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Flathead Catfish (*Pylodictis olivaris*) reproduction in Canada

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Abstract

Eleven Flathead Catfish (*Pylodictis olivaris*), representing at least five age classes, were collected between 2016 and 2018 in the lower Thames River, Ontario, Canada. The capture of two juveniles (total lengths 78 mm and 82 mm), the first records of juveniles in Canada, is a strong indication that reproduction has occurred. Previous records were thought to be individuals that dispersed from known populations in American waters of Lake Erie. Flathead Catfish is currently designated as data deficient by the Committee on the Status of Endangered Wildlife in Canada. These new findings may provide sufficient data to reconsider the conservation status of this species.

Key words: Flathead Catfish; *Pylodictis olivaris*; reproduction; Great Lakes; Lake St. Clair; Thames River; juvenile; young-of-year

Introduction

Flathead Catfish (*Pylodictis olivaris*) is found throughout the Mississippi River basin and lower Laurentian Great Lakes (Page and Burr 2011); however, it is uncertain whether the species is native to the Great Lakes basin (Fuller and Whelan 2018). It is a benthic fish species preferring turbid (Lee and Terrell 1987; Hesse 1994), warm water (Becker 1983) in low-gradient, moderate to large rivers (Lee and Terrell 1987), and is commonly associated with woody debris, undercut banks, and substrate depressions throughout its range (Becker 1983; Hesse 1994; Grussing *et al*. 1999; Jackson 1999; Daugherty and Sutton 2005a). Flathead Catfish reach sexual maturity between three and six years of age when fish are 375–539 mm in total length (TL; Minckley and Deacon 1959; Perry and Carver 1977). Reproduction occurs in June and July when water temperatures reach at least 22.2°C (Becker 1983). Flathead Catfish use depressions and natural cavities to construct nests (Cooper 1983; Cross 1967) and females lay up to 31 579 eggs (Becker 1983). A detailed description of the life history of Flathead Catfish was reported by Goodchild (1993).

Flathead Catfish is taxonomically and morphologically different from all other catfish species in the Great Lakes basin. Differences include its protruding lower jaw, ventrally compressed head, large adipose fin, and backward extensions of the premaxillary tooth patches (although Stonecat [*Noturus flavus*] shares the latter characteristic). Flathead Catfish has a varying amount of mottled pigmentation on the body, and the upper lobe of the caudal fin has a pale tip (Figure 1), although these traits can be absent or less obvious in larger fish. Flathead Catfish has a slightly forked caudal fin in contrast to the deeply forked caudal fin of Channel Catfish (*Ictalurus punctatus*).

Flathead Catfish has a short anal fin with a ray count of 13–18 (Trautman 1981), which differentiates it from Channel Catfish (25–28), Yellow Bullhead (*Ameiurus natalis*, 24–27), Brown Bullhead (*Ameiurus nebulosus*, 20–23) and, in some cases, Black Bullhead (*Ameiurus melas*, 17–21; Scott and Crossman 1998); all anal ray counts include rudimentary rays. Furthermore, Flathead Catfish has serrations on both edges of its pectoral spines whereas Channel Catfish and Brown and Black Bullheads have serrations only on the posterior edge. Madtoms (*Noturus* spp.) could be confused with juvenile Flathead Catfish, but are distinguished by a connected adipose fin and caudal fin, which are separate in Flathead Catfish.

In the Great Lakes, Flathead Catfish has been recorded in the Lake Erie, Lake St. Clair, Lake Huron, Lake Michigan, and Lake Superior basins. Since 1890, when Flathead Catfish was first recorded in Lake Erie, it has been documented in seven tribu-

Figure 1. Juvenile Flathead Catfish (*Pylodictis olivaris*), 78 mm total length, captured on 31 August 2016 in the lower Thames River, Ontario, Canada. Photo: Colin Illes.

taries and is believed to have spread to the Lake St. Clair (Goodchild 1993; COSEWIC 2008) and Lake Huron basins where it has been recorded in six tributaries since the first records in 1989 and 1991, respectively (Fuller and Whelan 2018). In Lake Michigan, Flathead Catfish was first recorded in 1922 and has since been documented in 11 tributaries (Fuller and Whelan 2018). In addition, there is a single record of a Flathead Catfish in the Lake Superior basin, captured in a pond in the Au Train River watershed and believed to be an unauthorized release (Fuller and Whelan 2018). A detailed description of the historical and current distribution of Flathead Catfish in the American Great Lakes basin is provided by Fuller and Whelan (2018).

Whether Flathead Catfish is native to the Great Lakes basin is not known because of poorly documented historical records. Historical publications variously mention (e.g., Trautman 1957) and do not mention (e.g., Evermann 1902) the presence of Flathead Catfish in the lower Great Lakes. Based on a review of the literature and capture data, Fuller and Whelan (2018) concluded that Flathead Catfish is not native to the Great Lakes basin, with the possible exception of a small population documented since 1890 in the Huron River, Lake Erie (Trautman 1957). Conversely, Roth *et al.* (2012) indicated that Flathead Catfish is native to the Erie and Michigan basins.

The origin of several other fishes in the Great Lakes basin is also unclear. Much like Flathead Catfish, Gizzard Shad (*Dorosoma cepedianum*), and Bigmouth Buffalo (*Ictiobus cyprinellus*) have uncertain origins in Lake Erie and may have spread from the Mississippi River basin into Lake Erie where populations have continually expanded because of warming temperatures (Miller 1957; Goodchild 1993). These fishes are considered native to the Great Lakes basin (e.g., Lee *et al.* 1980; Trautman 1981; Scott and Crossman 1998; Roth *et al.* 2012), despite a lack of historical records and vouchered specimens. This has been attributed to misidentification with other species (e.g., Alewife [*Alosa pseudoharengus*], Smallmouth Buffalo [*Ictiobus bubalus*]), and confusion with early introductions of Bigmouth Buffalo (Miller 1957; Trautman 1981). Gizzard Shad and Bigmouth Buffalo were first recorded in Lake Erie in 1848 and 1878, respectively (Miller 1957; Trautman 1981). Roth *et al.* (2012) identified only three species of questionable native status in the Great Lakes basin: Ghost Shiner (*Notropis buchanani*), questionably native to the Erie and Huron basins; and Brindled Madtom (*Noturus miurus*) and Orangethroat Darter (*Etheostoma spectabile*) to the Michigan basin.

In Canada, Flathead Catfish has been collected only in the Great Lakes basin with records limited to the western basin of Lake Erie and Lake St. Clair (COSEWIC 2008). The first Canadian capture of a Flathead Catfish was in Lake Erie, in 1978; it was caught west of Point Pelee, 3.2 km north of the tip, in a commercial trap net (Crossman and Leach 1979). Subsequently, three additional single specimens were captured in the Point Pelee area in 1986, 2005, and 2011 (COSEWIC 2008; Ontario Ministry of Natural Resources and Forestry [OMNRF] unpubl. data). All three fish were recorded in commercial trap nets west of Point Pelee and south of Sturgeon Creek within 8 km of each other. In 1989, Flathead Catfish was first captured by commercial long line in Lake St. Clair, 3.2 km from the mouth of the Thames River (Royal Ontario Museum unpubl. data). In 2001 and 2003, two additional Flathead Catfish were captured in Lake St. Clair in the St. Luke's Bay area, 10 km north of the Thames River mouth (Figure 2), both in a commercial trap net (OMNRF unpubl. data). Based on the four known single specimens captured in Canadian waters between 1978 and 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) could not determine whether Flathead Catfish was native to Canada or a vagrant and, thus, assessed it as data deficient (COSEWIC 2008).

Because of its preference for hard-to-sample habitats (e.g., beneath woody debris and structured substrate in deep water), low population abundance, and solitary behaviour, Flathead Catfish has been notori-

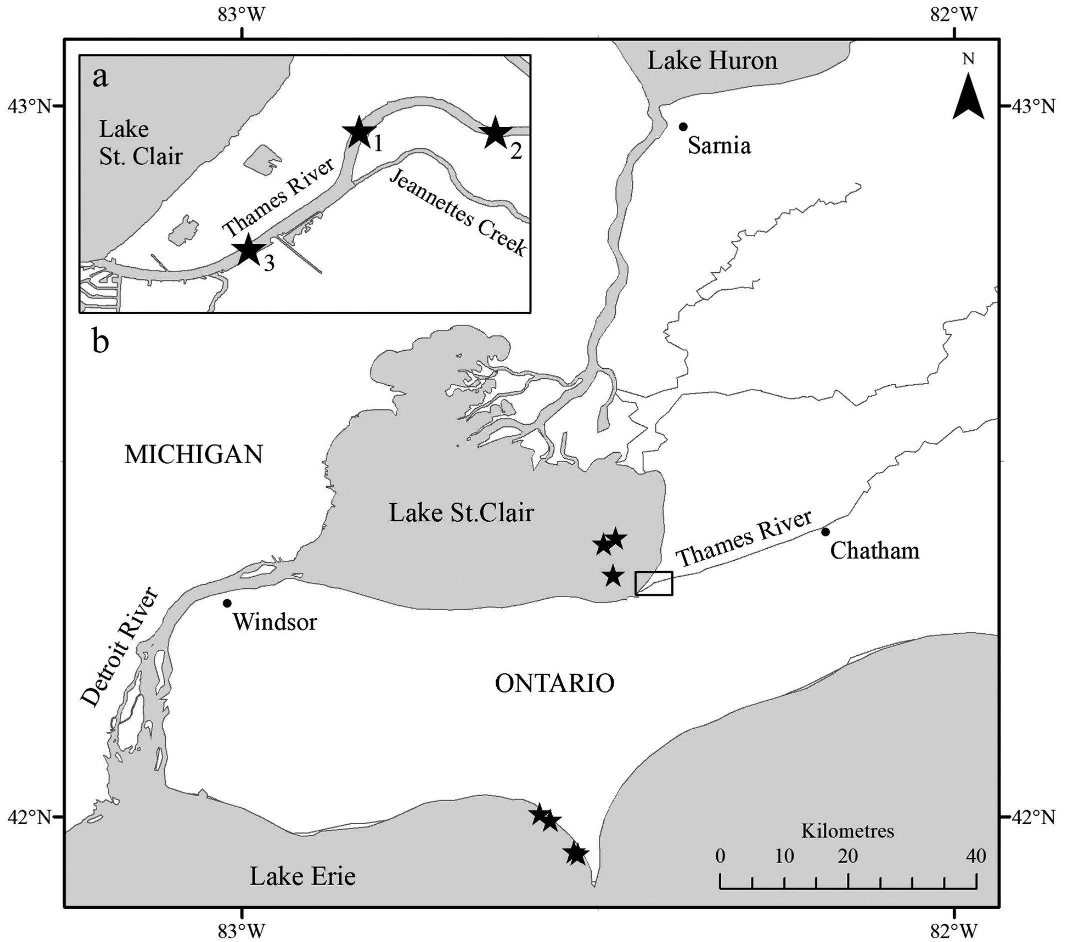

FIGURE 2. Capture locations of Flathead Catfish (*Pylodictis olivaris*) in Canadian waters of the Great Lakes basin, a. 2016–2018 and b. 1979–2018. Source: Unpublished data from Fisheries and Oceans Canada, the Ontario Ministry of Natural Resources and Forestry, and the Royal Ontario Museum, sourced under the Open Government Licence Ontario.

ously difficult to assess in river systems (Stauffer *et al*. 1996; Vokoun and Rabeni 1999). This has led to limited targetted sampling and knowledge about the species, especially in the Great Lakes (Daughtery and Sutton 2005a). To our knowledge, there has been only one population estimate for Flathead Catfish in the Great Lakes basin, conducted in the lower St. Joseph River, Michigan, which estimated an abundance of 5453 individuals (Daughtery and Sutton 2005b).

In this study, we report recent records of Flathead Catfish that indicate reproduction in the Canadian waters of the Great Lakes basin and discuss implications of these records for future management.

Methods

The Thames River, a tributary of Lake St. Clair, is a large, turbid river with a high diversity of fish and mussel species, 25 of which are at risk (Cudmore *et al*. 2004). The Thames River watershed has been impacted by agriculture and urban and rural development (Cudmore *et al.* 2004). In addition to supporting several imperilled species, the river is highly suitable for the reproduction of four species of invasive Asian carp (Cudmore *et al.* 2017) and, therefore, is sampled routinely by Fisheries and Oceans Canada's Asian Carp Program (Colm *et al*. 2019a).

This sampling occurred between May and November, 2013–2018, using seven gear types to target adult and juvenile Asian carp, while also collecting baseline fish community data (Marson *et al.* 2014, 2016, 2018; Colm *et al.* 2018, 2019a,b). Sampling effort in the lower Thames River during this period is summarized in Table 1.

Flathead Catfish were captured in the lower Thames River using three gear types: boat electrofishing (n =

TABLE 1. Summary of sampling effort in the lower Thames River, 2013–2018, as part of the early detection surveillance efforts of Fisheries and Oceans Canada's Asian Carp Program.

Year	Boat electrofishing		Hoop net		Mini-fyke net		Seine net		Trap net		Trammel net	
	No. sites	Effort, h	No. sites	Effort, h	No. sites	Effort, h	No. sites	Effort, hauls	No. sites	Effort, h	No. sites	Effort, h
2013	4	0.4	0	0.0	0	0.0	2	6	0	0.0	2	1.8
2014	19	3.1	3	112.4	0	0.0	0	0	4	91.4	5	1.8
2015	33	5.6	7	311.1	0	0.0	0	0	12	244.4	13	9.1
2016	25	4.6	0	0.0	6	130.4	0	0	7	153.6	8	5.4
2017	22	3.8	10	460.1	7	155.9	0	0	10	214.4	9	2.3
2018	28	6.0	9	397.4	16	355.1	2	5	13	293.8	14	12.4

Sources: Marson *et al.* 2014, 2016, 2018; Colm *et al.* 2018, 2019a,b.

4), hoop nets ($n = 2$), and trammel nets ($n = 5$). Before 2018, the boat electrofisher was dual-boom, 6.4 m in length, and fitted with a 7.5 Generator Powered Pulsator (Smith-Root, Vancouver, Washington, USA). In 2018, the boat electrofisher used in sampling was 7.3 m in length, dual-boom, and fitted with an Infinity Box (Midwest Lake Electrofishing, Polo, Missouri, USA). Two sizes of hoop nets were used: 1.5 m in diameter, 6.1 m in length, with 2.5-cm square mesh; and 0.91 m in diameter, 4.57 m in length, with 2.5-cm square mesh. Trammel nets were 183 m in length, 4.3 m in height, with 10.1-cm bar mesh and 45.7-cm outer wall panels. Trammel nets were often used in combination with boat electrofishing as this is an effective method for targetting Grass Carp (*Ctenopharyngodon idella*), a species of Asian carp, in the Great Lakes basin (D.M.M. pers. obs.); however, fishes captured with the two gear types were processed separately. All gear types and the scope of sampling (including other locations in the Great Lakes basin) are described in Colm *et al.* (2019a).

Results

During 2016–2018, 11 Flathead Catfish (Table 2) were captured in three locations in the lower Thames River, near the mouth of Jeannettes Creek, Kent County, Tilbury Township (42.329°N, 82.421°W) (Figure 2a). No Flathead Catfish were detected in 2013–2015, despite sampling in similar areas to 2016–2018. In August 2016, we recorded three Flathead Catfish, with TL 78–566 mm, at two locations. All three fish were captured using a boat electrofisher near shore in close proximity to woody debris on a clay–silt substrate (Table 2). The first location had an undercut bank with a single cluster of woody debris; the second had abundant large woody debris, including trees, logs, and branches, and a water depth of ~1 m at the bank. In June 2017, a Flathead Catfish measuring 365 mm TL was captured with a hoop net in a new location with abundant submerged logs and branches. This individual was caught farthest downstream, 1.3 km from the Thames River mouth. In September 2017, two Flathead Catfish measuring 833 mm and 815 mm TL were captured using a

TABLE 2. Capture data for Flathead Catfish (*Pylodictis olivaris*). Capture locations shown in Figure 2a.

Date	Total length, mm	Temp., °C	Turbidity, NTU	Max. site depth, m	Substrate	Coarse woody debris, Y/N	Gear type	Location of capture	ROM catalogue no.
30 Aug. 2016	566	26.29	28.77	4.2	Clay–silt	Y	Boat electrofishing	1	101500
30 Aug. 2016	82	27.17	27.44	2.0	Clay–silt	Y	Boat electrofishing	2	105705
31 Aug. 2016	78	26.67	25.77	2.1	Clay–silt	Y	Boat electrofishing	2	101375
20 June 2017	365	24.61	16.04	2.8	Clay–silt	Y	Hoop net	3	109946
13 Sept. 2017	833	20.34	23.70	4.1	Clay–silt	Y	Trammel net	1	NA
14 Sept. 2017	815	21.44	11.30	2.0	Clay–silt	Y	Boat electrofishing	2	NA
26 June 2018	820	23.71	23.11	5.0	Clay–silt	Y	Hoop net	2	NA
27 Sept. 2018	697	20.31	31.17	4.0	Silt–clay	Y	Trammel net with boat electrofishing	2	NA
27 Sept. 2018	765	20.22	20.86	3.8	Silt–clay	Y	Trammel net with boat electrofishing	1	NA
27 Sept. 2018	743	20.22	20.86	3.8	Silt–clay	Y	Trammel net with boat electrofishing	1	NA
2 Oct. 2018	388	18.29	25.13	4.0	Clay–silt	Y	Trammel net with boat electrofishing	3	NA

Source: Fisheries and Oceans Canada unpubl. data.
Note: NTU = nephelometric turbidity units, ROM = Royal Ontario Museum.

trammel net and boat electrofisher (Table 2). The 815-mm individual was the farthest upstream record, 6.3 km from the Thames River mouth. In 2018, five additional Flathead Catfish were collected, measuring 388–820 mm TL. The 820-mm individual was captured using a hoop net at the deepest recorded capture of 5 m. The other four Flathead Catfish were captured in trammel nets used in combination with boat electrofishing (Table 2).

Four specimens of Flathead Catfish captured in 2016 and early 2017 were preserved in 10% buffered formalin, stored in 70% ethanol, and catalogued at the Royal Ontario Museum (Table 2). Digital voucher photos were taken of the remaining seven fish before they were released.

Using length-at-age data from the literature (Mayhew 1969; Young and Marsh 1990; Kwak *et al.* 2006; Sakaris *et al.* 2006), we estimate that the 11 Flathead Catfish were from five different age classes (Figure 3).

Discussion

We report the first indication of Flathead Catfish reproduction in the Canadian waters of the Great Lakes basin. Over six consecutive years of sampling, 11 individuals were detected in the lower Thames River, Ontario. To our knowledge, no length-at-age data are available for Flathead Catfish in the Great Lakes basin. Flathead Catfish collected on 30 August 2016 and 31 August 2016 with TLs of 78 mm and 82 mm, respectively, are assumed to be young-of-year. In addition to being the first recorded juveniles in Canada, these are the first records of Flathead Catfish from a river system in Canada; previous detections were in large bays.

In the first year of growth, Flathead Catfish has been documented to reach 100 mm TL in Ohio (Trautman 1981) and 145 mm TL in Arizona (Young and Marsh 1990). Daugherty and Sutton (2005b) recorded Flathead Catfish measuring 87 mm and 93 mm TL, which were assumed to be young-of-year, while sampling the lower St. Joseph River, Michigan, June through September 2002–2003.

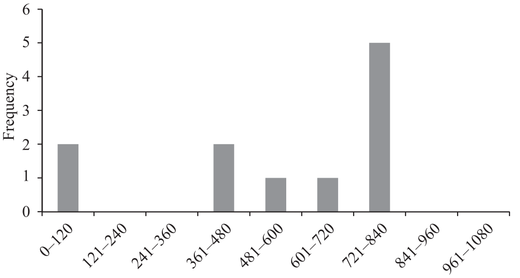

FIGURE 3. Length–frequency distribution of Flathead Catfish (*Pylodictis olivaris*) captured in the lower Thames River, 2016–2018, by Fisheries and Oceans Canada's Asian Carp Program.

Historical records of Flathead Catfish captured in Canada before 2001 were speculated to be individuals that dispersed from a known population in the Huron River, Lake Erie, and gained access to Lake St. Clair through the Detroit River (Goodchild 1993; COSEWIC 2008). The juvenile Flathead Catfish captured in our study would not likely be able to disperse from a Lake Erie tributary upstream through the strong-flowing Detroit River, providing further support for the likelihood that these individuals were the result of reproduction in the Thames River. Few studies have examined the movement of juvenile Flathead Catfish. Travnichek (2004) found a relationship between Flathead Catfish size and movement in the Missouri River: as size increased so did distance travelled. In their study, Flathead Catfish that were 305–380 mm TL travelled an average of 4.6 km in up to two years after tagging (Travnichek 2004). Stocking is an unlikely alternative method of introduction of the individuals captured here, as there is no documented stocking of Flathead Catfish in Ontario and, in the United States, Flathead Catfish are most often stocked as adults (Guier *et al.* 1981; Jenkins and Burkhead 1994). Introduction through the live fish trade is also unlikely, as there is no record that live Flathead Catfish have been imported into Canada (Mandrak *et al.* 2014) and surveys of six live fish markets and 20 pet stores in the Great Lakes region did not report Flathead Catfish (Rixon *et al.* 2005).

Flathead Catfish may be more abundant in the Canadian waters of the Great Lakes basin than currently known, and its range is likely not fully documented because of its cryptic behaviour and difficulty to sample (Goodchild 1993; Fuller and Whelan 2018). Continued Asian carp surveillance will further document the Flathead Catfish population in the Thames River. This work is also being conducted in 35 other locations in the Great Lakes basin and may provide information on new locations of Flathead Catfish populations.

The potential impacts of Flathead Catfish in the Great Lakes basin are unknown and should be further investigated to determine how this species should be managed. Pine *et al.* (2005) found that Flathead Catfish is primarily piscivorous, feeding on the most abundant fishes in rivers, which could lead to a change in local food-web structures. The presence and increased abundance of Flathead Catfish has been associated with decreases in the abundance of sunfishes (*Lepomis* spp.; Davis 1985; Thomas 1993; Bart *et al.* 1994; Ashley and Rachels 1998; Bonvechio *et al.* 2009), black basses (*Micropterus* spp.; Thomas

1993; Bonvechio *et al*. 2009), redhorses (*Moxostoma* spp.; Bart *et al*. 1994), Common Carp (*Cyprinus carpio*; Davis 1985; Bart *et al*. 1994), and bullheads (*Ameiurus* spp.; Davis 1985). Flathead Catfish may have some ecological benefits in the Great Lakes basin, as a predator of the invasive Common Carp and as a known host for Mapleleaf mussel (*Quadrula quadrula*; Howard and Anson 1922), which has been listed as special concern under the Canadian *Species at Risk Act* (SARA Registry 2019). The Thames River is thought to have the largest population of Mapleleaf in southwestern Ontario, and recent records of Flathead Catfish overlap with records of Mapleleaf from the lower Thames River in 2005 (COSEWIC 2016). Flathead Catfish has seasonally varying home ranges and movement patterns (Daugherty and Sutton 2005a), which are important characteristics of hosts that facilitate the genetic mixture of freshwater mussel populations in rivers (Elderkin *et al.* 2007).

The distribution of freshwater fishes is often restricted by temperature. Mandrak (1989) determined that Flathead Catfish had low potential for future expansion into the Great Lakes basin because of thermal restrictions. With climate change, the water temperature of the Great Lakes is expected to increase 2–3°C in southern Ontario and 3–4°C in northern Ontario by 2065 (Gula and Peltier 2012). Such an increase will benefit warm-water species, such as Flathead Catfish, by increasing recruitment success (Casselman 2002; Chu *et al*. 2005; Hansen *et al.* 2017). This increase in recruitment has the potential to expand the range of Flathead Catfish and lead to a greater abundance of the species in the Great Lakes basin (Casselman 2002).

Our research suggests that a better understanding of the potential ecological impacts and improved distribution modelling of Flathead Catfish in Canada is required. With climate change, many species are likely to undergo range expansions, bringing new threats to already imperilled native species. With limited resources, managers must balance this with the threats of new (or existing) invasive species that have a greater potential for damage (Rahel and Olden 2008; Rolls *et al.* 2017). In Canada, there is a need for clear management objectives for these species undergoing natural "invasions", that include consistent classification and terminology and a framework to prioritize them (Chu *et al.* 2005; Rahel and Olden 2008).

The capture of Flathead Catfish representing at least five age classes, including young-of-year fish, is a strong indication that reproduction has occurred in the lower Thames River. With the recent captures reported here, there may now be sufficient data for Flathead Catfish to be re-assessed by COSEWIC. Additional research targetting Flathead Catfish is recommended to (i) better understand the distribution of this species in Canada, (ii) evaluate the most effective gear for detection, (iii) estimate abundance, and (iv) understand the movement and habitat-use patterns in the Canadian waters of the Great Lakes basin.

Author Contributions

Writing – Original Draft: C.I. and J.E.C.; Writing – Review & Editing: C.I., J.E.C., N.E.M., and D.M.M.; Methodology: C.I., J.E.C., and D.M.M.; Visualization: C.I. and J.E.C.

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Literature Cited

Ashley, K.W., and R.T. Rachels. 1998. Changes in redbreast sunfish population characteristics in the Black and Lumber rivers, North Carolina. Pages 29–38 *in* Proceedings of the Fifty-second Annual Conference Southeastern Association of Fish and Wildlife Agencies. *Edited by* A.G. Eversole, K.C. Wong, and R.W. Luebke. Orlando, Florida, USA.

Bart, H.L., M.S. Taylor, J.T. Harbaugh, J.W. Evans, S.L. Schleiger, and W. Clark. 1994. New distribution records of Gulf Slope drainage fishes in the Ocmulgee River system, Georgia. Pages 4–9 *in* Southeastern Fishes Council Proceedings. *Edited by* M.M. Stevenson and G.R. Sedberry. Southeastern Fishes Council Inc., Charleston, South Carolina, USA.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press. Madison, Wisconsin, USA.

Bonvechio, T.F., D. Harrison, and B. Deener. 2009. Population changes of sportfish following flathead catfish introduction in the Satilla River, Georgia. Pages 133–139 *in* Proceedings of the Sixty-third Annual Conference Southeastern Association of Fish and Wildlife Agencies. *Edited by* A.G. Eversole, K.C. Wong, and B. Davin. Atlanta, Georgia, USA.

Casselman, J.M. 2002. Effects of temperature, global extremes, and climate change on year-class production of warmwater, coolwater, and coldwater fishes in the Great Lakes Basin. Pages 39–60 *in* Fisheries in a Changing

Climate. Symposium 32. *Edited by* N.A. McGinn. American Fisheries Society, Bethesda, Maryland, USA.

Chu, C., N.E. Mandrak, and C.K. Minns. 2005. Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. Diversity and Distributions 11: 299–310. https://doi.org/10.1111/j.1366-9516.2005.00153.x

Colm, J., D. Marson, and B. Cudmore. 2018. Results of Fisheries and Oceans Canada's 2016 Asian carp early detection field surveillance program. Canadian manuscript report 3147. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, Ontario, Canada.

Colm, J., D. Marson, and B. Cudmore. 2019a. Results of Fisheries and Oceans Canada's 2017 Asian carp early detection field surveillance program. Canadian manuscript report 3168. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, Ontario, Canada.

Colm, J., D. Marson, and B. Cudmore. 2019b. Results of Fisheries and Oceans Canada's 2018 Asian carp early detection field surveillance program. Canadian manuscript report 3168-1. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, Ontario, Canada.

Cooper, E.L. 1983. Fishes of Pennsylvania and the Northeastern United States. Pennsylvania State University Press, University Park, Pennsylvania, USA.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2008. Update COSEWIC Status Report on Flathead Catfish *Pylodictis olivaris*. COSEWIC, Ottawa, Ontario, Canada.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2016. COSEWIC assessment and status report on the Mapleleaf *Quadrula quadrula* (Great Lakes–Upper St. Lawrence population, Saskatchewan–Nelson Rivers population) in Canada. COSEWIC, Ottawa, Ontario, Canada.

Cross, F.B. 1967. Handbook of Fishes of Kansas. Museum of Natural History, University of Kansas, Lawrence, Kanas, USA.

Crossman, E.J., and J.H. Leach. 1979. First Canadian record of Flathead Catfish. Canadian Field-Naturalist 93: 179–180. Accessed 17 March 2020. https://www.biodiversitylibrary.org/page/28063496.

Cudmore, B., L.A. Jones, N.E. Mandrak, J.M. Dettmers, D.C. Chapman, C.S. Kolar, and G. Conover. 2017. Ecological risk assessment of Grass Carp (*Ctenopharyngodon idella*) for the Great Lakes basin. Canadian Science Advisory Secretariat Science Research Document 2016/118. Fisheries and Oceans Canada, Ottawa, Ontario, Canada.

Cudmore, B., C.A. MacKinnon, and S.E. Madzia. 2004. Aquatic species at risk in the Thames River watershed, Ontario. Fisheries and Oceans Canada, Burlington, Ontario, Canada. Accessed 15 May 2019. https://waves-vagues.dfo-mpo.gc.ca/Library/316802.pdf.

Daugherty, D.J., and T.M. Sutton. 2005a. Seasonal movement patterns, habitat use, and home range of flathead catfish in the Lower St. Joseph River, Michigan. North American Journal of Fisheries Management 25: 256–269. https://doi.org/10.1577/M03-252.2

Daugherty, D.J., and T.M. Sutton. 2005b. Population abundance and stock characteristics of flathead catfish in the lower St. Joseph River, Michigan. North American Journal of Fisheries Management 25: 1191–1201. https://doi.org/10.1577/M03-251.1

Davis, R.A. 1985. Evaluation of flathead catfish as a predator in a Minnesota lake. Investigational report 384. Division of Fish and Wildlife, Minnesota Department of Natural Resources, Saint Paul, Minnesota, USA. Accessed 5 March 2019. http://www.nativefishlab.net/library/textpdf/13980.pdf.

Elderkin, C.L., A.D. Christian, C.C. Vaughn, J.L. Metcalfe-Smith, and D.J. Berg. 2007. Population genetics of the freshwater mussel, *Amblema plicata* (Say 1817) (Bivalvia: Unionidae): evidence of high dispersal and post-glacial colonization. Conservation Genetics 8: 355–372. https://doi.org/10.1007/s10592-006-9175-0

Evermann, B.W. 1902. List of fishes known to occur in the Great Lakes or their connecting water. Bulletin of the United States Fish Commission 21: 95–96.

Fuller, P.L., and G.E. Whelan. 2018. The flathead catfish invasion of the Great Lakes. Journal of Great Lakes Research 44: 1081–1092. https://doi.org/10.1016/j.jglr.2018.07.001

Goodchild, A.C. 1993. Status of the Flathead Catfish, *Plyodictis olivaris*, in Canada. Canadian Field-Naturalist 107: 410–416. Accessed 17 March 2020. https://www.biodiversitylibrary.org/page/34810552.

Grussing, M.D., D.R. DeVries, and R.A. Wright. 1999. Stock characteristics and habitat use of catfishes in regulated sections of four Alabama rivers. Pages 15–34 *in* Proceedings of the Fifty-third Annual Conference Southeastern Association of Fish and Wildlife Agencies. *Edited by* A.G. Eversole, K.C. Wong, and P. Mazik. Baton Rouge, Louisiana, USA.

Guier, C.R., L.E. Nichols, and R.T. Rachels. 1981. Biological investigation of flathead catfish in the Cape Fear River. Pages 607–621 *in* Proceedings of the Thirty-fifth Annual Conference Southeastern Association of Fish and Wildlife Agencies. *Edited by* J. Sweeney and L. Nielsen. Tulsa, Oklahoma, USA.

Gula, J., and W.R. Peltier. 2012. Dynamic downscaling over the Great Lakes basin of North America using the WRF regional climate model: the impact of the Great Lakes system on regional greenhouse warming. Journal of Climate 25: 7723–7742. https://doi.org/10.1175/JCLI-D-11-00388.1

Hansen, G.J.A., J.S. Read, J.F. Hansen, and L.A. Winslow. 2017. Projected shifts in fish species dominance in Wisconsin lakes under climate change. Global Change Biology 23: 1463–1476. https://doi.org/10.1111/gcb.13462

Hesse, L.W. 1994. The status of Nebraska fishes in the Missouri River, flathead catfish, *Plydoictis olivaris*, and blue catfish, *Ictalurus furcatus* (Ictaluridae). Transactions of the Nebraska Academy of Sciences 21: 89–98.

Howard, A.D., and B.J. Anson. 1922. Phases in the parasitism of the Unionidae. Journal of Parasitology 9: 68–82. https://doi.org/10.2307/3271139

Jackson, D.C. 1999. Flathead catfish: biology, fisheries, and management. Pages 23–35 *in* Catfish 2000: Proceedings of the International Ictalurid Symposium. *Edited by* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon. American Fisheries Society, Bethesda, Maryland, USA.

Jenkins, R.E., and N.M. Burkhead. 1994. Freshwater Fishes of Virgina. American Fisheries Society. Bethesda, Maryland, USA.

Kwak, T.J., D.S. Waters, and W.E. Pine, III. 2006. Age, growth, and mortality of introduced flathead catfish in Atlantic Rivers and a review of other populations. North American Journal of Fisheries Management 26: 73–87. https://doi.org/10.1577/M04-144.1

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Raleigh, North Carolina, USA.

Lee, L.A., and J.W. Terrell. 1987. Habitat suitability index models: flathead catfish. Biological report 82(10, 152). United States Fish and Wildlife Service, National Ecology Research Center, Fort Collins, Colorado, USA.

Mandrak, N.E. 1989. Potential invasion of the Great Lakes by fish species associated with climatic warming. Journal of Great Lakes Research 15: 306–316. https://doi.org/10.1016/S0380-1330(89)71484-2

Mandrak, N.E., C. Gantz, L.A. Jones, D. Marson, and B. Cudmore. 2014. Evaluation of five freshwater fish screening-level risk assessment protocols and application to non-indigenous organisms in trade in Canada. Canadian Science Advisory Secretariat Research Document 2013/122. Fisheries and Oceans Canada, Burlington, Ontario, Canada.

Marson, D., J. Colm, and B. Cudmore. 2018. Results of Fisheries and Oceans Canada's 2015 Asian carp early detection field surveillance program. Canadian manuscript report 3146. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, Ontario, Canada.

Marson, D., E. Gertzen, and B. Cudmore. 2014. Results of the Burlington 2013 Asian carp early detection field monitoring program. Canadian manuscript report 3054. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, Ontario, Canada.

Marson, D., E. Gertzen, and B. Cudmore. 2016. Results of Fisheries and Oceans Canada's 2014 Asian carp early detection field surveillance program. Canadian manuscript report 3103. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Burlington, Ontario, Canada.

Mayhew, J.K. 1969. Age and growth of flathead catfish in the Des Moines River, Iowa. Transactions of the American Fisheries Society 98: 188–121. https://doi.org/10.1577/1548-8659(1969)98[118:AAGOFC]2.0.CO;2

Miller, R.R. 1957. Origin and dispersal of the Alewife, *Alsoa pseudoharengus*, and the Gizzard Shad, *Dorosoma cepedianum*, in the Great Lakes. Transactions of the American Fisheries Society 86: 97–111. https://doi.org/10.1577/1548-8659(1956)86[97:OADOTA]2.0.CO;2

Minckley, W.L., and J.E. Deacon. 1959. Biology of the Flathead Catfish in Kansas. Transactions of the American Fisheries Society 8: 344–355.

Page, L.M., and B.M. Burr. 2011. Peterson Field Guide to Freshwater Fishes. Second Edition. Houghton Mifflin, Boston, Massachusetts, USA.

Perry, W.G., and D.C. Carver. 1977. Length at maturity, total-collarbone length, and dressout for Flathead Catfish and length at maturity of Blue Catfish, southwest Louisiana. Pages 529–537 *in* Proceedings of the Thirty-first Annual Conference Southeastern Association of Fish and Wildlife Agencies. *Edited by* R.W. Dimmick and J.A. Grover. Knoxville, Tennessee, USA.

Pine, III, W.E., T.J. Kwak, D.S. Waters, and J.A. Rice. 2005. Diet selectivity of introduced Flathead Catfish in coastal rivers. Transactions of the American Fisheries Society 134: 901–909. https://doi.org/10.1577/T04-166.1

Rahel, F.J., and J.D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22: 521–533. https://doi.org/10.1111/j.1523-1739.2008.00950.x

Rixon, C.A.M., I.C. Duggan, N.M.N. Bergeron, A. Ricciardi, and H.J. Macisaac. 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. Biodiversity and Conservation 14: 1365–1381. https://doi.org/10.1007/s10531-004-9663-9

Rolls, R.J., B. Hayden, and K.K. Kahilainen. 2017. Conceptualising the interactive effects of climate change and biological invasions on subarctic freshwater fish. Ecology and Evolution 7: 4109–4128. https://doi.org/10.1002/ece3.2982

Roth, B.M., N.E. Mandrak, T.R. Hrabik, G.G. Sass, and J. Peters. 2012. Fishes and decapod crustaceans of the Great Lakes basin. Pages 105–135 *in* Great Lakes Policy and Management. Second Edition. *Edited by* W.W. Taylor and A. Lynch. Michigan State University Press, East Lansing, Michigan, USA.

Sakaris, P.C., E.R. Irwin, J.C. Jolley, and D. Harrison. 2006. Comparison of native and introduced flathead catfish populations in Alabama and Georgia: growth, mortality, and management. North American Journal of Fisheries Management 26: 867–874. https://doi.org/10.1577/M05-135.1

SARA (Species at Risk Act) Registry. 2019. Species profile, Mapleleaf. Government of Canada. Accessed 14 February 2020. https://species-registry.canada.ca/index-en.html#/species?keywords=Mapleleaf.

Scott, W.B., and E.J. Crossman. 1998. Freshwater Fishes of Canada. Revised Edition. Galt House Publishing, Oakville, Ontario, Canada.

Stauffer, K.W., R.C. Binder, B.C. Chapman, and B.D. Koenen. 1996. Population characteristics and sampling methods of flathead catfish *Plyodictis olivaris* in the Minnesota River: final report. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Saint Paul, Minnesota, USA.

Thomas, M.E. 1993. Monitoring the effects of introduced flathead catfish on sport fish populations in the Altamaha River, Georgia. Pages 531–538 *in* Proceedings of the Forty-seventh Annual Conference Southeastern Association of Fish and Wildlife Agencies. *Edited by* A.G. Eversole, K.C. Overacre, and M. Konikoff. Atlanta, Georgia, USA.

Trautman, M.B. 1957. The Fishes of Ohio with Illustrated Keys. Ohio State University Press, Columbus, Ohio, USA.

Trautman, M.B. 1981. The Fishes of Ohio with Illustrated Keys. Revised Edition. Ohio State University Press, Columbus, Ohio, USA.

Travnichek, V.H. 2004. Movement of flathead catfish in the Missouri River: examining opportunities for managing river segments for different fishery goals. Fisheries Management and Ecology 11: 89–96. https://doi.org/10.1046/j.1365-2400.2003.00377.x

Vokoun, J.C., and C.F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears, and methods. Pages 271–286 *in* Catfish 2000: Proceedings of the International Ictalurid Symposium. *Edited* by E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon. American Fisheries Society, Bethesda, Maryland, USA.

Young, K.L., and P.C. Marsh. 1990. Age and growth of flathead catfish in four southwestern rivers. California Fish and Game 76: 224–233.

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