's Corner to Big Bend Conservation Area during targeted sampling for Northern Madtom (Barnucz et al. 2026). Based on sampling from 2006, mean site density was 3.94 fish/site, and the detection probability of individual Eastern Sand Darter in the Thames River was estimated to be 14.1% (95% CI: 7.1–24.7%) but decreased sharply as the proportional cover of woody debris and boulders increased (Appendix 2).

Detroit River: A single Eastern Sand Darter (46 mm TL) was captured in a trawl in the Detroit River in October 2013 near Peace Fountain in Windsor. This represents the only capture of the species from the Detroit River to date (Kindree and Mandrak 2020). Given that suitable sampling gears have been used in the Detroit River in 2010–2022 (Kindree and Mandrak 2020, Aguiar et al. 2021), it remains uncertain if this capture is associated with a population or represents an individual dispersed (or flushed) from Lake St. Clair. Additional targeted sampling through time would help resolve the status of Eastern Sand Darter in the Detroit River.

Lake Erie – Western Basin: Eastern Sand Darter has been detected along the north shore of Lake Erie's Western Basin (n = 2; 1975) and around Pelee Island (n = 3; 1953). It was last captured in the Western Basin in 1975 (Paine 1976). Extensive nearshore sampling was conducted with beach seines in 2005 and 2006 (Reid and Mandrak 2008), and with beach seines and boat electrofishing in 2007 and 2008 (Yunker et al. 2009), and offshore bottom trawling has been conducted annually by MNRF from 1987–2022, but Eastern Sand Darter was not detected (A. Cook, MNRF, pers. comm.).

[2] There was a single record in the North Sydenham River near Wilkesport in 1996.

Rondeau Bay: In the fall of 2018, targeted seining was conducted at beaches in Erieau and in Rondeau Provincial Park; four Eastern Sand Darter were collected (range: 53–67 mm TL) (LeBaron et al. 2020). Individuals were detected at different ends of the Rondeau Provincial Park boundaries; additional targeted sampling would help resolve the distribution and status within Rondeau Bay.

Catfish Creek: Eastern Sand Darter was detected in Catfish Creek in 1922 and 1941. Limited sampling has occurred in this area; however, it is thought to be extirpated from this location.

Big Otter Creek: Eastern Sand Darter was historically known from around Tillsonburg and near Calton. It has not been detected since 1955 and is considered extirpated. Targeted sampling occurred in 2008 but no individuals were detected (Dextrase 2013). In 2018, targeted sampling was conducted at 52 sites throughout the historical distribution but no individuals were captured (Barnucz et al. 2020). A detailed habitat assessment (including substrate analysis) was conducted in 2020 to inform potential reintroduction efforts (Barnucz et al. 2022b).

Long Point Bay: Eastern Sand Darter is known to occur from the Inner Bay of Long Point Bay and at Second Island Outlet south of Pottohawk Point. Most of the records of Eastern Sand Darter are from the MNRF trawl program, with annual index station sampling from 1980–2022 (A. Bonsall, MNRF, pers. comm.). Eastern Sand Darter was last captured in 1996. Despite annual surveys, there remain large areas of suitable sand habitat in Long Point Bay where targeted sampling would be help inform the distribution of Eastern Sand Darter in this locality.

Big Creek (Norfolk County): In Big Creek, Eastern Sand Darter is known to occur from Highway 60 in Walsingham to the outlet in inner Long Point Bay. It was last detected there in 2008 (Dextrase 2013); targeted sampling in sand habitats has not occurred in Big Creek since this time. Targeted sampling would help resolve the species' current status in this locality.

Grand River: In the Grand River, Eastern Sand Darter is known to occur from Wilkes Dam in Brantford to approximately 10 km downstream of Cayuga. In 2010, 149 individuals were captured (Ginson et al. 2015). It was detected during trawling efforts in 2010 (n = 411), 2011 (n = 615), 2013 (n = 502), 2015 (n = 1), 2016 (n = 56), and during seining in 2018 (n = 60) (Fish Biodiversity Database). It was also detected in 2014 (n = 151), 2015 (n = 164), and 2016 (n = 41) (MNRF unpublished data). In 2019, it was detected during targeted sampling efforts while trawling (n = 66) and seining (n = 455) (Gáspárdy et al. 2021). In 2022, Eastern Sand Darter was targeted in habitats containing sand and fine gravel substrates in a stratified-random design to develop indices of population abundance. A total of 610 individuals were captured by seine, ranging in total length from 27 to 67 mm (Gáspárdy et al. 2025). Observed mean site density was estimated as 0.075 fish/m^2 in the Brantford section, and 0.019 fish/m^2 in the Caledonia section (Lamothe et al. 2026). The detection probability of individual Eastern Sand Darter in the Grand River was estimated to be 52.0% (95% CI: 35.4–66.8%) using the stratified-random sampling design, but decreased with increasing river width and river velocity (Appendix 2).

West Lake DU

West Lake, Lake Ontario: Eastern Sand Darter was first discovered in West Lake in 2013. Most of the detections occurred along the boundary of Sandbanks Provincial Park (Reid and Dextrase 2014). Nine individuals were collected by seine net in June, and subsequent sampling in September yielded 866 individuals. An additional 318 individuals were detected in 2014 ranging in size from 20–69 mm TL, and another 45 in 2015 (Reid and Dextrase 2014, LeBaron et al. 2020). Other sand beaches along the north shore of Lake Ontario were targeted in 2009, and 2013–2015 (including at: North Beach, Presquile, and Sandbanks provincial parks, and Wellers Bay) but Eastern Sand Darter was only detected in West Lake (LeBaron et al. 2020). An eDNA based survey was undertaken in West Lake and along a similar sand spit-area of habitat in Wellers Bay; Eastern Sand Darter DNA was detected in West Lake but not Wellers Bay (Reid and Haxton 2020). Additional exploratory sampling at beach habitats in Lake Ontario may reveal additional occupied localities. West Lake represents the only population in the Lake Ontario drainage. Observed mean site density was 3.6 fish/site with bag seines and 16.1 fish/site with beach seines (Appendix 2).

Population Status Assessment

To assess the population status of Eastern Sand Darter in Ontario, each population was ranked in terms of its abundance (Relative Abundance Index) and trajectory (Population Trajectory) (Table 5). The revised population status assessment is intended to replace the previous population status assessment (Bouvier and Mandrak 2010). The Relative Abundance Index was assigned as Extirpated, Low, Medium, High, or Unknown. Sampling parameters such as gear used, area sampled, sampling effort, and whether the study was targeting Eastern Sand Darter were considered. The number of Eastern Sand Darter caught during each sampling period (Table 1) and estimates of occupied area (Table 11) were then considered when assigning the Relative Abundance Index. The Relative Abundance Index is a relative parameter in that the values assigned to each population are relative to the most abundant population. In the case of the Southwestern Ontario DU, all populations were assigned an Abundance Index relative to the Grand River, which is considered the largest population (Lamothe et al. 2026). The West Lake DU has only one population, so a relative assessment cannot be made; however, the density is similar to the upstream (Brantford) portion of the Grand River and the estimated occupied area is similar (Table 11), suggesting it should receive the same Relative Abundance Index as the Grand River. Population Trajectory was assessed as Decreasing, Stable, Increasing, or Unknown for each population based on the best available information about the current trajectory of the population. The number of individuals caught over time for each population was considered.

Table 5. Relative Abundance Index and Population Trajectory of each Eastern Sand Darter population in Canada. Certainty has been associated with the Relative Abundance Index and Population Trajectory rankings and is listed as: 1 = quantitative analysis; 2 = catch-per-unit-effort (CPUE) or standardized sampling; 3 = expert opinion. Note that West Lake is a separate designatable unit (DU)and is not assessed relative to Southwestern Ontario populations.

Drainage (DU)	Population	Relative Abundance Index	Certainty	Population Trajectory	Certainty
Lake Huron (Southwestern Ontario)	Ausable River	Extirpated	2	Extirpated	3
Lake St. Clair (Southwestern Ontario)	Lake St. Clair	Low	2	Unknown	3
	Sydenham River	Low	2	Decreasing	2
	Thames River	Medium	1	Stable	2
Lake Erie (Southwestern Ontario)	Western Basin	Presumed Extirpated	3	Unknown	3
	Rondeau Bay	Low	2	Unknown	3
	Catfish Creek	Extirpated	3	Extirpated	3
	Big Otter Creek	Extirpated	2	Extirpated	3

Drainage (DU)	Population	Relative Abundance Index	Certainty	Population Trajectory	Certainty
	Long Point Bay	Unknown	3	Unknown	3
	Big Creek	Unknown	3	Unknown	3
	Grand River	High	1	Stable	2
Lake Ontario (West Lake)	West Lake	High	2	Unknown	3

The Relative Abundance Index is presumed extirpated for the Western Basin of Lake Erie as no individuals have been detected since 1975, despite suitable sampling (Reid and Mandrak 2008, Yunker et al. 2009). There are no records of Eastern Sand Darter in Long Point Bay or Big Creek over the timeframe evaluated (despite some sampling in Long Point Bay), resulting in uncertainty in the status. Although repeated, standardized sampling has not been conducted to inform trends through time for any population, the Grand and Thames rivers have yielded consistently large catches of Eastern Sand Darter through time, suggesting the Population Trajectories are likely stable. Catches of the species have declined at index stations sampled in the Sydenham River in the last 20 years (Poos et al. 2008, SCRCA unpublished data).

The Relative Abundance Index and Population Trajectory values were then combined in the Population Status Matrix (Table 6). Each Population Status is subsequently ranked as Poor, Fair, Good, Unknown, or Not Applicable (Table 7).

Table 6. The Population Status Matrix combines the Relative Abundance Index and Population Trajectory rankings to establish the Population Status for each Eastern Sand Darter population in Canada. The resulting Population Status is categorized as Extirpated, Poor (red), Fair (yellow), Good (green), or Unknown.

		Population Trajectory			
		Increasing	Stable	Decreasing	Unknown
Relative Abundance Index	Low	Poor	Poor	Poor	Poor
	Medium	Fair	Fair	Poor	Poor
	High	Good	Good	Fair	Fair
	Unknown	Unknown	Unknown	Unknown	Unknown
	Extirpated	Extirpated	Extirpated	Extirpated	Extirpated

Table 7. Population Status for all Eastern Sand Darter populations in Canada resulting from an analysis of both the Relative Abundance Index and Population Trajectory. Certainty assigned to each Population Status is reflective of the lowest level of certainty associated with either initial parameter (Relative Abundance Index or Population Trajectory). Poor = red, fair = yellow, good = green, DU = designatable unit.

Drainage (DU)	Population	Revised Population Status (Certainty)
Lake Huron (Southwestern Ontario)	Ausable River	Extirpated (2)
Lake St. Clair (Southwestern Ontario)	Lake St. Clair	Poor (3)
	Sydenham River	Poor (3)
	Thames River	Fair (2)
Lake Erie (Southwestern Ontario)	Western Basin	Presumed Extirpated (3)
	Rondeau Bay	Poor (3)
	Catfish Creek	Extirpated (3)
	Big Otter Creek	Extirpated (2)
	Long Point Bay	Unknown (3)
	Big Creek	Unknown (3)
	Grand River	Good (2)
Lake Ontario (West Lake)	West Lake	Good (2)

***Element 3:** Estimate the current or recent life-history parameters for Eastern Sand Darter (Southwestern Ontario and West Lake DUs)*

Life-history parameters for Eastern Sand Darter were estimated for the population model presented in Appendix 1 and are summarized in Table 8. These parameters are derived from Southwestern Ontario DU populations. Life-history parameters have not been measured or estimated for the West Lake DU, so they are applied to both DUs here. These are intended to replace life-history parameters and population modelling for the Southwestern Ontario DU presented in Finch et al. (2011) owing to new data and modelling approaches.

Many life-history characteristics of Eastern Sand Darter in southwestern Ontario remain unknown. For example, longevity (T_{max}) may be age-3 (Finch et al. 2013) or age-4 (Drake et al. 2008) and age at maturity (T_{mat}) has been observed as age-1 or age-2 across populations (Finch et al. 2013). Clutch size has been reported to range from 56–71.5 eggs, and the number of clutches is thought to range from 1–3 per year (COSEWIC 2009, Finch et al. 2013). Uncertainties were represented in the population models with probability distributions to capture the range of values possible for the species. Variables incorporated into population models as distributions included longevity (T_{max}), age-at-maturity (T_{mat}), age-1 survival rate (σ_{1+}), clutch size (f), clutch number per year (C), clutch size coefficient of variation (CV_f), and maximum population growth rate (λ_{max};Table 8).

Table 8. Parameter values incorporated in the matrix population model for Eastern Sand Darter (see Appendix 1 for full methods). Fixed parameters were held constant across model runs and uncertain parameters were sampled randomly from the specified distribution.

Parameter	Definition	Value
T_{max}	Longevity	$Unif(3, 4)$
T_{mat}	Age-at-maturity	$Unif(1, 2)$
σ_{1+}	Age-1+ survival rate	$Beta(15.88, 25.26)$
σ_0	Age-0 survival rate	Solved for
CV_σ	Survival rate coefficient of variation	0.2
f	Clutch size	$Gamma(55.7, 0.91)$
C	Clutch number per year	$Unif(1, 2, 3)$
CV_f	Clutch size coefficient of variation	$Unif(0.05, 0.15)$
φ	Sex ratio at birth	0.5
ρ_i	Proportion mature at Age-1	0.91, 1, 1, 1
Pr_{cat}	Probability of catastrophic event	$Unif(0.05, 0.20)$
λ_{max}	Maximum population growth rate	$Unif(1.56, 2.69)$

Habitat and Residence Requirements

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

Eastern Sand Darter occupies areas with sand and fine gravel substrate in streams or rivers near depositional areas, or sandy shoals in lakes and bays. Presence of sand and fine gravel is considered the most important habitat variable (Daniels 1993, Dextrase et al. 2014); however, specific size classes of sand seem less important. In a laboratory experiment, Eastern Sand Darter selected fine, medium, and coarse grain sands preferentially over very coarse sand (Thompson et al. 2017). Habitat descriptions by life stage presented in Bouvier and Mandrak (2010) are still considered to be valid; however, new information is summarized below to supplement those habitat descriptions.

Larval and Young-of-Year

In 2017, a larval fish survey was undertaken in the Sydenham River using drift nets from April 19 to August 2 (Gáspárdy et al. 2026). A total of 597 drift nets were set across 25 sampling days in Florence, resulting in the collection of over 13,000 larval fishes. This was a community-level survey and did not attempt to target Eastern Sand Darter spawning habitat. All larval fishes were measured, weighed, and either identified visually or sent for genetic analysis to confirm individual species identification. Sixteen larval Eastern Sand Darter were detected in 16 drift nets across 11 sampling days between June 8 and July 26. At sampling visits in which larval Eastern Sand Darter were detected, mean air temperature was 26.2 °C, mean water temperature was 23.7 °C, mean conductivity was 599.2 µS/cm, mean pH was 8.18, mean water clarity was 0.21 m, and mean turbidity was 41.43 NTU (Table 9). Mean daily water temperature was 18.81 °C on the first day larval Eastern Sand Darter were detected and 22.41 °C on the last day they were detected. There were no aquatic macrophytes in the riffle where drift nets were set, and the dominant substrate type in the riffle was boulder and cobble. The mean length of larval Eastern Sand Darter was 8.1 mm (range: 4.1–19.1 mm). Two eggs collected at Florence on June 15 were confirmed as Eastern Stand Darter. Bulk larval samples were also collected in drift nets elsewhere in the Sydenham River over this time. Eastern Sand Darter was present in three drift nets set in Alvinston (July 12, July 18, and August 1), and four drift nets set in Oil Springs (June 6, July 5, July 11, and July 19); these are suspected to be larvae based on the gear type used.

There is limited new information regarding young-of-year (YOY) habitat use of Eastern Sand Darter. Dextrase (2013) found that YOY and adults typically occupied the same habitats in the Thames River, and that YOY may be more tolerant of silt than adults.

Table 9. Mean (range) of habitat parameters measured at sites when larval Eastern Sand Darter (ESD) was present in the sample, and at sites with no ESD where larval sampling was conducted on the Sydenham River in 2017 (Gáspárdy et al. 2026).

Habitat parameter	ESD Present	All Other Sites
Air temperature (°C)	25.07 (14.32–30.65)	22.17 (12.1–36.14)
Water temperature (°C)	23.14 (17.60–27.22)	19.91 (11.96–26.67)
Conductivity (uS/cm)	600.66 (544.40–657.00)	566.91 (425.98–673.88)
Dissolved Oxygen (mg/L)	7.64 (6.25–11.90)	8.56 (5.83–11.38)
Turbidity (NTU)	41.54 (19.34–111.44)	34.48 (11.51–125.98)
pH	8.22 (8.03–8.55)	8.22 (7.99–8.44)
Water clarity (m)	0.20 (0.12–0.31)	0.24 (0.07–0.44)

Adult

Recent studies have corroborated previous descriptions of adult Eastern Sand Darter habitat. The presence of sand substrates remains the most important habitat variable for this species, but specific size-classes of sand seem less important (Thompson et al. 2017, 2018). It remains unclear to what degree flow plays a role in Eastern Sand Darter habitat selection, as the species occurs in lentic systems, and lotic systems with varying flow regimes. Thompson et al. (2018) found Eastern Sand Darter in the Elk River, West Virginia in sand habitats along a gradient of flow conditions from faster meander point bars to shallow embayments with no flow, with average water velocity ranging from 0.00–0.78 m/s. It is thought that flow may play a greater role in more turbid systems to prevent suspended sediments from settling so long as sand and fine gravel are retained (Poos et al. 2010). Similarly, the species' relationship with depth is also variable; it is typically found at depths less than 1.5 m but this finding is likely influenced by sampling gear and available depths, as it has been detected up to 14 m (Scott and Crossman 1973, Ricard et al. 2018, COSEWIC 2022). Raab et al. (2018) generally captured Eastern Sand Darter in the deeper, slower flowing trawled areas in the Grand River. The species generally prefers clear water but persists in turbid areas (range of 1.14–346.61 NTU at sites where it was detected in the Thames River, a system with high turbidity [Fish Biodiversity Database]). Eastern Sand Darter occurrence decreased with aquatic vegetation cover in Quebec (Ricard et al. 2018), and sites where it was detected in southwestern Ontario had a mean of 97.7% open water (i.e., no aquatic vegetation). Dextrase et al. (2014) found that site-scale habitat parameters were more important than reach- or catchment-scale parameters, but noted that abundance was greater upstream in the Grand and Thames rivers (where water clarity was also greater). In contrast, the probability of Eastern Sand Darter occurrence increased with increasing upstream drainage area in the Elk River, West Virginia (Thompson et al. 2018).

Lamothe et al. (2019) found that Eastern Sand Darter occupancy probability increased with water clarity, depth, and velocity in the Grand River. N-mixture models described in Appendix 2 suggest that site-scale abundance in the Grand River tended to be greater at sites that had greater proportions of sand or gravel and was lower at more turbid sites (Figure A2.2). The mean abundance estimates corresponded to sites with mean percent sand and gravel of 82.7% (range: 50–100%) and mean turbidity of 7.27 NTU (range: 1.1–47.03 NTU) from the sampled locations. Similarly, in the Thames River, mean abundance was higher at sites that had substrate with higher proportions of sand or gravel and higher water clarity (Figure A2.5). Site quality was lower in the Thames River than the Grand River with mean percent sand or gravel of 45.6% (range: 0–100%) and mean water clarity of 26.7 cm (range: 2.5–94.0 cm).

In West Lake, Eastern Sand Darter was sampled in September of 2013, 2014, and 2015 and was detected at 79 of 175 surveyed sites (LeBaron et al. 2020). At sites where Eastern Sand Darter was captured, mean water temperature was 18.8 °C (range: 12.8–26.2 °C), mean conductivity was 278 µs/cm (range: 257–308 µs/cm), and mean maximum depth was 0.70 m (range: 0.34–1.29 m). The substrate at occupied sites was composed mostly of sand (mean: 98.6%) with the remaining 1.4% composed of fine-grain sediment. Across all sites sampled in West Lake, Logperch (*Percina caprodes*) had the highest mean relative abundance (27.7%), followed by Round Goby (27.0%), and Eastern Sand Darter (17.5%) (LeBaron et al. 2020). Occupancy-based modelling by Reid and Dextrase (2017) did not find any strong relationships between Eastern Sand Darter site occupancy and habitat variables (except depth in certain circumstances) in West Lake, which likely related to the study design targeting assumed suitable habitat. An N-mixture model from West Lake found that density was highest at sites with the highest percent of sand, and with greater depths, although this relationship was not linear (Figure A2.3).

Habitat Functions, Features, and Attributes

A description of the functions, features, and attributes associated with the habitat of Eastern Sand Darter in Ontario can be found in Table 10. The habitat required for each life stage has been assigned a life-history function that corresponds to a biological requirement of Eastern Sand Darter. In addition to the life-history function, a habitat feature has been assigned to each life stage. A feature is considered to be the structural component of the habitat necessary for the species. Habitat attributes have also been provided; these are measurable components describing how the habitat features support the life-history function for each life stage. The habitat functions, features, and attributes outlined in Table 10 were adapted from the Recovery Strategy for Eastern Sand Darter in Ontario (DFO 2012), supplemented with additional, recent information to guide any future identification of critical habitat for this species.

Table 10. Summary of the essential habitat functions, features, and attributes for each life stage of Eastern Sand Darter in Canada. Habitat attributes from published literature (see Bouvier and Mandrak 2010) and those recorded during recent (2010–2022, May through October) sampling events (Fish Biodiversity Database) have been used to identify critical habitat (DFO 2012, 2017).

Life Stage	Habitat Functions	Features	Attributes		
			Scientific Literature	Recent Occurrence Records	Critical Habitat Identification
Spawn to hatch (likely occurs in April through July in Ontario)	• Spawning • Nursery	• Reaches of streams and rivers with sand substrate • Sandy shoals, bars, and beaches • Shallow pools and bays in lakes	• Not observed in the wild	• Eggs detected when mean water temperature was 24.5 °C in the Sydenham River	• Moderate current or wave action • Mix of sand and fine gravel (e.g., 0.06–8.0 mm) • Well-oxygenated substrates • Little to no aquatic vegetation • Warm and stable water temperatures (spawning in Ontario generally thought to occur from 18.8–25.5 °C, but has been reported from 14.5–25.5 °C elsewhere in its range)
Young-of-year (hatch to end of first year)	• Feeding • Cover (fossorial behaviour)	• Reaches of streams and rivers with sand substrate • Sandy shoals, bars, and beaches • Shallow pools and bays in lakes	• Same as adult habitat	• Larvae detected when mean water temperature was 17.60–27.22 °C in the Sydenham River • Same as adult habitat	• Juveniles have been caught in the same habitat as adults

Life Stage	Habitat Functions	Features	Attributes: Scientific Literature	Attributes: Recent Occurrence Records	Attributes: Critical Habitat Identification
Adult (likely age-1+)	• Feeding • Cover (fossorial behaviour)	• Reaches of streams and rivers with sand substrate • Sandy shoals, bars, and beaches • Shallow pools and bays in lakes	• Sand and fine gravel substrates (0.063–8.0 mm) (Dextrase 2013, Thompson et al. 2017, 2018) • Sufficient dissolved oxygen (> 1.14 mg/L; Firth et al. 2023) • Summer water temperatures < 37 °C and ideally < 33.4 °C (Firth et al. 2021a) • Generally clear water (Dextrase 2013)	**Rivers:** • Water quality - mean summer water temperature: 24.5 °C and mean fall water temperature: 13.1 °C (range: 8.75–30.10 °C); mean conductivity 698.07 μs/cm (range: 202–1,132 μs/cm); mean dissolved oxygen: 8.55 mg/L (range: 1.10–13.57 mg/L); mean Secchi depth: 0.28m (range: 0.06–0.98); mean turbidity: 40.45 NTU (range 1.14–346.61 NTU); • Substrate - mean percent composition - sand: 55.5%; gravel: 26.2%; cobble 16.9%; silt: 4.6% • Mean depth: 1.6 m (range: 0.16–4.50 m); mean water velocity: 0.30 m/s (range: 0.0–1.36 m/s) **West Lake** (LeBaron et al. 2020): • Water quality – mean summer water temperature: 18.8 °C (range: 12.8–26.2 °C); mean conductivity: 278 μs/ms (range: 257–308 μs/ms); mean maximum depth: 0.70 m (range: 0.34–1.29 m); • Substrate – mean percent composition – sand: 98.6%; fines: 1.4% (LeBaron et al. 2020)	• Slow to moderate current or wave action contributing to depositional areas • Sand or fine gravel (e.g., 0.06–8.0 mm) with minimal fines (< 0.06 mm) • Little or no aquatic vegetation • Sufficient Chironomidae, Cladocera, Ostracoda, Oligochaeta, and Ephemeroptera • Clear and turbid waters

Element 5: *Provide information on the spatial extent of the areas in Eastern Sand Darter (Southwestern Ontario and West Lake DUs)'s distribution that are likely to have these habitat properties*

The spatial extent of areas likely to contain habitat properties required by Eastern Sand Darter has not been explicitly quantified, but has been approximated for each occupied area in the Southwestern Ontario DU and West Lake DU (Table 11). Mandrak et al. (2014) developed a conceptual framework for delineating critical habitat for SARA-listed fishes based on the functional habitat requirements for each life stage. Estimates of range size for each population were made based on available information about waterbody size and shape, and occurrence records. Estimates of occupied area for each population in the Southwestern Ontario DU and the West Lake DU are presented in Table 11. It is likely that the entirety of the areas identified in Table 11 are not suitable habitat, and that additional habitat is used by the species for completing its life cycle beyond these areas.

Critical habitat for the Southwestern Ontario DU has been identified in the Sydenham, Thames, and Grand rivers, and in Big Creek (Norfolk County) and Long Point Bay (DFO 2012, 2017). The spatial extent of habitat properties likely to support Eastern Sand Darter in West Lake is the southern end of the lake from Sheba's Island across to the Sandbanks barrier adjacent to Lake Ontario.

Table 11. Estimated area occupied was coarsely generated based on methods in Mandrak et al. (2014), or Lamothe et al. (2026) where stated; note it is unlikely the entire area includes suitable and occupied habitat. DU = designatable unit.

Drainage (DU)	Population	Estimated Area Occupied (m^2)	Method Used
Lake Huron (Southwestern Ontario)	Ausable River	0	NA (Extirpated)
Lake St. Clair (Southwestern Ontario)	Lake St. Clair	1) 378,140,421 2) 704,609,441	1) convex polygon 2) whole waterbody
	Sydenham River	3,909,120	Convex polygon (continuous Ontario Hydro Network [OHN] Watercourse segments)
	Thames River	5,890,400	Lamothe et al. 2026
Lake Erie (Southwestern Ontario)	Western Basin	85,018,942	convex polygon
	Rondeau Bay	1) 4,182,876 2) 7,091,664	1) Convex polygon 2) Convex polygon expanded to full provincial park shore
	Catfish Creek	0	NA (Extirpated)
	Big Otter Creek	0	NA (Extirpated)
	Long Point Bay	343,719,284	Whole waterbody
	Big Creek	159,821	Convex polygon (continuous OHN Watercourse segments)
	Grand River	9,639,261	Lamothe et al. 2026
Lake Ontario (West Lake)	West Lake	1) 5,083,265 2) 19,036,784	1) Convex polygon 2) Whole waterbody

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

There are several large dams and structures that likely constrain movement of Eastern Sand Darter. On the Grand River, Eastern Sand Darter is not known to occur upstream of the Wilkes Dam in Brantford or below the Dunnville Dam, and the Caledonia Dam disrupts its distribution. Dextrase (2013) found that Eastern Sand Darter occupancy in wadable areas was reduced for approximately 25 km upstream of the Caledonia and Dunnville dams, likely due to deposition of fine sediments, and the distance upstream from dams was positively associated with site occupancy in this system (Figure 6). Lake St. Clair could be a barrier given the small size of Eastern Sand Darter; however, numerous detections in the eastern portion of the lake coupled with recent genetic evidence that suggests there may be mixing of the Sydenham and Thames river populations, indicate that it may not be a barrier to the species.

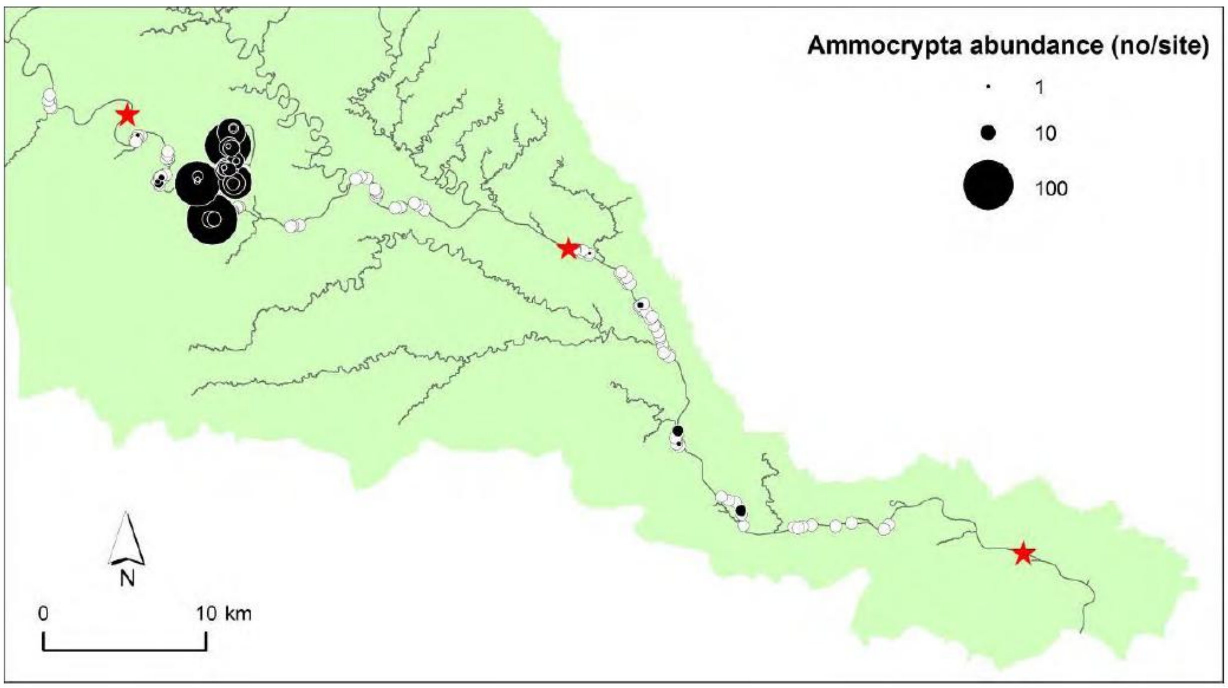

Figure 6. Longitudinal variation in Eastern Sand Darter occupancy and relative abundance for sites in the lower Grand River watershed – black circles represent relative abundance of detected Eastern Sand Darter, white circles represent sample sites, stars represent main stem dams. Figure reproduced from Dextrase (2013) with permission.

The West Lake DU is likely constrained to within the lake itself due to the adjacent colder waters of Lake Ontario. The next closest populations are approximately 200 km away in either the aux Saumons River (Quebec DU) or the Grand River (Southwestern Ontario DU); there is no evidence of recent admixture of the West Lake population with any of the other Eastern Sand Darter populations in Quebec, Southwestern Ontario, or the Ohio River drainage in the United States of America (USA) (Walter et al. 2022).

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

Residence is defined in SARA as a "dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating". Residence is interpreted by DFO as having been constructed, created, or at least modified by the organism. In the context of the above narrative description of habitat requirements for each larval, juvenile, and adult life stages, Eastern Sand Darter does not construct residences during its life cycle.

Threats and Limiting Factors to the Survival and Recovery

Element 8: *Assess and prioritize the threats to the survival and recovery of the Eastern Sand Darter (Southwestern Ontario and West Lake DUs)*

Siltation and sedimentation of watercourses is considered the greatest threat to Eastern Sand Darter across its range. The greatest threats to the Southwestern Ontario DU relate primarily to agricultural and urban development (e.g., increased turbidity and siltation of watercourses, nutrient loading, contaminants and toxic substances), physical modifications in the form of barriers or shoreline/nearshore alteration (altered flow and sediment transport regimes, barriers to movement), aquatic invasive species (Round Goby), and climate change (extreme temperatures and droughts) (COSEWIC 2009, 2022, Bouvier and Mandrak 2010). Incidental harvest by baitfishers was previously identified as a possible threat in southwestern Ontario, but analyses of baitfish harvest suggest this activity poses little threat to Eastern Sand Darter in Ontario (Drake and Mandrak 2014, COSEWIC 2022). Threats to the West Lake DU are thought to be from aquatic invasive species, specifically Round Goby.

Threats are thoroughly described for the Southwestern Ontario DU in existing documents (COSEWIC 2009, 2022, Bouvier and Mandrak 2010) with the most recent and complete account for both DUs in COSEWIC (2022). In brief, siltation of watercourses results in increased turbidity, which is likely to impede foraging success for Eastern Sand Darter (ambush feeding style), and fine sediments settling out can reduce available oxygen at the substrate interface that is important for egg development and survival, for juvenile growth, and for adults during fossorial periods (Drake et al. 2008, Finch 2009). Pollution and toxic substances may negatively affect growth and/or reproduction directly, but may also reduce the supply of macroinvertebrates. Physical modifications like channel straightening or nearshore alteration may lead to greater flow peaks or lows, can alter local substrate, and/or lead to changes in sediment transport that influence the availability of clean sand bars (COSEWIC 2009, 2022, Bouvier and Mandrak 2010). Physical modifications to surrounding lands that result in greater impervious surface area can lead to increased runoff and overland transport of sediment and other pollutants.

Round Goby is an aggressive benthic invader that has rapidly spread through the Great Lakes and into many tributaries, including all tributaries that support Eastern Sand Darter. Eastern Sand Darter abundance was negatively correlated with Round Goby abundance in the Grand River (Raab et al. 2018) and a reduction of Eastern Sand Darter has been observed to coincide with the upstream dispersal of Round Goby in the Sydenham River (C. Paterson, SCRCA, pers. comm.). Round Goby may compete with Eastern Sand Darter directly for food and space, but has also increased competition among other benthic invertivores (Poos et al. 2010, Firth et al. 2021b).

Additional research investigating impacts of Round Goby on Eastern Sand Darter has been completed since COSEWIC (2022). Sampling at index stations in the Sydenham River to investigate the expansion of Round Goby has suggested a decline in Eastern Sand Darter and an increase in Round Goby from 2016–2022 (SCRCA unpublished data). Through this sampling, Eastern Sand Darter was captured in 2016 (n = 56) and 2020 (n = 1), with none captured in 2021 or 2022. However, Round Goby was captured in all years: 2016 (n = 356), 2020 (n = 196), 2021 (n = 233), and 2022 (n = 397). Although this represents a snapshot in time, Eastern Sand Darter was more abundant at these sites prior to 2016 based on historical accounts (Poos et al. 2008). Targeted sampling for Round Goby recently completed in the Ausable River and Big Otter Creek found that Round Goby catch per unit area (CPUA) generally decreased moving upstream away from the river mouth, while the CPUA of darters generally increased (McAllister et al. 2022). Round Goby showed a moderately positive association with Logperch, Johnny Darter, and Greenside Darter, and a moderately negative association with Rainbow Darter in the Ausable River, and moderately negative associations with Johnny Darter and small-bodied percid species overall in Big Otter Creek. Firth et al. (2021b) found increased diet overlap among the benthic fish community following the invasion of Round Goby in the Sydenham River. There were six significant diet overlaps before invasion, and 20 following invasion, and a general shift towards specialist feeding strategies. Long-term consequences of these overlaps (e.g., fitness effects) are uncertain. Direct impacts to Eastern Sand Darter were assumed to be minimal, likely because of its relatively specialized feeding on chironomids in sand habitats; however, future indirect impacts are expected as Round Goby increases in abundance (Firth et al. 2021b). In West Lake, Round Goby was frequently caught at the same sites as Eastern Sand Darter and was the most abundant small benthic fish, making up 49.7% of all fishes caught (Reid and Dextrase 2017). It was detected in 57–96% of seine hauls where a darter was captured, depending on seine type.

Eastern Sand Darter has been ranked as vulnerable or highly vulnerable to impacts of climate change largely due to the presence of natural or artificial barriers, and due to limited variability in historical thermal and hydrological conditions (Hoving et al. 2013, Brinker et al. 2018). Although the species displays plasticity in its thermal responses, the relatively small difference between ambient summer stream temperatures observed in southwestern Ontario and its CT_{max} suggests the species may have limited capacity to withstand further temperature increases (Firth et al. 2021a). Extreme drought events associated with climate change may lead to exposure of sand bars, or displacement to marginal or unsuitable habitats (COSEWIC 2022). Surface water monitoring data from the Province of Ontario suggests that the frequency of Level 2 drought conditions has increased throughout the range of Eastern Sand Darter between 2001–2010 and 2011–2022 (Figure 7); Level 2 indicates stream flow is 50–70% of the lowest historical mean monthly level (Ontario Low Water Program unpublished data). Drought conditions are also likely to result in further water-taking for irrigation. Other extreme events such as flooding are also increasing in frequency and severity (e.g., West Lake experienced two 100-year floods in the last decade [M. Gunning, Quinte Conservation, pers. comm.]), which can lead to shifts in the number, size, and location of sand bars as bed material is moved both laterally to the floodplain and longitudinally downstream.

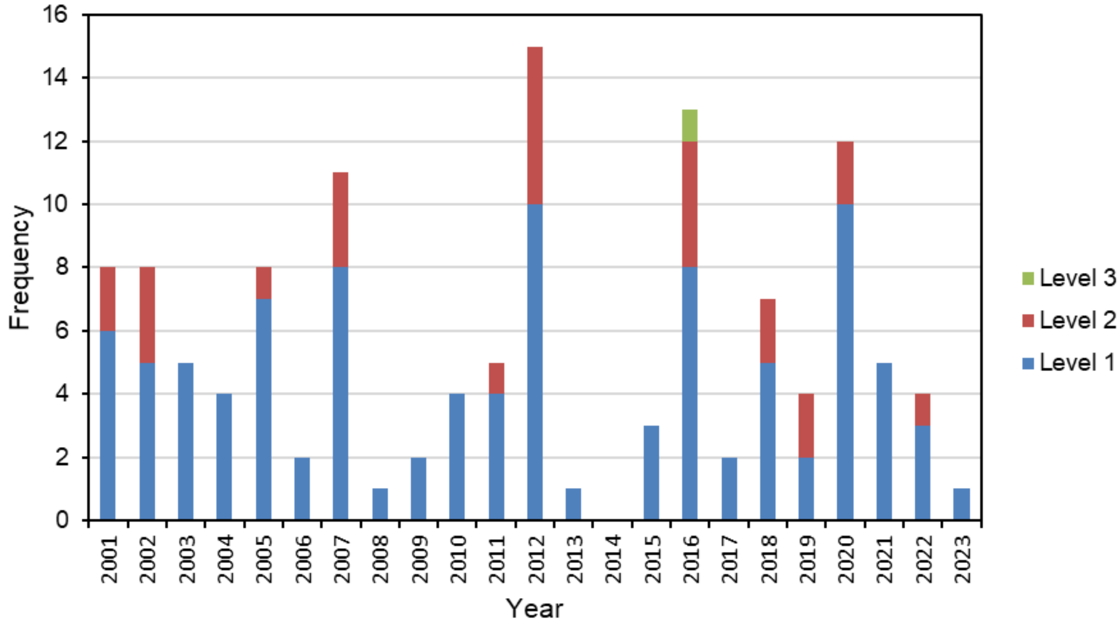

Figure 7. Frequency of Level 1 (blue), Level 2 (red), and Level 3 (green) drought condition events across the seven Conservation Authorities in which Eastern Sand Darter occurs. The mean number of Level 1 drought events from 2001–2010 was 4.40 and from 2011–2022 was 4.42, and the mean number of Level 2 drought events from 2001–2010 was 0.90 and from 2011–2022 was 1.42. Level 1 occurs when the mean monthly stream flow is 70–100% of the lowest historical monthly mean, Level 2 is 50–70%, and Level 3 is <50%.

An additional threat to Eastern Sand Darter not previously described relates to application of lampricides, including granular Bayluscide for Sea Lamprey (*Petromyzon marinus*) assessment and control. In an analysis of relative risk to fishes and mussels of conservation concern, the risk of granular Bayluscide applications to Eastern Sand Darter was deemed low due to limited spatial overlap and intensity of applications within known habitat, and a low toxicity score based on a surrogate species (Yellow Perch [*Perca flavescens*]; Andrews et al. 2021). However, mortalities of other darter species (*Etheostoma nigrum* and *E. olmstedi*) have been observed following applications of other lampricides (Fisheries Technical Committee 1999), and impacts to preferred prey species may indirectly impact Eastern Sand Darter (Schiff and Garnett 1961, Gilderhaus 1979, Andrews et al. 2021). In an analysis of direct mortality to Eastern Sand Darter from granular Bayluscide applications, the degree to which an Eastern Sand Darter population would be impacted varied greatly depending on the density of the species at the application site, and the proportion of available habitat that was actually occupied by an Eastern Sand Darter population. A worst case scenario of a 90% population decline after 100 years occurred when density was low (i.e., approximately 2.28 fish/100 m^2; likely in the Sydenham River), a small proportion of habitat was occupied, and applications occurred yearly (Smyth and Drake 2021). The potential impacts of granular Bayluscide to Eastern Sand Darter is currently relevant to the Sydenham and Thames rivers, and possibly Long Point Bay and Big Creek (Norfolk County) in the Southwestern Ontario DU, but could become important for other populations and the West Lake DU should applications expand spatially.

Additional threats for West Lake may be important but data are lacking to thoroughly evaluate their impacts to Eastern Sand Darter (M. Gunning, Quinte Conservation, pers. comm.; COSEWIC 2022). Recreational activities including swimming and boating are known to occur along the shores of Sandbanks Provincial Park where most Eastern Sand Darter records are from. Swimmers and beach-users occur in high density during the summer months, and boaters are observed parking vessels in sand habitats along the beach. The impacts to fishes from these activities are unknown, but may pose a greater threat to Eastern Sand Darter when spawning occurs and eggs are developing in sand. Dredging to maintain vessel channels is also known to occur between West Lake and Lake Ontario, which could lead to mortality and displacement of individuals. The spatial scale of these activities is likely small, but impacts are not known. Nutrient inputs from leaching septic tanks and from invasive Mute Swans (*Cygnus olor*) may negatively affect Eastern Sand Darter, but the extent of this threat and mechanism of impact are not well understood. Lastly, several housing development projects are anticipated for the northwest shoreline of West Lake. These activities are unlikely to directly impact Eastern Sand Darter, but may lead to increased sediment and contaminant inputs during construction and resulting from increased impervious surfaces and reduced vegetated buffers.

Although threats are assessed independently here, Eastern Sand Darter in Ontario (both DUs) are facing multiple threats concurrently, which likely interact in complex and context-dependent ways. Interactions between climate change (particularly reduced flows and water temperature), invasive species, sedimentation, and other pollutants have been shown to have synergistic effects in other aquatic taxa (Beermann et al. 2018, Luck and Ackerman 2022), but outcomes in fish may depend on life stage and taxonomy in addition to environmental context (Lange et al. 2018).

A threat assessment was completed for each population of Eastern Sand Darter following guidelines in DFO (2014). Full details of the threat assessment and all definitions are found in Appendix 3. The threat scores for the Southwestern Ontario DU and West Lake DU are presented in Table 12 and 13, respectively.

Table 12. Threat Level assessment of all Eastern Sand Darter populations in the Southwestern Ontario DU, resulting from an analysis of both the Threat Likelihood of Occurrence and Threat Level of Impact. The number in brackets refers to the Causal Certainty associated with the threat impact (1 = Very High; 2 = High; 3 = Medium; 4 = Low; 5 = Very Low). Red text indicates populations that are considered extirpated but are potential candidates for reintroduction efforts.

Threat Category	Subcategory	Details	Ausable River	Lake St. Clair	Sydenham River	Thames River	Western Basin	Rondeau Bay	Big Otter Creek	Big Creek (Norfolk County)	Long Point Bay	Grand River
Natural Systems Modifications	Dams & water management/use	Deposition of fines above dams and reduced flow below	Unknown (5)	NA	Low (5)	Low (5)	NA	NA	Unknown (5)	Low (5)	NA	Medium (1)
Invasive & other Problematic Species & Genes	Invasive non-native species	Round Goby	Medium (4)	Medium (4)	Medium (4)	Medium (4)	Medium (4)	Medium (4)	Medium (4)	Medium (4)	Medium (4)	Medium (4)
Pollution	Domestic and urban wastewater	Detergents, heavy metals, hydrocarbons, hormones and pharmaceutical compounds, chloride	Medium (5)	Low (5)	Medium (5)	Medium (5)	Low (5)	Medium (5)	Low (5)	Low (5)	Medium (5)	Medium (5)
	Agricultural and forestry effluents	Sediments, pesticides, herbicides, fertilizers	Medium (4)	Low (4)	Medium (4)	Medium (4)	Low (4)	Low (4)	Medium (4)	Medium (4)	Low (4)	Medium (4)
	Industrial and Military Effluents	granular Bayluscide; petro-chemical industry	Low (5)	Low (5)	Low (3)	Low (3)	Low (5)	Low (5)	Low (5)	Low (5)	Low (5)	Low (5)
Climate change and severe weather	Droughts	Water loss exposure of sand bars	Medium (5)	Low (5)	Medium (5)	High (5)	Low (5)	Low (5)	Medium (5)	Medium (5)	Low (5)	Medium (5)
	Extreme temperatures	Increased temperatures and periods of hypoxia	Low (4)	Low (4)	Low (4)	Low (4)	Low (4)	Low (4)	Low (4)	Low (4)	Low (4)	Low (4)

Several of the watersheds that support Eastern Sand Darter have extensive agricultural land use. For example, the Sydenham River watershed has 82% agricultural land use and 4,700 km of agricultural drains (C. Paterson, SCRCA, pers. comm.), and the lower Thames River watershed has 80% agricultural land use and approximately 4,080 km of agricultural drains (V. McKay, Lower Thames Valley Conservation Authority, pers. comm.). The mechanisms of impact are not well understood, but present levels of agriculture do not appear to be causing a continued decline of 30–70% of the Eastern Sand Darter populations to warrant a Level of Impact of Medium. Historical tobacco farming thought to be responsible for the extirpation of Eastern Sand Darter in Big Otter Creek and Catfish Creek, and declines in Big Creek, has shifted in recent decades in favour of less intensive cash crops, fruit, and herbs (P. Gagnon, Long Point Region Conservation Authority, pers. comm.). This shift in production alongside improved land stewardship initiatives has resulted in improvements to water quality in some watersheds, but intensive agriculture continues to cause habitat stress to Eastern Sand Darter, especially in the Southwestern Ontario DU.

Table 13. Threat Level assessment of Eastern Sand Darter, West Lake designatable unit, resulting from an analysis of both the Threat Likelihood of Occurrence and Threat Level of Impact. The number in brackets refers to the Causal Certainty associated with the threat impact (1 = Very High; 2 = High; 3 = Medium; 4 = Low; 5 = Very Low).

Threat Category	Subcategory	Details	West Lake
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	Medium (4)

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

The most important habitat property for Eastern Sand Darter (Southwestern Ontario and West Lake DUs) is the presence of silt-free sand and fine gravel bars with sufficient dissolved oxygen at the substrate surface (particularly during egg laying/rearing). Any activities that directly alter substrate composition (e.g., removing or covering sand and fine gravel), lead to increased turbidity or sediment loads in the watercourse, alter flow regimes such that sediments settle out, or lead to decreased dissolved oxygen are likely to threaten habitat for this species. These activities could include, but are not limited to:

- Land-use practices that result in increased turbidity/siltation (e.g., agricultural or urban land development with greater overland transport of sediments or poor soil retention practices), or decreased riparian buffers;
- Upstream agricultural drain maintenance activities that increase turbidity and siltation downstream where Eastern Sand Darter occurs;
- Cattle access to streams/tributaries that causes resuspension of sediments and nutrients;
- Bridge or culvert construction or maintenance that result in altered substrate locally or increased turbidity downstream;
- Construction of dams, impoundments, or barriers that result in increased siltation above and shifts to flow below;

- Shoreline development and modifications that directly change the quantity or quality of sand or fine gravel depositional zones (e.g., rip-rap installations or other hardening), or that alter flow and sediment transport regimes resulting in loss of these areas through time.

Element 10: *Assess any natural factors that will limit the survival and recovery of the Eastern Sand Darter (Southwestern Ontario and West Lake DUs)*

There are some natural factors that may limit the survival and recovery of Eastern Sand Darter (both DUs). Eastern Sand Darter may be especially susceptible to stochastic disturbances because of its life cycle and specialized feeding. It has a relatively short generation time (~2.18 years) and lifespan (3–4 years) (Appendix 1), with few reproductive events per individual. It also specializes on sand substrates, which typically support less diverse and abundant benthic invertebrate prey compared to more stable substrate types (Ciutti et al. 1992, Jones et al. 2012, da Silva Pereira et al. 2017). It has a relatively restricted trophic niche, which may limit it from seeking alternative food sources if preferred prey are reduced (Burbank et al. 2019). Eastern Sand Darter co-occurs with several piscivorous fishes that may opportunistically feed on it; however, its cryptic colouration and fossorial behaviour are thought to afford it some protection (COSEWIC 2009).

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

The Southwestern Ontario DU of Eastern Sand Darter co-occurs with numerous SARA-listed fishes and mussels that face similar threats (related to agricultural land use and pollutants) and would benefit from these threats being abated. Other benthic species, in particular, would benefit, such as mussels of conservation concern that share sand or fine gravel benthic habitats and are reliant on healthy host fish populations for completing their life cycles, and Northern Madtom that relies on complex, coarse substrates for completing its life cycle. West Lake supports three other SARA-listed fishes, Pugnose Shiner (*Notropis anogenus;* SARA-Threatened), Bridle Shiner (*Notropis bifrenatus;* SARA-Special Concern), and Grass Pickerel (*Esox americanus vermiculatus;* SARA-Special Concern). Although these species are typically found in wetlands and likely occupy different parts of West Lake, they all prefer clear waters and would benefit from abatement of threats that cause increased turbidity or sedimentation.

There is no targeted, standardized long-term monitoring program for either the Southwestern Ontario or West Lake DUs of Eastern Sand Darter. Targeted sampling occurs periodically for addressing specific research questions, and the species is incidentally captured during a variety of other fish sampling projects (e.g., trawling targeting Northern Madtom or Round Goby). DFO's Invasive Carp Program conducts routine surveillance in several of the rivers occupied by the Southwestern Ontario DU that may detect aquatic invasive species (AIS) of concern; but this sampling is unlikely to detect Eastern Sand Darter due to gear and spatial limitations. Water quality monitoring is also routinely conducted by federal, provincial, and municipal agencies across Ontario, which would identify some contaminants of concern and changes in nutrient concentrations.

Abatement of threats may have contributed to Eastern Sand Darter being rediscovered in two waterbodies in Ohio: the Maumee River after a 65-year absence (Tessler et al. 2012), and Raccoon Creek after 57 years (Hopkins and Zimmerman 2014). Reductions in silt loads and improvements in agricultural practices are thought to be responsible, in part, for the recolonizations.

Recovery Targets

Element 12: *Propose candidate abundance and distribution target(s) for recovery*

Candidate abundance targets were estimated using population viability analysis and estimates of minimum viable population (MVP) size. Methods and results from population modelling are found in Appendix 1. This analysis uses the most recent data and is intended to replace previous targets identified elsewhere (e.g., Finch et al. 2011, 2013, 2018, Lamothe et al. 2021).

For the Southwestern Ontario DU, the median MVP estimate with a 99% persistence probability over 100 years was ~7,000 (CI: 2,600–18,200) adult (i.e., age-1+) females. If a 1:1 sex ratio is assumed, then MVP including all adult Eastern Sand Darter was ~14,000 (CI: 5,200–36,400) (see Appendix 1). The minimum area for population viability (MAPV) represents the quantity of habitat required to support a population of MVP size. MAPV is estimated by dividing the MVP estimate by density. Density estimates were available for Southwestern Ontario DU populations in the Grand and Thames rivers and for the West Lake DU (Table 14). Density in the Grand River varied between the upstream (Brantford) section having a relatively high density, and the downstream (Caledonia) section having a relatively low density. Density estimates are not currently available for other Southwestern Ontario DU populations. Applying the low-density Grand River MAPV estimate would be the most precautionary in the short-term, but the potential for higher densities exist if threats are mitigated and/or habitat is of high quality, which would lead to less habitat being required to achieve an MVP-sized population. These density estimates are calculated from sampling that likely captures age-1+ individuals only, and thus the MAPV values using these densities likely represent the area required for age-1+ individuals. Nursery habitat for YOY Eastern Sand Darter may need to be accounted for separately, if the habitat features differ from age-1+.

Table 14. Candidate distribution targets for Eastern Sand Darter in the Southwestern Ontario designatable unit (DU) and West Lake DU. The Minimum Area for Population Viability (MAPV) (with 95% credible interval (CI)) is the area required to support a population of MVP size. Targets for other populations in the Southwestern Ontario DU not identified below should use the low density Grand River estimate.

DU	Population	Estimated Density	Unit	Median MAPV m^2 (95% CI)
Southwestern Ontario	Grand River (high density upstream)	0.075 (0.036–0.181)	fish/m^2	178,145 (46,920–656,861)
Southwestern Ontario	Grand River (low density downstream)	0.019 (0.008–0.054)	fish/m^2	712,588 (164,104–2,995,805)
Southwestern Ontario	Thames Density	0.040 (0.026–0.066)	fish/m^2	344,884 (112,238–1,062,645)
West Lake	West Lake	0.080 (0.049–0.136)	fish/m^2	167,991 (53,451–533,472)

Potential abundance estimates were developed for the Ausable River and Big Otter Creek (Southwestern Ontario DU) by Lamothe et al. (2026) to help inform future reintroduction efforts. These estimates were based on a resampling procedure of aggregated densities from the Grand and Thames rivers and the proportion of total habitat available to and suitable for the species (Ausable River: 2,301,090 m^2; Big Otter Creek: 1,134,382 m^2). These models assumed that reintroduced populations of Eastern Sand Darter would have a similar structure and life-history between the source and recipient locations, with estimates of potential abundance representing population-specific carrying capacities. The median potential abundance for

Eastern Sand Darter in the Ausable River was 22,499 age-1+ individuals, but could be as low as 6,766, given 5–10% assumed suitable habitat, or as high as 43,221, given 45–50% suitable habitat. The median potential abundance for Big Otter Creek was 11,027 age-1+ individuals, but could be as low as 3,341 given 5–10% suitable habitat, or as high as 21,289 given 45–50% suitable habitat (Lamothe et al. 2026). These potential abundance estimates are meant to represent the population size that could theoretically be supported based on available habitat in those systems and estimated densities from the Grand and Thames river populations, and are not meant to represent the abundance required to sustain a population in those systems. Ultimately, the availability of suitable habitat would need to be confirmed to ensure these areas meet or exceed the MAPV values in Table 14.

Element 13: *Project expected population trajectories over a scientifically reasonable time frame (minimum of 10 years), and trajectories over time to the potential recovery target(s), given current Eastern Sand Darter (Southwestern Ontario and West Lake DUs) population dynamics parameters*

Population estimates of the Southwestern Ontario DU are limited, and estimates of population growth rates are not available for any populations. Estimates of population size or growth rate are not available for the West Lake DU. Given the recent discovery of the West Lake population and limited follow-up sampling, inferences about population size and trajectory cannot be made at this time. Standardized monitoring through time would be needed to inform population trajectory for both DUs.

Element 14: *Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12*

The quantity of suitable habitat required to support an MVP-sized population of Eastern Sand Darter with a 99% probability of persistence was estimated to be approximately 178,145 (46,920–656,861) m^2 in the Brantford section and 712,588 (164,104–2,995,805) m^2 in the Caledonia section of the Grand River; 344,884 (112,238–1,062,645) m^2 in the Thames River; and approximately 167,991 (53,451–533,472) m^2 in West Lake (Table 14). Assuming that other populations in the Southwestern Ontario DU have a similar density to the lower section of the Grand River (i.e., low density; 0.019 fish/m^2), the MAPV would be approximately 712,588 m^2 for those locations as well. The estimated occupied area (Table 11) for all populations (except Big Creek, Norfolk County) exceeds this precautionary MAPV estimate; however, these area estimates assume that the entire area is suitable and available for use by Eastern Sand Darter, which is unlikely to be true.

In 2022, reaches of the Grand River occupied by Eastern Sand Darter were scanned using sonar and image processing was completed to estimate the substrate composition (Milne Technologies 2023). This habitat survey revealed approximately 80% of the total aquatic habitat from Brantford to 25 km upstream of Caledonia dam and 30% of the total aquatic habitat from the Caledonia Dam to Cayuga contained depositional substrates. Both of these stretches exceeded the most conservative MAVP estimate, suggesting sufficient suitable habitat is available for the species in the Grand River.

Element 15: *Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters*

Presently, the Grand and Thames river populations (Southwestern Ontario DU), and the West Lake DU appear to be above the MVP target for 99% probability of persistence, assuming density is similar across wadable and non-wadable habitats and at least 5–10% of total habitat is available and suitable in the Thames River (Table 4) and in the Brantford section of the Grand River (Table 3). The proportion of suitable habitat needs to meet 20–25% in the Middleport section, and exceed 20–25% in the Caledonia, and Cayuga sections of the Grand River (Table 3) to achieve MVP in those sections. Elasticity analyses could be used to inform how best to change vital rates to achieve a population growth rate leading to recovery targets for the remaining Southwestern Ontario DU populations; however, the lack of current information on population dynamics (e.g., current population sizes or population growth rates) prevents this analysis.

Scenarios for Mitigation of Threats and Alternatives to Activities

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

Threats to species survival and recovery can be reduced by implementing mitigation measures to reduce or eliminate potential harmful effects that could result from works, undertakings, or activities (w/u/a) associated with projects in Eastern Sand Darter habitat. A review has been completed summarizing the types of w/u/a that have occurred in habitat known to be occupied by Eastern Sand Darter. The DFO Program Activity Tracking for Habitat (PATH) database was reviewed to estimate the number of w/u/a that have occurred during the period from November 2013 through August 2022 within the range of Eastern Sand Darter in Ontario (Southwestern Ontario and West Lake DUs). There were 116 projects identified within the distribution, and of those, 59 projects were within 2 km of historical or recent occurrence records of either DU (Table 15). These 59 w/u/a/ were mostly related to dredging/excavation, shoreline protection, boating/marina infrastructure (e.g., boat houses, boat launches/ramps, breakwaters, docks, piers), other infrastructure (bridges/ culverts/causeways), and aquatic vegetation removal. Additionally, 38 projects occurred in Eastern Sand Darter critical habitat, and 16 of those occurred within 2 km of historical or recent occurrence records. Other projects occurring in proximity to, but not in the known area of, Eastern Sand Darter habitat may have also have had impacts, but were not included. Some projects may not have been reported to DFO as they may have met self-assessment requirements. No projects were identified in the historical distribution of Eastern Sand Darter in the Ausable River. The review did not include Catfish Creek.

There were five projects authorized under the *Fisheries Act* within the habitat of Eastern Sand Darter. Most other projects were deemed low risk to fishes and fish habitat and were addressed through letters of advice with standard mitigations. Without appropriate mitigation, projects or activities occurring adjacent or close to areas inhabited by Eastern Sand Darter could have impacted the species (e.g., through increased sedimentation and/or nutrient loading). Based on the assumption that historical and anticipated development pressures are likely to be similar, it is expected that similar types of projects will likely occur in or near Eastern Sand Darter habitat in the future. The primary project proponents were adjacent land owners, municipalities, and private corporations.

Habitat-related threats to Eastern Sand Darter can been linked to the Pathways of Effects developed by DFO’s Fish and Fish Habitat Protection Program (FFHPP). DFO FFHPP has developed guidance on mitigation measures for 18 Pathways of Effects for the protection of aquatic species at risk in the Ontario and Prairie Region (formerly Central and Arctic Region; Coker et al. 2010) (Table 15). This guidance should be referred to when considering mitigation and alternative strategies for habitat-related threats. For mitigations and alternatives to non-habitat related threats (invasive species and incidental baitfish harvest), refer to Bouvier and Mandrak (2010).

Table 15. Threats to Eastern Sand Darter (Southwestern Ontario and West Lake designatable units [DUs]) and the Pathways of Effect associated with each threat – this table is intended to accompany Coker et al. (2010) for details on mitigations to each habitat-related threat. 1 – Vegetation clearing; 2 – Grading; 3 – Excavation; 4 – Use of explosives; 5 – Use of industrial equipment; 6 – Cleaning or maintenance of bridges or other structures; 7 – Riparian planting; 8 – Streamside livestock grazing; 9 – Marine seismic surveys; 10 – Placement of material or structures in water; 11 – Dredging; 12 – Water extraction; 13 – Organic debris management; 14 – Wastewater management; 15 – Addition or removal of aquatic vegetation; 16 – Change in timing, duration and frequency of flow; 17 – Fish passage issues; 18 – Structure removal. NI indicates no projects were identified.

Work/ Undertaking/ Activity	**Threats** (associated with work/undertaking/activity)				**Watercourse/Waterbody** (number of works/undertakings/activities between November 2013 and January 2022)									
	Pollution: Sedimentation	Pollution: Nutrient loading	Pollution: Contaminants and Toxic Substances	Dams and Barriers	**Lake St. Clair**	**Sydenham River**	**Thames River**	**Western Basin**	**Rondeau Bay**	**Big Otter Creek**	**Long Point Bay**	**Big Creek**	**Grand River**	**West Lake**
Applicable pathways of effects for threat mitigation and project alternatives	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 18	1, 4, 7, 8, 11, 12, 13, 14, 15, 16	1, 4, 5, 6, 7, 11, 12, 13, 14, 15, 16, 18	-										
Water Crossings (bridges, culverts, piping)	✓	-	✓	✓	NI	NI	7	NI	0	NI	1	8	2	NI
Shoreline/Streambank Works (dykes, bank stabilization, infilling, beach creation, riparian vegetation management)	✓	✓	✓	✓	NI	NI	NI	2	3	NI	1	NI	NI	4
Instream Works (drain maintenance, aquatic vegetation removal, dredging, channel modifications/realignments)	✓	✓	✓	✓	NI	NI	2	2	3	4	4	NI	3	NI

Work/ Undertaking/ Activity	Threats (associated with work/undertaking/activity)				Watercourse/Waterbody (number of works/undertakings/activities between November 2013 and January 2022)									
	Pollution: Sedimentation	Pollution: Nutrient loading	Pollution: Contaminants and Toxic Substances	Dams and Barriers	**Lake St. Clair**	**Sydenham River**	**Thames River**	**Western Basin**	**Rondeau Bay**	**Big Otter Creek**	**Long Point Bay**	**Big Creek**	**Grand River**	**West Lake**
Applicable pathways of effects for threat mitigation and project alternatives	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 18	1, 4, 7, 8, 11, 12, 13, 14, 15, 16	1, 4, 5, 6, 7, 11, 12, 13, 14, 15, 16, 18	-										
Structures in Water (boat launches, docks/boathouses, effluent outfalls, water intakes)	✓	✓	✓	✓	NI	1	1	2	NI	NI	NI	8	NI	NI

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

The mitigation measures outlined above and in Bouvier and Mandrak (2010) support the goal of increasing survivorship and reducing impacts to Eastern Sand Darter (Southwestern Ontario and West Lake DUs). Population growth of Eastern Sand Darter (Southwestern Ontario DU) is affected most strongly by reproductive parameters (fecundity and age-0 survival) (Appendix 1). Improvements to spawning and nursery habitat are likely to provide the greatest increase to productivity and survivorship (Finch et al. 2018). Lamothe et al. (2026) coarsely estimated the benefit to the species of incorporating an additional population (i.e., a reintroduction to a historically occupied area), which suggested a reduction in the probability of extinction for the DU. Options for improving productivity should be evaluated on a case by case basis in relation to the status of each population and its threats.

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

Total habitat supply does not appear to be limiting to Eastern Sand Darter in the Southwestern Ontario DU or West Lake DU; however, precise estimates of the availability of suitable habitat are not available for most populations. Habitat improvements in areas where the species could be reintroduced (e.g., Big Otter Creek, Ausable River) should focus on reducing siltation of the watercourses and/or improving flow conditions such that silt does not settle out on sand and fine gravel depositional areas (Barnucz et al. 2020, Lamothe et al. 2026).

Element 19: *Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 16 and the increase in productivity or survivorship associated with each measure in element 17*

No clear links have been identified between mitigation measures and Eastern Sand Darter productivity, mortality, or other vital rates. Therefore, it is difficult to provide guidance about the effect of mitigation measures on productivity or mortality rates.

Element 20: *Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values*

Without a direct link between mitigation measures and Eastern Sand Darter mortality rates or productivity, this information cannot be provided under mitigation scenarios.

Element 21: *Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process*

The parameter values incorporated in the population models (presented in Table 8) are based on the best available data for the Eastern Sand Darter Southwestern Ontario DU and, in the absence of any new data, should be used for population modelling for this DU. These parameters are assumed to apply to the West Lake DU until more detailed information becomes available. Details regarding how the parameters were estimated and source data used are outlined in Appendix 1.

Allowable Harm Assessment

Element 22: *Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery*

The impact of anthropogenic harm was assessed with a deterministic elasticity analysis of population growth rate and density, and simulation analysis. Refer to Appendix 1 for complete methods and results. Given limited DU-specific information, these results are assumed to be applicable for both the Southwestern Ontario and West Lake DUs. These results are intended to replace harm modelling presented in Finch et al. (2011).

Results were generally consistent across all analyses. On an annual basis and in most circumstances, Eastern Sand Darter populations were most sensitive to changes to fertility parameters (clutch size, number of clutches per year, and age-0 survival rate) followed by perturbations to age-1+ survival rate. Sensitivity to age-specific clutch size and survival rate decreased with age. On average, Eastern Sand Darter populations were not sensitive to longevity; however, some scenarios produced large elasticities.

The simulation analysis demonstrated the impact of greater amounts of harm and transient harm (2, 5, and 10 year frequencies). Continuous harm to all ages greater than ~40% or to fertility greater than ~50% generally led to population extirpation. At a 2-year harm frequency, harm greater than ~60 and 70% to all ages and fertility, respectively, caused extirpation. The impact of harm decreased at frequencies of 5 and 10 years. At a 10-year frequency, there was little impact of even high levels of harm when age-0 and age-1+ Eastern Sand Darter were impacted separately. When all age-classes were impacted, significant long-term impacts occurred with harm values greater than ~75%.

CONCLUSIONS

In Ontario, the current and historical distribution of Eastern Sand Darter is limited to two broad areas: Southwestern Ontario and Eastern Ontario. Each area represents a separate DU based on genetic distinctiveness, geographical isolation, and inferred local adaptation. The Southwestern Ontario DU includes eight extant localities (Lake St. Clair, Sydenham River, Thames River, Western Lake Erie, Rondeau Bay, Big Creek [Norfolk County], Long Point Bay, and Grand River), and three populations considered extirpated (Ausable River, Catfish Creek, and Big Otter Creek). The West Lake DU consists of a single population in West Lake, Lake Ontario.

Eastern Sand Darter inhabits streams, rivers, and shoals of lakes or bays dominated by sand and fine gravel substrate. In rivers, it is generally associated with sandy depositional areas. In lacustrine systems, it is generally found nearshore on sand substrate, typically near wave-protected, sandy beaches. It appears tolerant of a range of depth and flow conditions, as long as sand is present. The species is tolerant of low dissolved oxygen at the adult stage, but well-oxygenated sand is likely important for egg and YOY survival and development. The minimum viable population size with a 99% probability of persistence over 100 years is ~7,000 (CI: 2,600–18,200) age-1+ females, or ~14,000 (CI: 5,200–36,400) age-1+ individuals of both sexes. A population of median MVP size would require a median of 167,991–712,588 m^2 of suitable habitat, depending on the local density.

The greatest threats to the Southwestern Ontario DU over the next 10 years are thought to be sedimentation and other pollutants (e.g., toxic substances, nutrients) predominantly associated with agricultural and urban land uses; Round Goby; and, climate change. Round Goby is considered the greatest threat to the West Lake DU over the next 10 years. In general, Eastern

Sand Darter populations were most sensitive to changes in fertility parameters (clutch size, number of clutches per year, and age-0 survival rate) followed by perturbations to age-1+ survival rate. Harm to these life-stages should be minimized to avoid jeopardizing the survival and recovery of both DUs found in Ontario. Reintroduction efforts in the Ausable River or Big Otter Creek may improve the probability of persistence of the Southwestern Ontario DU, should harm to source populations be minimized.

Major uncertainties remain that could impact the interpretation of this advice. The population status in the Detroit River, Western Basin of Lake Erie, Rondeau Bay, Long Point Bay, and Big Creek (Norfolk County) is not clear as there have been too few or no recent detections of Eastern Sand Darter but limited targeted sampling. Additionally, there are large areas of sand habitat that are unexplored in beach habitats along the north shore of Lake Ontario (e.g., Pleasant Bay and Huyck's Bay). The population trajectory is unknown for most populations (both DUs). Uncertainties that could impact the population modelling and allowable harm assessment include: uncertain life-history parameters, population structure and whether each locality represents a single pan-mictic population, links between human activities and vital rates, and whether population demographics and life-history information collected from the Southwestern Ontario DU are applicable to the West Lake DU. The magnitude and mechanism of impact of threats to all population (both DUs) remain poorly understood. Other potential threats were identified for the West Lake DU, but they lack context and supporting information for proper assessment.

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APPENDIX 1: METHODS AND RESULTS OF POPULATION MODEL

Methods

Information on Eastern Sand Darter (ESD) vital rates was compiled to build a matrix population model (Caswell 2001) that incorporates parameter uncertainty, environmental stochasticity, and density-dependence. Life-history variables and model structure were sourced from previously published ESD population models (Finch et al. 2018, Lamothe et al. 2021). Elasticity and simulation analyses were used to quantify the impact of anthropogenic harm to populations. Estimates of recovery targets for abundance and habitat were made with estimation of the minimum viable population (MVP) size and the minimum area for population viability (MAPV). All analyses and simulations were conducted using the statistical program R Version 4.2.0 (R Core Team 2022).

The Population Model

The ESD life cycle was modelled using a stochastic, female-only, density-dependent, birth-pulse, pre-breeding, stage-structured population matrix model with an annual projection interval (Caswell 2001). Many aspects of ESD life-history are uncertain or variable among populations (Finch et al. 2018). This uncertainty was incorporated into the population model by allowing life-history parameters to vary among simulation replicates by drawing the uncertain parameters from specified probability distributions providing a range of plausible values (Table 8). This allows different model runs to incorporate different parameter combinations and provides results that span the full extent of the uncertainty.

Longevity (T_{max}) and age-at-maturity (T_{mat}) are important parameters for defining the structure of the population model. In Canada, longevity may be age-3 (Finch et al. 2013) or age-4 (Drake et al. 2008) depending on the population. As well, age-at-maturity has been observed at age-1 or age-2 across populations (Finch et al. 2013). To allow for variability in T_{mat} and T_{max} among simulations the matrix was structured as a stage-structured matrix with three stages (Figure A1.1). Stage-1 represented age-1 ESD, stage-2 represented age-2 ESD, and stage-3 represented age-3+ ESD.

The projection matrix **A** is the product of the transition matrix **B**, consisting of the life-history characteristics, and the density-dependence matrix **D** (see Equation A1.8 below) representing the density-dependence effects, where:

$$\mathbf{B} = \begin{bmatrix} F_1 & F_2 & F_3 \\ \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & P_3 \end{bmatrix}, \tag{A1.1}$$

and:

$$\mathbf{A} = \mathbf{B} \circ \mathbf{D}, \tag{A1.2}$$

where the symbol ∘ represents the Hadamard product or the element by element multiplication of the matrices. Stage-specific abundance, $\boldsymbol{n}$, each year, y, is calculated from:

$$\boldsymbol{n}_{y+1} = \mathbf{A}_{n,y}\boldsymbol{n}_y, \tag{A1.3}$$

where $\boldsymbol{n}$ is a vector of stage-specific abundance and the population projection matrix **A** varies among years due to environmental conditions and population size affecting vital rates.

Stage-based matrix models incorporate estimates of F_i, stage-specific fertility (σ_i), stage-specific survival rate, and the probability of survival and remaining in stage 3 (P_3). Fertility (F_i) represents the number of female offspring produced per adult female annually and comprises all reproductive parameters including: fecundity, sex ratio, spawning periodicity, and survival from the egg state to age-1. P_3 is a function of stage-3 survival and transition probability (τ_3) describing the likelihood of remaining in stage-3. P_3 is calculated as:

$$P_3 = \sigma_3(1 - \tau_3), \tag{A1.4}$$

with,

$$\tau_3 = \frac{{\sigma_3}^{Tmax-2} - {\sigma_3}^{(Tmax-2-1)}}{({\sigma_3}^{Tmax-2} - 1)}\,. \tag{A1.5}$$

When T_{max} is 4, P_3 describes the number of age-3 ESD that survive to age-4 and when T_{max} is 3, P_3 reduces to 0 such that no individuals survive to age-4.

Survival rate was estimated for ESD populations in the Thames River using Chapman-Robinson catch curve analysis (Finch et al. 2018). Mean survival rate was 0.386 (SD = 0.075) representing age-1+ individuals. In the population model, annual survival was assumed to be the same for age-1+ age-classes and was included as a stochastic variable. Age-1+ survival was drawn from a beta distribution such that the value could not be less than 0 or greater than 1 with shape parameters 15.88 and 25.26, which gives a mean of 0.386 and standard deviation of 0.075. Age-0 survival rate was unknown and was solved for to give a projection matrix with a particular population growth rate. Survival rate was varied inter-annually to represent environmental stochasticity. Finch et al. (2018) estimated that annual survival rate varied among years with a coefficient of variation (CV) of 0.2.

Fertility describes the number of female offspring surviving to age-1 produced annually per adult female in the population and is calculated as:

$$F_i = R\rho_i f_i C\sigma_0. \tag{A1.6}$$

R is the sex ratio at birth which was assumed to be 50%. ρ_i is the proportion of females mature at age-*i*. Finch et al. (2018) observed that within a population that matured at age-1, approximately 91% of females were mature at age-1 and all age-2+ ESD were mature; therefore, ρ_1 was set to 0.91 when T_{mat} was 1 and 0 when T_{mat} was 2, and ρ_2 and ρ_3 were set to 1. Fecundity or clutch size (f), is the number of eggs produced per clutch per female. Reported mean clutch sizes for ESD populations range from 56.0 to 71.5 (COSEWIC 2009, Finch et al. 2013). Clutch size was incorporated as a stochastic parameter with a mean of 61.2 and standard deviation of 8.2 (Faber 2006, Finch et al. 2013). The value for clutch size was drawn from a gamma distribution such that clutch size was always positive with shape and rate parameters of 55.7 and 0.91, respectively, which gave 99% CIs of 48.4-84.4, representing a reasonable amount of variation. C is the number of clutches produced per year, which was allowed to vary between 1 and 3 clutches between simulation replicates. Clutch size was varied across years to simulate environmental stochasticity. The amount that clutch size may vary was unknown; as a result, the CV of f was incorporated as a stochastic variable and drawn from a uniform distribution between 0.05 and 0.20; 0.05 was selected to represent low inter-annual variability and 0.20 was selected to mirror the variability of survival rate.

Density-dependence was assumed to act during the first year of life and implemented using a Beverton-Holt function with age-0 survival rate a function of adult density:

$$d = \frac{\sigma_{0,max}/\sigma_{0,1}}{1 + {}^{b}/_{K}N}, \tag{A1.7}$$

where *N* is age-1+ density, *K* is carrying capacity, *b* is the density-dependence coefficient, $\sigma_{0,1}$ is age-0 survival rate when the population is stable, and $\sigma_{0,max}$ is age-0 when the population is at maximum population growth rate (λ_{max}). In a previous population model (Lamothe et al. 2021), λ_{max} was estimated to be between 1.56 and 2.69 from an allometric relationship (Randall et al. 1995). In this model, λ_{max} was incorporated as a stochastic variable and drawn from a uniform distribution with a minimum value of 1.56 and maximum value of 2.69 [$Unif(1.56, 2.69)$]. $\sigma_{0,max}$ was then solved for in the same manner as $\sigma_{0,1}$ to find the value that resulted in a population growing at its maximum rate. The value *b* was calculated by rearranging Equation A1.7 with $N = K$, as: $b = \sigma_{0,max} / \sigma_{0,1} - 1$. The density-dependence matrix, **D**, was structured as:

$$\mathbf{D} = \begin{bmatrix} d & d & d \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \qquad \text{(A1.8)}$$

and incorporated into Equation A1.2.

Impact of Harm

The impact of anthropogenic harm on an ESD population was assessed with deterministic elasticity analysis of the projection matrices and stochastic simulations. Elasticity analysis of matrix elements provides a method to quantify the impact of changes to vital rates on a population. Specifically, elasticities measure the proportional change to population growth rate (λ) or population abundance (N) that results from a proportional change in a vital rate (v). For example, an elasticity of λ value of 0.2 for age-1+ survival indicates that a 10% change in survival rate (e.g., $0.386 \times (1 + 0.1) = 0.425$) would cause a 2% increase in population growth rate (e.g., $1 \times (1 + 0.1 \times 0.2) = 1.02$).

Elasticities are useful as they allow for assessment of how impactful changes to vital rates and other model parameters are to a population and because they represent proportional changes their values are directly comparable. They are preferable to simulation analyses because of the speed with which they can be estimated, allowing for many more perturbations to be examined than simulations. Elasticities are limited, however, as they represent permanent changes, accurately represent only small perturbations (i.e., <30% changes), and assume all other model parameters remain unchanged. Therefore, simulation analysis was used to examine the effects of transient or periodic harm to a population.

Deterministic Elasticity Analysis

Elasticities of λ (ε_λ) are calculated by taking the scaled partial derivatives of λ with respect to a vital rate (v; Caswell 2001):

$$\varepsilon_\lambda = \frac{v}{\lambda} \sum_{i,j} \frac{\partial \lambda}{\partial a_{i,j}} \frac{\partial a_{i,j}}{\partial v}\,, \qquad \text{(A1.9)}$$

where a_{ij} is the projection matrix element in row *i* and column *j*.

Elasticities of N (ε_N) are calculated from the sensitivities of N ($\frac{d\hat{\mathbf{N}}}{d\boldsymbol{v}^\top}$) where (Caswell 2019):

$$\frac{d\hat{\mathbf{N}}}{d\boldsymbol{v}^\top} = \left(\mathbf{I}_i - \mathbf{A} - \left(\hat{\mathbf{N}}^\top \otimes \mathbf{I}_i\right)\frac{\partial vec\mathbf{A}}{\partial \mathbf{N}^\top}\right)^{-1} \left(\hat{\mathbf{N}}^\top \otimes \mathbf{I}_i\right)\frac{\partial vec\mathbf{A}}{\partial \boldsymbol{v}^\top}, \qquad \text{(A1.10)}$$

and:

$$\varepsilon_{\mathrm{N}} = diag\left(\hat{\mathbf{N}}\right)^{-1} \frac{dN}{d\boldsymbol{v}^\top} diag(\boldsymbol{v}). \qquad \text{(A1.11)}$$

$\mathbf{A}$ is the projection matrix of dimension $i \times i$, $\mathbf{I}_i$ is an identity matrix of dimension $i \times i$, $\widehat{\mathbf{N}}$ is a vector of equilibrium densities, $\frac{\partial vec\mathbf{A}}{\partial \mathbf{N}^{\mathsf{T}}}$ is the partial derivatives of matrix $\mathbf{A}$ with respect to stage densities, $\frac{\partial vec\mathbf{A}}{\partial \boldsymbol{v}^{\mathsf{T}}}$ is the partial derivatives of matrix $\mathbf{A}$ with respect to the vital rates or the model parameters of interest, T is the transpose operator, and $\otimes$ represents the Kronecker product. $diag(\widehat{\mathbf{N}})$ and $diag(\boldsymbol{v})$ represent diagonal matrices with the equilibrium densities and parameter values on the diagonal, respectively, and 0s on the off diagonal entries. See Caswell (2019) for more details.

A range of potential vital rate elasticities were estimated by allowing uncertain parameters (Table 8) to vary. As well, population growth rate was allowed to vary by incorporating the effect of density on age-0 survival rate (Equation A1.7). This was accomplished by randomly generating adult density as a proportion of carrying capacity (0–1,000%) using a draw from a uniform distribution on a log scale ($e^{Unif(\log(0.01),\log(K\times 10))}$). $\lambda = 1$ when $N_a = K$, $\lambda < 1$ when $N_a > K$, and $\lambda > 1$ when $N_a < K$ up to a maximum λ of 2.69. The elasticity analyses were replicated 5,000 times.

Simulation

Simulation analysis was used to investigate the impacts of periodic stage-specific harm on adult population density. Life-stages were impacted by a level of harm, ranging from 0 to 99%, at different frequencies: 1, 2, 5, and 10 years, over a 100 year simulation. The initial carrying capacity was then compared to the mean population size over the final 15 years of the simulation to determine the effect of the harm, quantified as the proportion of initial K_a. The frequency indicates how often harm was applied; a frequency of 1 indicates that harm is constant and applied every year, while a frequency of 10 indicates that harm is periodic and applied once every 10 years. As a density-dependent model, the population has the potential to recover between applications of harm as conditions are returned to the initial state. No competitor species exist as this is a single-species model. The simulations incorporated parameter uncertainty and environmental stochasticity and were replicated 2,000 times.

Recovery Targets

Abundance: Minimum Viable Population (MVP)

The concept of demographic sustainability was used to identify potential minimum recovery targets for ESD. Demographic sustainability is related to the concept of MVP (Shaffer 1981), and was defined as the minimum adult population size that results in a desired probability of persistence over 100 years [~45.8 ESD generations, where generation time (ζ) was estimated from stochastic projection matrices (Caswell 2001) with λ = 1 where ζ = 2.18 (CI: 1.34–2.62)]. MVP was estimated using simulation analysis, which incorporated parameter uncertainty, environmental stochasticity, and density-dependence.

Important elements incorporated in population viability analysis include the choice of time frame over which persistence is determined, the severity and frequency of catastrophic events, and the quasi-extinction threshold below which a population is deemed unviable. The choice of time frame is arbitrary and without biological rational. It must be long enough to be of consequence for the population examined but not so long as to be an unreasonable timeframe for management considerations; 100 years was selected.

Catastrophes, such as drought, disease, or chemical spills, represent events that cause a >50% decrease in population size. The rate at which severe catastrophes impact ESD populations is unknown. Based on a meta-analysis, Reed et al. (2003) determined that catastrophic die-offs (defined as a one-year decrease in population size >50%) occurred at a rate of 14% generation^{-1} on average among vertebrate populations. The rate of catastrophic die-offs among ESD populations is unknown and was included in simulations as a stochastic parameter by drawing from a uniform distribution with limits of 0.05 and 0.20 [$Unif(0.05, 0.20)$] to allow for catastrophe rates of 5% to 20% per generation. This equates to a large-scale die-off occurring approximately every 44 years (at a 5% generation^{-1} rate) to every 11 years (at a 20%·generation^{-1} rate), calculated by dividing generation time by the catastrophe rate. The impact of a catastrophe affects all life-stages simultaneously and was drawn randomly from a beta distribution scaled between 0.5 and 1, with shape parameters of 0.762 and 1.5 (Reed et al. 2003; $Beta(0.762, 1.5) \times (1 - 0.5) + 0.5$), representing the probability of a 50 to 100% decline in population size.

Quasi-extinction represents the compounding effects of Allee effects, demographic stochasticity, and inbreeding depression (Lande 1988) leading a population to extinction once the threshold is crossed. The value of the quasi-extinction threshold cannot be empirically measured; therefore, 25 adult females was used as a reasonable approximation (Morris and Doak 2002).

Simulations were conducted for populations with various initial abundances of adult females, ranging from 50 to 30,000 (initial density represented carrying capacity, K, where λ = 1) and catastrophe rates ranging from 5% to 20% per generation. The simulations were conducted for 100 years and replicated 20,000 times. The number of quasi-extinctions was tracked across simulations and the probability of extinction (P_{ext}) was modelled with a logistic regression that was a function of $\log_{10}$-transformed initial female density [$\log_{10}(N_a)$], catastrophe rate (P_{cat}), and all uncertain population model parameters (Table 8) where:

$$P_{ext} = \frac{1}{1+e^{-(X\beta)}}, \qquad \text{(A1.12)}$$

Where $\boldsymbol{X}$ is a matrix of all covariates and $\boldsymbol{\beta}$ a vector of coefficients including the intercept.

Habitat: Minimum Area for Population Viability (MAPV)

Minimum area for population viability (MAPV) represents the quantity of habitat required to support a population of MVP size. MAPV is estimated by dividing the MVP estimate by population density. Density estimates were available for ESD populations in the Grand River, Thames River, and West Lake, estimated using N-mixture models (Appendix 2). Because MAPV values are calculated using densities estimated from survey catches, they likely represent the area required for age-1+ ESD. Nursery habitat of YOY ESD may need to be accounted for in addition to MAPV values, if the habitat features differ from age-1+ habitat.

Results

Impact of Harm

The impact of anthropogenic harm was assessed with deterministic elasticity analysis of population growth rate (λ, Figure A1.2) and density (N, Figure A1.2) and simulation analysis (Figure A1.3). Results were generally consistent across all three analyses. In most circumstances, ESD population growth rates were most impacted by changes to fertility parameters [clutch size, (all ages), number of clutches per year, and age-0 survival rate] followed by perturbation to age-1+ survival rate. Sensitivity to age-specific clutch size and survival rate decreased with age. On average, ESD populations were not sensitive to longevity; however, some scenarios produced large elasticities.

Life-history characteristics had a significant influence on vital rate elasticities (Figure A1.4). Many of the elasticity distributions were bi-modal (Figures A1.2) driven by the value of age-at-maturity (Figure A1.4). Elasticity values were greater for clutch size and other fertility parameters when $T_{mat} = 1$, while elasticity values were greater for age-1+ survival rates when $T_{mat} = 2$; this pattern is also evident in transient harm simulations, particularly at larger harm values (Figure A1.3). Population growth rate also had a strong influence on elasticity estimates. Maximum age had large elasticities at low population growth rates, likely providing resilience for declining populations (λ < 1). The elasticity estimates for clutch size increased with population growth rate while the estimates for age-1+ survival rate decreased. The effect of population growth rate on elasticity estimates was diminished when $T_{mat} = 2$.

The simulation analysis demonstrated the impact of greater amounts of harm and transient harm (2, 5, and 10 year frequencies). Continuous harm to all ages of greater than ~40% or to fertility of greater than ~50% generally led to population extirpation. At a 2-year harm frequency, harm of greater than ~60 and 70% to all ages and fertility, respectively, caused extirpation. The impact of harm decreased at frequencies of 5 and 10 years. At a 10-year frequency, there was little impact of even high levels of harm when age-0 and age-1+ ESD were impacted separately. When all age-classes were impacted, significant long-term impacts (>25% declines in abundance) occurred with harm values exceeding ~75%.

Recovery Targets

Demographic sustainability was assessed using simulation analysis, which incorporated parameter uncertainty, environmental stochasticity, and density-dependence. Simulation outputs, binomial quasi-extinctions (1: extinct; 0: extant), were fitted using a logistic regression as a function of adult female population size, catastrophe rate, and uncertain life-history parameters. Only population size, catastrophe rate, and maximum population growth rate had a significant effect on extinction probability (Table A1.2). The other life-history parameters had a significant influence on extinction risk over the range of values included (Table A1.1) and over the length of time (100 years) simulated.

MVP size was estimated from the logistic regression model using randomly selected catastrophe rates [$P_{cat} = Unif(0.05, 0.20)$] and maximum population growth rates [$\lambda_{max} = Unif(1.56, 2.69)$] and finding the adult female population size that resulted in a 1% probability of extinction (Figure A1.5). The median MVP estimate was ~7,000 (CI: 2,600–18,200). If a 1:1 sex ratio is assumed, then MVP including all adult ESD was ~14,000 (CI: 5,200–36,400). Smaller MVP estimates correspond to populations with a lower catastrophe rate and greater population growth rate. Mean extinction probability of any adult female population size can be estimated from the fitted logistic relationship for a given catastrophe rate as (Table A1.1):

$$P_{ext} = \frac{1}{1+e^{-(5.71-2.99\,log_{10}(\mathrm{N_a})+16.94\mathrm{P_{cat}}-0.44\lambda_{max})}}. \tag{A1.13}$$

The amount of habitat required to support an MVP-sized population was calculated for each locality for which density estimates were available (Appendix 2). Uncertainty in MAPV estimates resulted from uncertainty in locality-specific estimates of mean density and uncertainty in MVP (Figure A1.5). MAPV estimates were smallest for West Lake and the Grand River Brantford section, and lowest for the Grand River Caledonia section (Table A1.2; Figure A1.6).

Table A1.1. Logistic regression model results for Eastern Sand Darter extinction probability. Na represents adult female population size, λmax represents maximum population growth rate, and Pcat represents catastrophe rate.

Parameter	Estimate	Standard Error	p-value
Intercept	5.71	0.59	< 0.001
$log_{10}(N_a)$	-2.99	0.11	< 0.001
λ_{max}	-0.44	0.20	0.029
P_{cat}	16.94	1.69	< 0.001

Table A1.2 Median (95% confidence intervals) density and minimum area for population viability (MAPV) estimates for Eastern Sand Darter populations with available data.

Populations	Density (fish m^{-2})	MAPV (km^2)
Grand River (high density upstream)	0.074 (0.036–0.181)	0.18 (0.05–0.66)
Grand River (low density downstream)	0.019 (0.007–0.054)	0.71 (0.16–3.00)
Thames Density	0.039 (0.026–0.066)	0.34 (0.11–1.06)
West Lake	0.080 (0.049–0.136)	0.17 (0.05–0.53)

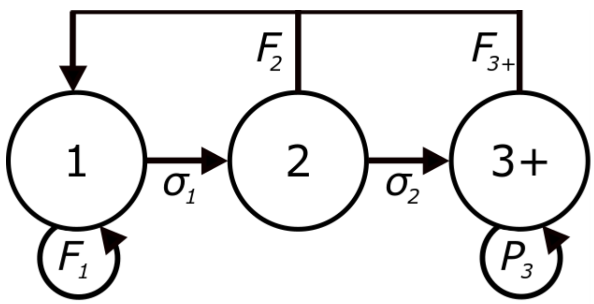

Figure A1.1. Generalized life cycle used to model the population dynamics of Eastern Sand Darter. F_i represents stage-specific annual fertility, σ_i represents stage-specific survival rate, and P_3 represents the probability of surviving and remaining in stage 3.

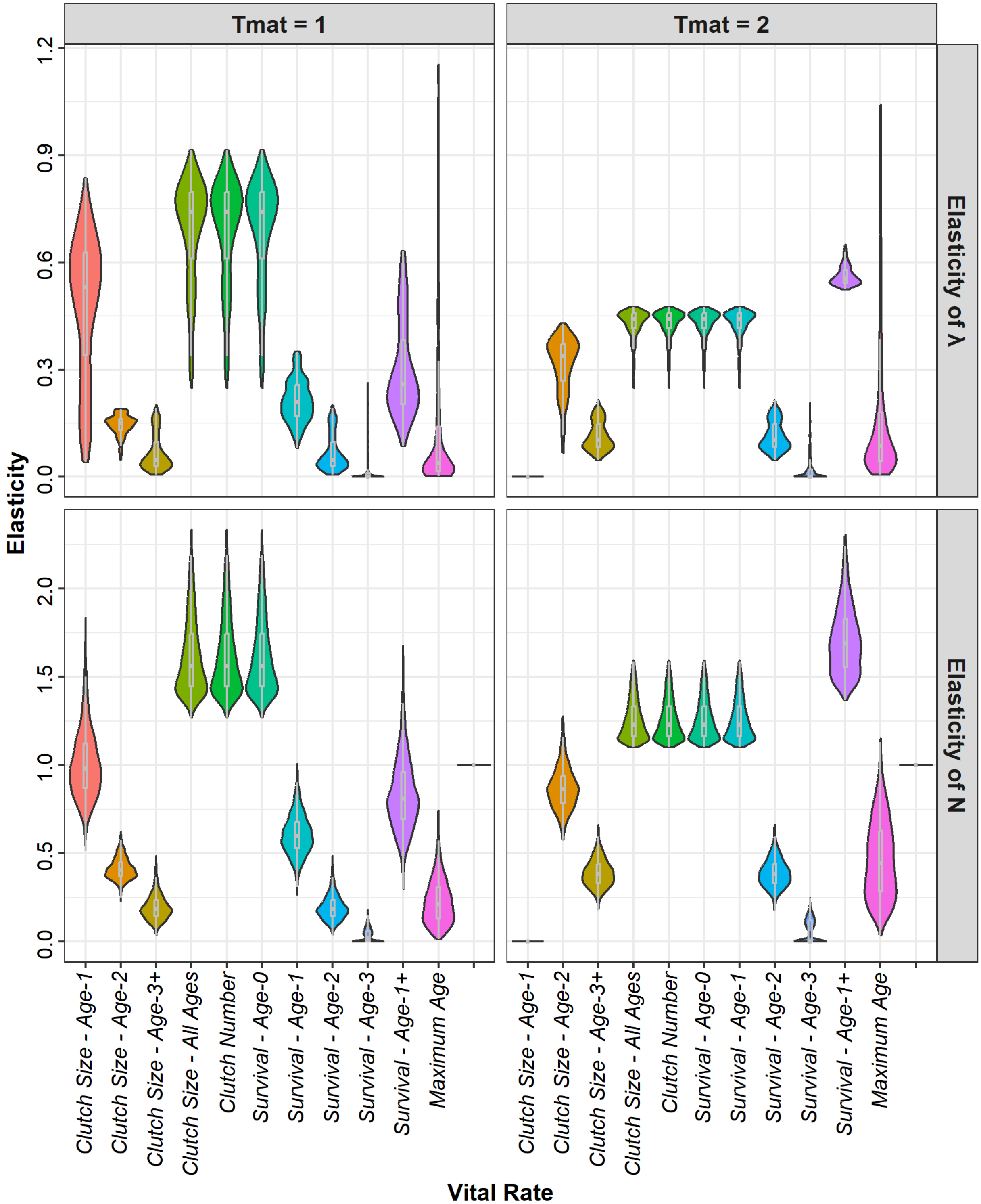

Figure A1.2. Elasticity of λ (top panels) and N (bottom panels) for Eastern Sand Darter (ESD) populations represented with violin and box plots. Elasticity of N values represents abundance changes for all age-1+ ESD. Results reflect uncertainty in life-history characteristics and different values of population growth; left panels represents estimates with age-at-maturity (T_{mat}) = 1 and right panels represent estimates with T_{mat} = 2.

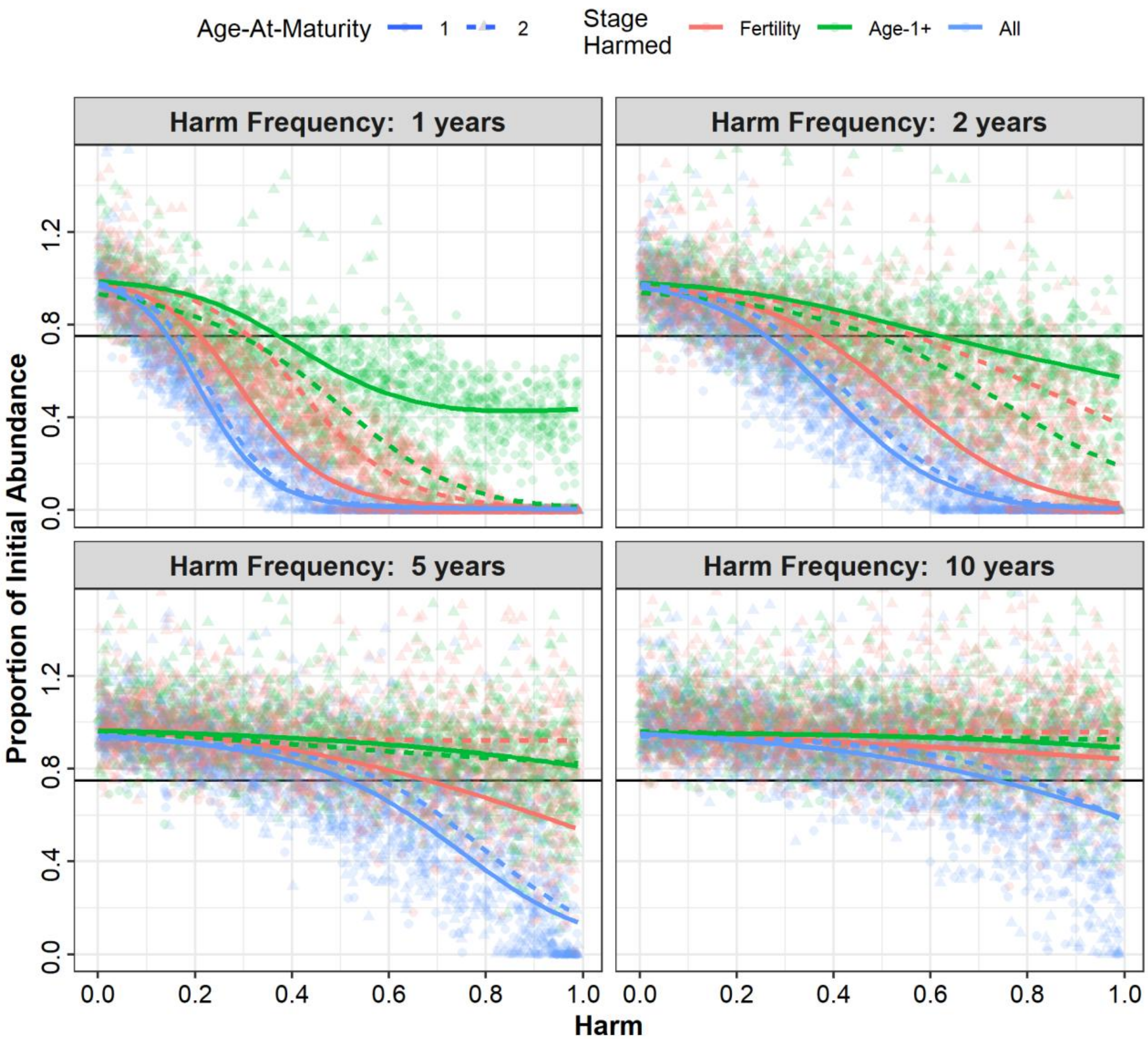

Figure A1.3. Results of simulation analysis examining the proportional change in stable population size that resulted for anthropogenic harm occurring at different frequencies (1, 2, 5, and 10 year intervals). Harm was applied to different life stages: Fertility, age-1+, and all life stages, represented by colour. The black horizontal line indicates a 25% reduction in population size. Stage harmed: fertility = red, age-1+ = green, all = blue.

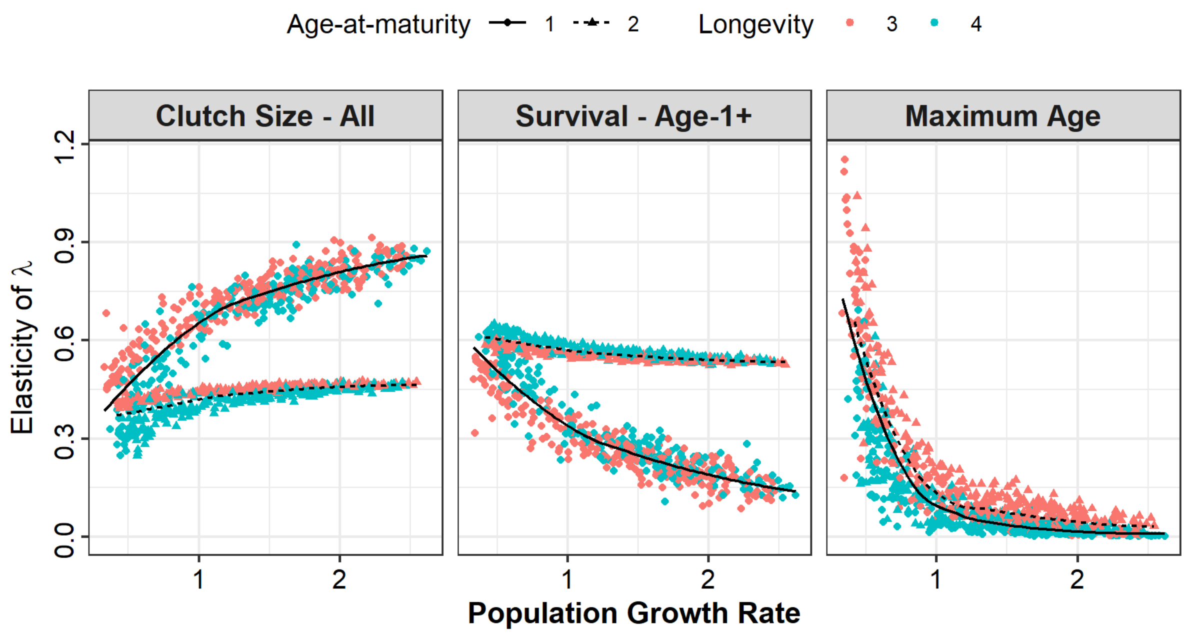

Figure A1.4. Elasticity of λ analysis results for Eastern Sand Darter populations plotted against population growth rate. Panels represent select vital rate elasticities. Colour indicates the longevity in years (3 = red, 4 = blue) and plot symbol represents age-at-maturity.

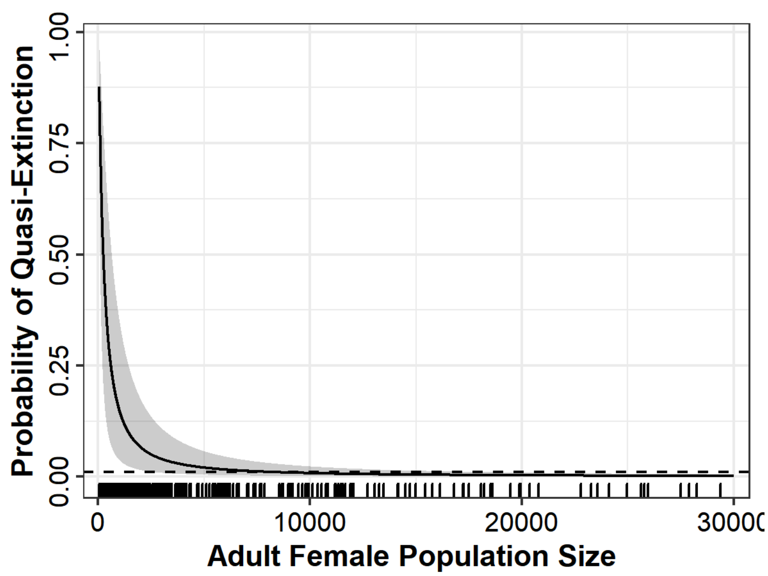

Figure A1.5. The probably of quasi-extinction as a function of adult female populations size. The rug plot indicates quasi-extinctions. The solid line represent the logistic regression trend with the grey region representing the 95% confidence intervals (for P_{cat} ranging from 5% to 20% per generation and λ_{max} ranging from 1.56 to 2.69). The dashed line indicates a 1% probability of extinction.

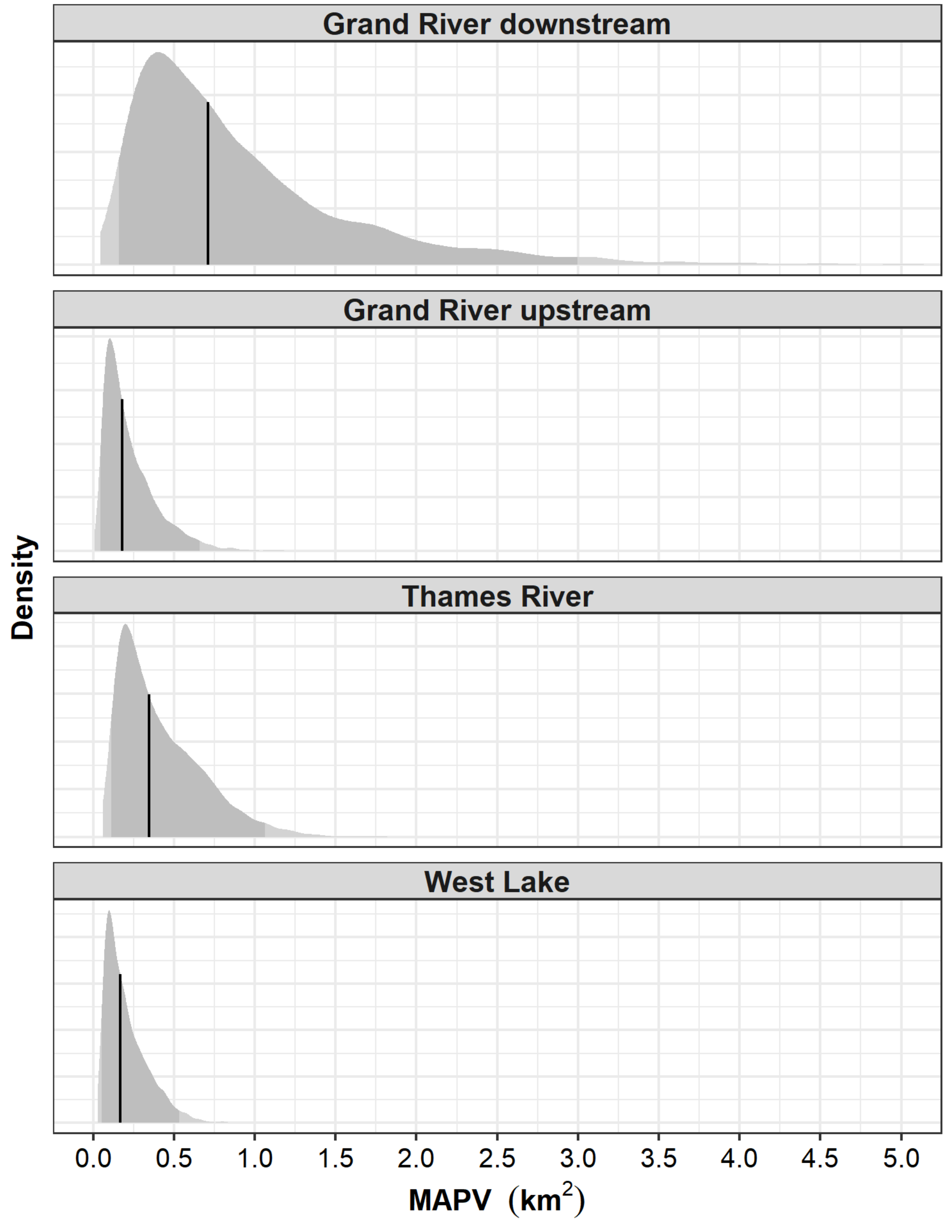

Figure A1.6. Kernel density plot of the minimum area for population viability (MAPV) for Eastern Sand Darter populations in four locations: Grand river upstream (Brantford), Grand River downstream (Caledonia), Thames River, and West Lake.

APPENDIX 2: METHODS AND RESULTS OF N-MIXTURE MODELS

Methods

Eastern Sand Darter (ESD) catch data were available from the Grand River (Gáspárdy et al. 2025), West Lake (Reid and Dextrase 2017), and the Thames River (Dextrase et al. 2014). The Grand River survey was the most recent, occurring in 2022, and used three-pass removal sampling with a bag seine. The West Lake survey was conducted in 2013 and 2014 and used five-pass removal sampling with bag and beach seines. The Thames River data were collected in 2006 using three-pass removal sampling with a bag-seine.

Removal sampling data from each location were fit with N-mixture models (Kéry and Royle 2016) to estimate 'true' ESD site density (N) in each system by accounting for detection probability (p). N-mixture models consists of two sub-models, the abundance model and the detection model. The sub-models can include additional covariates at the site, *i*, or sample, *j*, level. The models were structured as:

$$C_{ij}|N_i \sim Multinomial(N_i, \pi(p_{ij})) \quad \text{(A2.1)}$$
$$N_i \sim NB(\lambda_i, k) \quad \text{(A2.2)}$$
$$logit(p_{ij}) = \alpha_0 + a_1 X^p_{1,i,j} + \cdots + a_k X^p_{k,i,j} + u_{ij} \quad \text{(A2.3)}$$
$$\log(\lambda_i) = offset(Area) + \beta_0 + \beta_1 X^N_{1,i} + \cdots + \beta_l X^N_{l,i}, \quad \text{(A2.4)}$$

where C_{ij} is ESD catch (fish/seine) at site *i* and sample *j*. The abundance model utilized the negative binomial distribution because of evident over-dispersion in preliminarily analysis; λ is the expected site abundance and k is the size parameter for the negative binomial distribution. Because all surveys used removal sampling, seine hauls occurring subsequent to the first at each site are conditional on the previous hauls. As a result, the detection probability model used a multinomial distribution with cell probabilities, π, calculated as the product of probability of detection during sample *j* and the probability of not being detected in the previous samples (e.g., $\pi_3 = (1 - p_1)(1 - p_2)p_3$).

Over-dispersion was present in the detection model as well. To account for this, a sample-specific random effect (u_{ij}) was included to allow for excess variability in detection among samples, where $u_{ij} \sim \mathcal{N}(0, \sigma_{sample})$. α_0 is the detection model intercept and a_k represents coefficients for the up to k detection covariates, $X^p_{k,i,j}$; detection covariates could be site- or sample-specific. β_0 is the abundance model intercept with β_l up to l site-specific abundance covariates, $X^N_{l,i}$. All covariates were centred and scaled. Covariates included in location-specific models differed due to difference among systems and data availability. Covariates included in model fitting were incorporated based on past analyses (Dextrase et al. 2014, Reid and Dextrase 2017) and from preliminary modelling using generalized linear models. The abundance model included sampled area as an offset to account for any difference in sampling effort within a survey and provides expected values in units of fish/m^2.

A Bayesian approach was used to fit the N-mixture models using NIMBLE (de Valpine et al. 2017, de Valpine et al. 2022a) in R 4.2.2 (R core team 202) with the nimble package (de Valpine et al. 2022b). Vague priors were used for all model variables.

Model fit was assessed using the Bayesian p-value approach where a fit statistic is estimated for the observed data and simulated data obtained from the posterior distributions. The Bayesian p-value describes the proportion of the simulated fit statistics that exceed the fit statistic for the observed data, with a value close to 0.5 indicating good fit. Three fit statistics were used: the chi-square statistic, calculated as:

$$chi\text{-}square = \sum (y - E(y))^2 / E(y), \qquad \text{(A2.5)}$$

the Freeman-Tukey statistic, calculated as:

$$Freeman\text{-}Tukey = \sum(\sqrt{y} - \sqrt{E(y)})^2, \qquad \text{(A2.6)}$$

and the sum of squares statistic, calculated as:

$$sum\ of\ squares = \sum(y - E(y)/\sigma_y)^2. \qquad \text{(A2.7)}$$

Each fit statistic was used to assess model fit for both the detection and abundance model components. In addition, a Bayesian p-value was used to confirm the that model produced an appropriate amount of 0s.

Results

In the Grand River, 100 sites were sampled; models were built using data collected from 96 sites due to missing covariate data at some sites. At 62 of the 96 sites, no ESD were detected (64.5%). In total, 610 ESD were captured with per site catches ranging from 0–174. Mean site density across all sites was 6.35 fish/site with a mean of 9.94 fish/site in the Brantford section and 1.74 fish/site in the Caledonia section.

The N-mixture model for the Grand River (Table A2.1) indicated that detection probability was influenced by river width and velocity, decreasing with both variables (Figure A2.1). Detection probability was generally high, 52.0% (CI: 35.4–66.8), but variable among samples as the estimate of excess variability was 0.91 indicating a large amount of over-dispersion. Site density was greater in the upstream Brantford section than the downstream Caledonia section; expected density in the Caledonia section was 0.019 (CI: 0.008–0.054) fish/m^2, while expected density in the Brantford section was 0.075 (CI: 0.036–0.181) fish/m^2. Site density tended to be larger at sites that had substrate with greater proportions of sand or gravel and lower at more turbid sites (Figure A2.2). The mean density estimates correspond to sites with mean percent sand and gravel (82.7%; range: 50–100%) and mean turbidity (7.27 NTU; range: 1.10–47.03) from the sampled locations. Density was variable across sites as indicated by the small size parameter for the negative binomial distribution.

In West Lake, 120 sites were included in the model, 60 were sampled with bag seines and 60 used beach seines. No ESD were captured at 45 (37.5%) of the sites. In total, 1,184 ESD were captured: 217 with bag seines and 967 with beach seines. ESD detections per site ranged from 0–48 (mean site density: 3.6 fish/site) with bag seines and 0–133 (mean site density: 16.1 fish/site) with beach seines. Sampled area was greater with beach seines, approximately 188 m^2, compared to 94 m^2 for the bag seines.

The N-mixture model for West Lake (Table A2.2) maintained seine type as an important factor for detection probability. Detection probability was 7.9% (4.0–15.1) with the bag seine and 28.6% (21.7–34.7) with the beach seine. Detection probability was variable across seines with the seine-specific random effect important for model fit. Site density was influenced by percent sand, longitude, and depth (Figure A2.3). Depth was incorporated as a second degree polynomial, with low densities at shallow (<0.3 m) depths and increased to a plateau at depths between ~0.6 and 1.0 m. Mean expected site density was similar to the Brantford section of the Grand River, 0.081 (CI: 0.049–0.136) fish/m^2. The mean density estimates correspond to sites with mean percent sand (97.9%; range: 70–100%), mean longitude (-77.29: range: -77.33– -77.26) and mean depth (0.54 m; range: 0.14–0.96) from the sampled locations.

In the Thames River, 131 sites were sampled. No ESD were detected at 65 sites (49.6%). In total, 516 ESD were captured with per site detections ranging from 0–79 and mean site density of 3.94 fish/site. Sampled area per seine, however, varied across sites, ranging from 30–92 m^2 with a mean of 80.1 m^2.

The N −mixture model for the Thames River (Table A2.3) indicated that detection probability was influenced by percent cover (the proportion of a site estimated to consist of woody debris and boulders), decreasing sharply at sites with more cover (Figure A2.4). Detection probability was lower in the Thames River survey than the Grand River; mean detection probability was 14.1% (CI: 7.1–24.7). Detection probability was variable across seines with the seine-specific random effect important for model fit. Site density was intermediate between the two Grand River sections with expected mean density of 0.040 (CI: 0.026–0.066) fish/m^2 that increased at sites that had substrate with greater proportions of sand or fine gravel, and greater water clarity (Figure A2.5). Site quality was lower in the Thames River than the Grand River with mean percent sand or gravel of 45.6% (range: 0–100) and mean water clarity of 26.7 cm (range: 2.5–94.0).

For all N-mixture models there was no indication of lack of fit in either the detection or abundance model across all fit statistics (Table A2.4) once over-dispersion was accounted for in both model components. As well, the appropriate number of 0s was predicted from the model fit relative to what was observed.

Table A2.1. N-mixture model results for the Grand River. Parameter estimates are provided for the detection and abundance sub-models as the mean values with the standard deviation (sd), and lower (LCI) and upper (UCI) 95% credible intervals.

Parameters	Symbol	Mean	sd	LCI	UCI
Detection Model					
Fixed effects					
Intercept	α_0	0.07	0.32	-0.60	0.70
Water velocity (m/s)	α_1	-0.81	0.26	-1.32	-0.29
Stream Width (m)	α_2	-1.03	0.41	-1.85	-0.25
Hyper-parameters					
Dispersion parameter	σ_{sample}	0.91	0.19	0.58	1.34
Abundance Model					
Fixed Effects					
Intercept	β_0	0.65	0.49	-0.24	1.68
River Section (Brantford)	β_1	1.37	0.62	0.14	2.59
Percent Sand & Gravel	β_2	1.14	0.39	0.39	1.93
Turbidity (ntu)	β_3	-1.09	0.59	-2.29	0.04
Hyper-parameters					
Dispersion parameter	k	0.16	0.03	0.10	0.23

Table A2.2. N-mixture model results for West Lake. Parameter estimates are provided for the detection and abundance sub-models as the mean values with the standard deviation (sd), and lower (LCI) and upper (UCI) 95% credible intervals.

Parameters	Symbol	Mean	sd	LCI	UCI
Detection Model					
Fixed effects					
Intercept	α_0	-2.45	0.39	-3.18	-1.72
Beach Seine	α_1	1.52	0.39	0.77	2.26
Hyper-parameters					
Dispersion parameter	σ_{sample}	0.66	0.7	0.53	0.80
Abundance Model					
Fixed Effects					
Intercept	β_0	-2.51	0.26	-3.02	-1.99
Percent Sand	β_1	0.62	0.18	0.26	0.96
Depth (m^2)	β_2	1.07	0.19	0.71	1.47
Depth^2 (m^2)	β_3	-0.38	0.20	-0.77	0.03
Longitude	β_4	-0.79	0.19	-1.16	-0.43
Hyper-parameters					
Dispersion parameter	k	0.5	0.08	0.36	0.67

Table A2.3. N-mixture model results for the Thames River. Parameter estimates are provided for the detection and abundance sub-models as the mean values with the standard deviation (sd), and lower (LCI) and upper (UCI) 95% credible intervals.

Parameters	Symbol	Mean	sd	LCI	UCI
Detection Model					
Fixed effects					
Intercept	α_0	-1.81	0.37	-2.57	-1.12
Percent Cover	α_1	-2.02	0.67	-3.38	0.78
Hyper-parameters					
Dispersion parameter	σ_{sample}	0.85	0.15	0.58	1.18
Abundance Model					
Fixed Effects					
Intercept	β_0	-3.23	0.24	-3.66	-2.72
Percent Sand & Gravel	β_1	1.13	0.21	0.73	1.54
Water Clarity (cm)	β_2	0.99	0.16	0.69	1.32
Hyper-parameters					
Dispersion parameter	k	0.62	0.13	0.41	0.90

Table A2.4. Goodness-of-fit statistics (Bayesian p-values) for N-mixture models developed for the Grand River, West Lake, and the Thames River. Values close to 0.5 (e.g., >0.2 and <0.8) indicate appropriate fit.

Model	Chi-square	Freeman-Tukey	Sum of Squares	Prop. Of Zeros
Grand River				
Detection	0.454	0.547	0.530	NA
Abundance	0.466	0.396	0.519	0.733
West Lake				
Detection	0.354	0.795	0.623	NA
Abundance	0.509	0.540	0.459	0.515
Thames River				
Detection	0.503	0.501	0.448	NA
Abundance	0.445	0.532	0.474	0.499

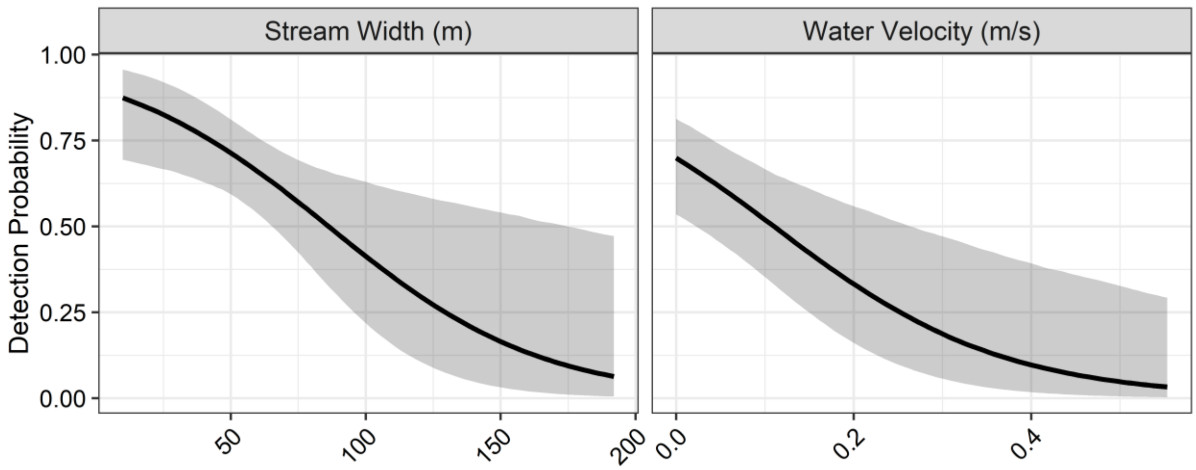

Figure A2.1. N-mixture model predictions of Eastern Sand Darter detection probability in the Grand River as a function of stream width (m) and water velocity (m/s). The solid line represents the median prediction and the grey area represents 95% credible intervals. Figure reproduced from Lamothe et al. (2026).

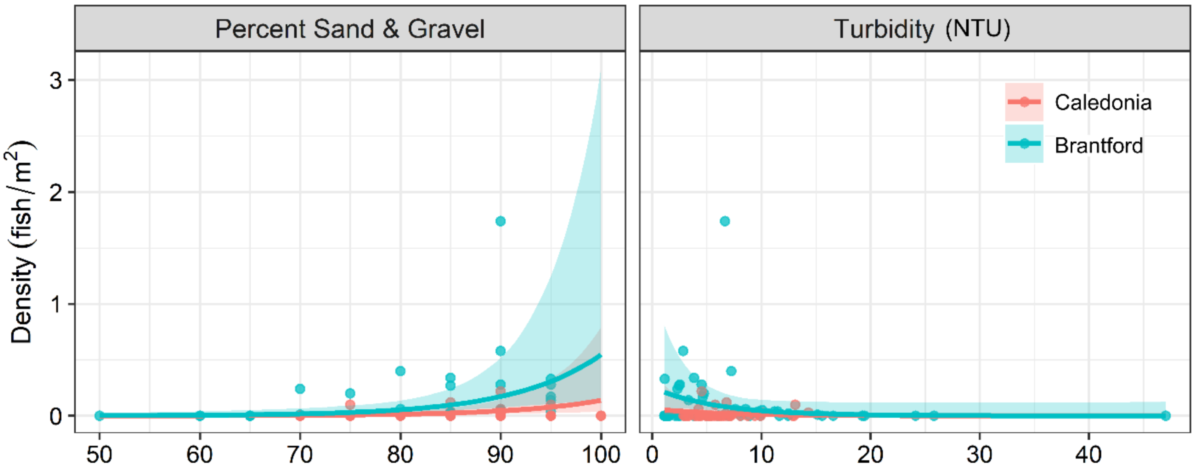

Figure A2.2. N-mixture model predictions of Eastern Sand Darter density (fish/m²) in the Brantford (blue) and Caledonia (red) sections of the Grand River across percent sand and gravel and turbidity measurements. The solid line represents median predictions and the shaded area represents 95% credible intervals. Predicted densities in the percent sand and gravel panel incorporate mean turbidity (7.27 NTU) and predicted densities in the turbidity panel incorporate mean percent sand and gravel (82.7%). Figure reproduced from Lamothe et al. 2026.

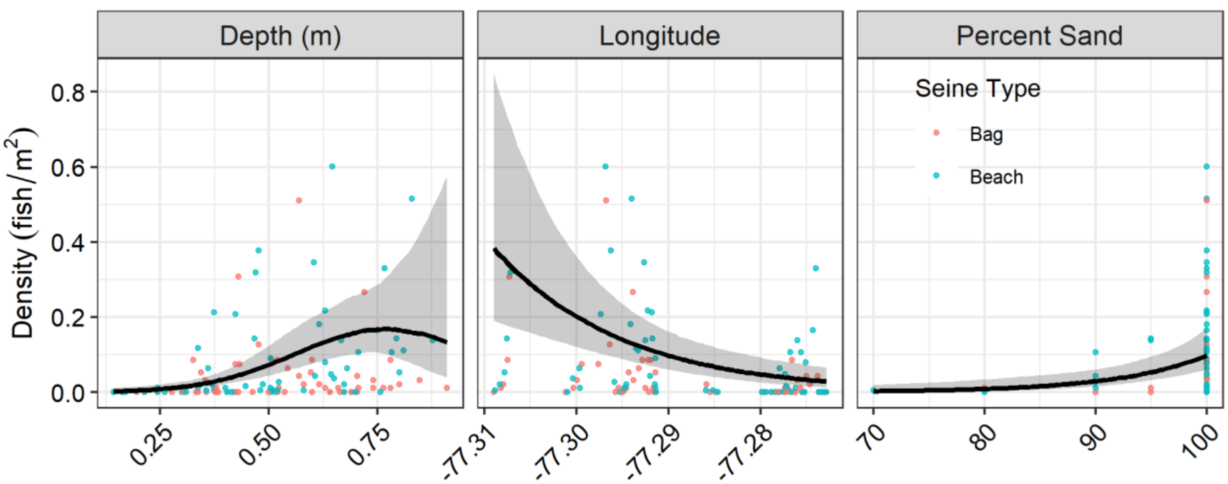

Figure A2.3. N-mixture model predictions of Eastern Sand Darter density (fish/m²) in West Lake across depth (m), longitude, and percent sand measurements. The solid line represents median predictions and the shaded area represents 95% credible intervals. Blue points correspond to samples using beach seines and red dots correspond to samples using bag seines. Predicted densities correspond to estimates at mean depth (0.54 m), mean longitude (-77.29), and mean percent sand (97.9%) in the respective panels. Figure reproduced from Lamothe et al. (2026).

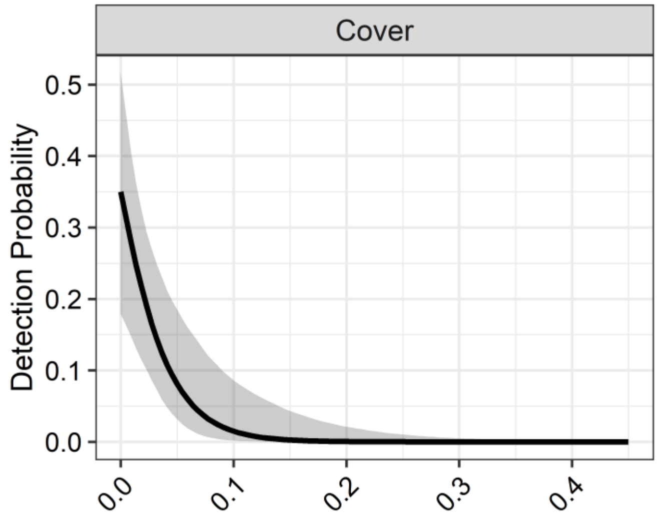

Figure A2.4. N-mixture model predictions of Eastern Sand Darter detection probability in the Thames River as a function of the proportion of a site consisting of woody debris and boulders (i.e., cover). The solid line represents the median prediction and the grey area represents 95% credible intervals. Figure reproduced from Lamothe et al. (2026).

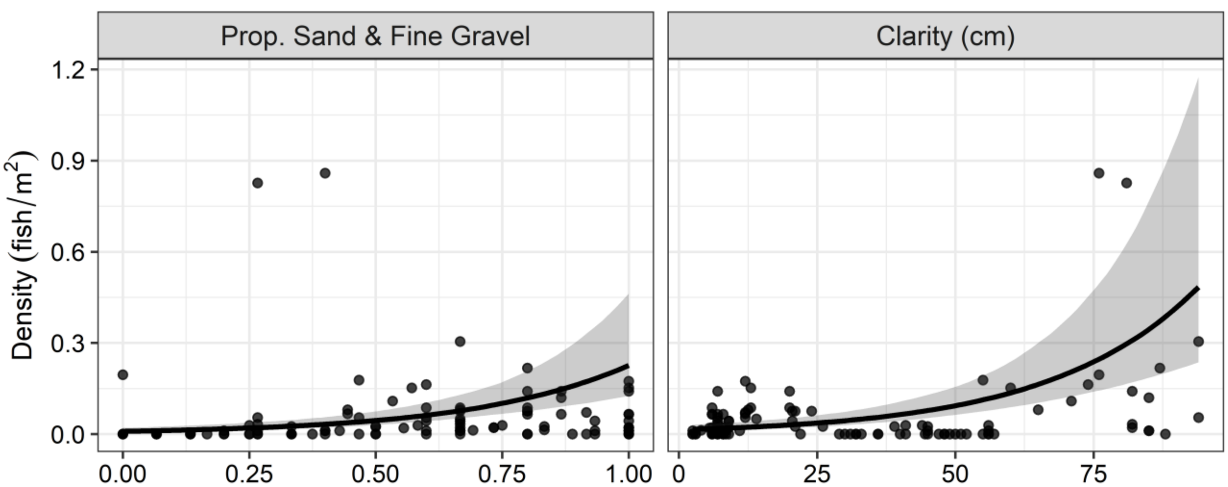

Figure A2.5. N-mixture model predictions of Eastern Sand Darter density (fish/m^2) in the Thames River across proportion (prop.) of sand and fine gravel and water clarity (cm) measurements. The model was built using data from Dextrase (2013). The solid line represents the median prediction and the grey area represents 95% credible intervals. Predicted densities in the proportion of sand and gravel panel incorporate mean clarity (26.7 cm) and predicted densities in the clarity panel incorporate mean proportion sand and gravel (0.456). Figure reproduced from Lamothe et al. (2026).

APPENDIX 3: THREAT ASSESSMENT

Threats were assessed for each population following guidelines in DFO (2014). Each threat was ranked in terms of the threat Likelihood of Occurrence (LO), threat Level of Impact (LI) and Causal Certainty (CC). The Likelihood of Occurrence was assigned as Known, Likely, Unlikely, Remote, or Unknown, and refers to the probability of a specific threat occurring for a given population over 10 years or 3 generations, whichever is shorter. The Level of Impact was assigned as Extreme, High, Medium, Low, or Unknown and refers to the magnitude of the impact caused by a given threat, and the level to which it affects the survival or recovery of the population (Table A3.1). Additional rationale for the Level of Impact scores is presented in Table A3.2. The level of certainty associated with each threat was assessed and classified as: 1 = very high, 2 = high, 3 = medium, 4 = low, and 5 = very low. The Population-Level Threat Occurrence (PTO), Threat Frequency (PTF), and Threat Extent (PTE) were also evaluated and assigned a status based on the definitions outlined in Table A3.1 (rankings in Table A3.3.1–A3.3.4 and A3.4 for the Southwestern Ontario and West Lake DUs, respectively). The Likelihood of Occurrence and Level of Impact for each population were subsequently combined in the population-level Threat Risk Matrix (Table A3.5; rankings in Table 9 and 10 for the Southwestern Ontario and West Lake DUs, respectively). The DU-level Threat Assessment in Table A3.6 is a roll-up of the population-level threats identified in Table 9 for the Southwestern Ontario DU; the roll-up is not completed for the West Lake DU as it has only one population.

Table A3.1. Definition and terms used to describe likelihood of occurrence (LO), level of impact (LI), causal certainty (CC), population level threat occurrence (PTO), threat frequency (PTF), and threat extent (PTE) reproduced from DFO (2014).

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

Table A3.2. Rationale and references for threat scoring. References presented are specific to Eastern Sand Darter in Ontario; refer to COSEWIC (2009), Bouvier and Mandrak (2010), and COSEWIC (2022) for more complete reviews of each threat and associated references.

Threat Category	Subcategory	Details	Rationale	References
Natural Systems Modifications	Dams & water management/use	Deposition of fines above dams and altered flow below	Level of Impact scored 'low' for areas with dams upstream of the species' distribution and 'medium' when dams disrupt the distribution	Dextrase 2013
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	Level of Impact scored the same across localities - Round Goby is in relatively high abundances across the range of Eastern Sand Darter in Ontario and is expected to have similar impacts across habitat types	Poos et al. 2010, Raab et al. 2018, Firth et al. 2021b, McAllister et al. 2022
Pollution	Domestic and urban wastewater	Detergents, heavy metals, hydrocarbons, hormones and pharmaceutical compounds, chloride	Level of Impact considered the proportion of urban land use and number of wastewater treatment plants in the watershed (if available); larger systems with high water exchange rates were scored lower	
	Agricultural and forestry effluents	Sediments, pesticides, herbicides, fertilizers	Level of Impact considered the proportion of agricultural land use in the watershed; larger systems with high water exchange rates were scored lower	Daniels 1993, Drake et al. 2008
	Industrial and Military Effluents	granular Bayluscide and petro-chemical industry	Level of Impact is considered low for systems receiving gB applications, but has the potential to have high impacts in some scenarios. Impacts of the petro-chemical industries along the St. Clair and Detroit rivers are poorly understood, but have the potential to impact Eastern Sand Darter in Lake St. Clair and the Detroit River.	Smyth and Drake 2021, Andrews et al. 2021
Climate Change and Severe Weather	Droughts	Water loss and exposure of sand bars	Level of Impact considered medium in rivers as refuge pool habitat may not have sand available (may be high in the Thames River due to limited baseflow), and low in lakes and bays.	Brinker et al. 2018, Hoving et al. 2013
	Extreme temperatures	Increased temperatures and periods of hypoxia	Level of Impact considered low overall over the next 10 years; however, impacts have the potential to be greater in rivers compared to lakes and bays due to greater buffering capacity in the latter.	Brinker et al. 2018, Firth et al. 2021a, 2023

Table A3.3.1. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent (PTE) for the Lake St. Clair, Sydenham River, and Thames River populations of Eastern Sand Darter in the Southwestern Ontario Designatable Unit. Definitions and terms used to describe the threat ratings are found in Table A3.1.

Threat Category	Subcategory	Details	Lake St. Clair						Sydenham River						Thames River					
			LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE
Natural Systems Modifications	Dams & water management/use	Deposition of fines above dams and reduced flow below	NA	NA	NA	NA	NA	NA	R	L	5	H/C	C	R	R	L	5	H/C	C	R
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B
Pollution	Domestic and urban wastewater	Detergents, heavy metals, hydrocarbons, hormones and pharmaceutical compounds, chloride	K	L	5	H/C/A	C	B	K	L	5	H/C/A	C	B	K	M	5	H/C/A	C	B
	Agricultural and forestry effluents	Sediments, pesticides, herbicides, fertilizers	K	L	4	H/C/A	C	B	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B
	Industrial and Military Effluents	granular Bayluscide (apparently); petro-chemical industry	K	L	5	H/C/A	C	B	K	L	3	H/C/A	C	B	K	L	5	H/C/A	C	B
Climate Change and Severe Weather	Droughts	Water loss exposure of sand bars	K	L	5	H/C/A	R	B	K	M	5	H/C/A	R	B	K	H	5	H/C/A	R	B
	Extreme temperatures	Increased temperatures and periods of hypoxia	K	L	5	H/C/A	R	B	K	L	5	H/C/A	R	B	K	L	5	H/C/A	R	B

Table A3.3.2. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent (PTE) for the Western Basin (Lake Erie) and Rondeau Bay populations of Eastern Sand Darter in the Southwestern Ontario Designatable Unit. Definitions and terms used to describe the threat ratings are found in Table A3.1.

Threat Category	Subcategory	Details	Western Basin (Lake Erie)						Rondeau Bay					
			LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE
Natural Systems Modifications	Dams & water management/use	Deposition of fines above dams and reduced flow below	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B
Pollution	Domestic and urban wastewater	Detergents, heavy metals, hydrocarbons, hormones and pharmaceutical compounds, chloride	K	L	5	H/C/A	C	B	K	M	5	H/C/A	C	B
	Agricultural and forestry effluents	Sediments, pesticides, herbicides, fertilizers	K	L	4	H/C/A	C	B	K	L	4	H/C/A	C	B
	Industrial and Military Effluents	granular Bayluscide (apparently); petro-chemical industry	R	L	5	NA	NA	NA	R	L	5	NA	NA	NA
Climate Change and Severe Weather	Droughts	Water loss exposure of sand bars	K	L	5	H/C/A	R	B	K	L	5	H/C/A	R	B
	Extreme temperatures	Increased temperatures and periods of hypoxia	K	L	5	H/C/A	R	B	K	L	5	H/C/A	R	B

Table A3.3.3. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent (PTE) for the Big Creek (Norfolk county), Long Point Bay, and Grand River populations of Eastern Sand Darter in the Southwestern Ontario Designatable Unit. Definitions and terms used to describe the threat ratings are found in Table A3.1.

Threat Category	Subcategory	Details	Big Creek (Norfolk County)						Long Point Bay						Grand River					
			LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE
Natural Systems Modifications	Dams & water management/use	Deposition of fines above dams and reduced flow below	U	U	5	NA	NA	NA	NA	NA	NA	NA	NA	NA	K	M	1	H/C/A	C	B
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B
Pollution	Domestic and urban wastewater	Detergents, heavy metals, hydrocarbons, hormones and pharmaceutical compounds, chloride	K	L	5	H/C/A	C	B	K	M	5	H/C/A	C	B	K	M	5	H/C/A	C	B
	Agricultural and forestry effluents	Sediments, pesticides, herbicides, fertilizers	K	M	4	H/C/A	C	B	K	L	4	H/C/A	C	B	K	M	4	H/C/A	C	B
	Industrial and Military Effluents	granular Bayluscide (apparently); petro-chemical industry	R	L	5	NA	NA	NA	R	L	5	NA	NA	NA	R	L	5	NA	NA	NA
Climate Change and Severe Weather	Droughts	Water loss exposure of sand bars	K	M	5	H/C/A	R	B	K	L	5	H/C/A	R	B	K	M	5	H/C/A	R	B
	Extreme temperatures	Increased temperatures and periods of hypoxia	K	L	5	H/C/A	R	B	K	L	5	H/C/A	R	B	K	L	5	H/C/A	R	B

Table A3.3.4. Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent (PTE) for the Ausable River and Big Otter Creek extirpated populations of Eastern Sand Darter in the Southwestern Ontario Designatable Unit. Definitions and terms used to describe the threat ratings are found in Table A3.1.

Threat Category	Subcategory	Details	Ausable River						Big Otter Creek					
			LO	LI	CC	PTO	PTF	PTE	LO	LI	CC	PTO	PTF	PTE
Natural Systems Modifications	Dams & water management/use	Deposition of fines above dams and reduced flow below	U	U	5	H/C/A	C	R	U	U	5	NA	NA	NA
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B
Pollution	Domestic and urban wastewater	Detergents, heavy metals, hydrocarbons, hormones and pharmaceutical compounds, chloride	K	M	5	H/C/A	C	B	K	L	5	H/C/A	C	B
	Agricultural and forestry effluents	Sediments, pesticides, herbicides, fertilizers	K	M	4	H/C/A	C	B	K	M	4	H/C/A	C	B
	Industrial and Military Effluents	granular Bayluscide (apparently); petro-chemical industry	R	L	5	NA	NA	NA	R	L	5	NA	NA	NA
Climate Change and Severe Weather	Droughts	Water loss exposure of sand bars	K	M	5	H/C/A	R	B	K	M	5	H/C/A	R	B
	Extreme temperatures	Increased temperatures and periods of hypoxia	K	L	5	H/C/A	R	B	K	L	5	H/C/A	R	B

Table A3.4 Threat Likelihood of Occurrence (LO), Level of Impact (LI), Causal Certainty (CC), Population-level Threat Occurrence (PTO), Population-level Threat Frequency (PTF), and Population-level Threat Extent (PTE) of the Eastern Sand Darter population in the West Lake Designatable Unit. Definitions and terms used to describe the threat ratings are found in Table A3.1.

Threat Category	Subcategory	Details	West Lake					
			LO	LI	CC	PTO	PTF	PTE
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	K	M	4	H/C/A	C	B

Table A3.5. The Threat Level Matrix combines the Likelihood of Occurrence and Level of Impact rankings to establish the Threat Level for each Eastern Sand Darter population. The resulting Threat Level has been categorized as low (green), medium (yellow), high (red), or unknown. Reproduced from DFO (2014).

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

Table A3.6. Designatable Unit-level Threat Assessment for Eastern Sand Darter, Southwestern Ontario designatable unit (DU), resulting from a roll-up of the population-level Threat Assessment for this DU (Table 9). The DU-level Threat Assessment retains the highest level of risk for any population, all categories of Threat Occurrence and Threat Frequency are retained, and the DU-level Threat Extent is the mode of the population-level Threat Extent.

Threat Category	Subcategory	Details	DU-Level Threat	Threat Occurrence	Threat Frequency	Threat Extent
Natural Systems Modifications	Dams & water management/use	Deposition of fines above dams and reduced flow below	Medium (1)	H/C/A	C	B
Invasive & Other Problematic species & Genes	Invasive non-native species	Round Goby	Medium (4)	H/C/A	C	B
Pollution	Domestic and urban wastewater	Detergents, heavy metals, hydrocarbons, hormones and pharmaceutical compounds, chloride	Medium (5)	H/C/A	C	B
	Agricultural and forestry effluents	Sediments, pesticides, herbicides, fertilizers	Medium (4)	H/C/A	C	B
	Industrial and Military Effluents	granular Bayluscide; petro-chemical industry	Low (3)	H/C/A	C/R	B
Climate change and severe weather	Droughts	Water loss exposure of sand bars	High (5)	H/C/A	R	B
	Extreme temperatures	Increased temperatures and periods of hypoxia	Low (4)	H/C/A	R	B

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