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U.S. Geological Survey Tunison Laboratory of Aquatic Science Research to Rehabilitate Native Prey Fish of the Lake Ontario Fish Community—Coregonine Fishes

Scientific Investigations Report 2024–5094

U.S. Department of the Interior
U.S. Geological Survey

Cover. Cisco (*Coregonus artedi*) reared at the U.S. Geological Survey (USGS) Tunison Laboratory of Aquatic Science in Cortland, New York, and newly released into Keuka Lake, N.Y., October 18, 2018; nearest fish has surgery scar from acoustic tag implantation. Photograph by M. Chalupnicki, USGS.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
micrometer(μm)	$0.3937x10^{-5}$	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Abbreviations

ANFH	Allegheny National Fish Hatchery
FCS	Fish Culture Station
FWS	U.S. Fish and Wildlife Service
NEFC	Northeast Fishery Center
NYSDEC	New York State Department of Environmental Conservation
OMNRF	Ontario Ministry of Natural Resources and Forestry
OTC	Oxytetracycline
TLAS	Tunison Laboratory of Aquatic Science
USGS	U.S. Geological Survey
UV	ultraviolet
YC	fish year class

U.S. Geological Survey Tunison Laboratory of Aquatic Science Research to Rehabilitate Native Prey Fish of the Lake Ontario Fish Community—Coregonine Fishes

James E. McKenna, Jr.,[1] James H. Johnson,[1] Steven Lapan,[2] Marc Chalupnicki,[1] Gregg Mackey,[1] Mike Millard,[3] Kevin Loftus,[4] Michael Connerton,[2] Christopher Legard,[2] Brian Weidel,[1] Dimitry Gorsky[3]

Abstract

Restoration of native coregonines to Lake Ontario of the Laurentian Great Lakes will improve the diversity of forage for salmonid predators and ecological function in the lake, but efficacy of experimental releases for native species restoration must be evaluated. The Coregonine Research Program at the U.S. Geological Survey Tunison Laboratory of Aquatic Science encompasses a diverse array of research, with an emphasis on improved culture methods and field assessments of experimentally released juvenile coregonines. This research is carried out to support the Fish Community Objectives of the Lake Ontario Committee, is funded largely by the Great Lakes Restoration Initiative, and is done in collaboration with other laboratories and agencies, particularly, the U.S. Fish and Wildlife Service; New York State Department of Environmental Conservation; Ontario Ministry of Natural Resources and Forestry; and other U.S. Geological Survey laboratories. The Tunison Laboratory of Aquatic Science and partners have developed new and innovative hatchery techniques to raise cisco and bloater to life stages suitable for survival in Lake Ontario; assessed adult bloater survival in Lake Ontario; and evaluated survival, return rate, and reproduction of adult cisco in historic spawning locations in Lake Ontario embayments. Successes, challenges, and research needs are discussed.

Introduction

Loss of native fishes from North America's Lake Ontario (fig. 1) has been caused largely by anthropogenic changes to habitat conditions, harvest, and the biotic environment (for example, invasive species; Mills and others, 2003). Historically, *Coregonus artedi* (cisco), *C. clupeaformis* (lake whitefish), *C. kiyi* (kiyi), *C. hoyi* (bloater), and other deepwater coregonine species were the primary forage species for predatory fish in Lake Ontario and the basis of large fisheries, with millions of fish harvested annually (Van Oosten, 1930; Eshenroder and others, 2016). All coregonine species—except cisco, lake whitefish, and *Prosopium cylindraceum* (round whitefish)—were extirpated from Lake Ontario during the past century, and the remaining species are severely depleted (Bronte and others, 2017; Stewart and others, 2017).

Conservation Hatchery

Managers may choose from two basic options for conservation or restoration of a population or community: (1) alter habitat (typically repair) or (2) manipulate the number of individuals of a species or population through harvest (removing individuals) and (or) stocking (adding individuals). Hatcheries are a critical tool for adding individuals to a population and have most often been focused on supplementing fish to directly support fisheries (Baillie and others, 2015; Trushenski and others, 2018). However, hatcheries are becoming vital tools for restoration, and research conservation hatcheries are key facilities for understanding the culture and release methods that are most effective for conservation and restoration of native fish populations (Lochmann, 2019). The U.S. Geological Survey (USGS) Great Lakes Science Center's Tunison Laboratory of Aquatic Science (TLAS) is a research facility capable of rearing sufficiently large numbers of fish to support the field experimentation needed to determine the effectiveness of fish population manipulation efforts to restore extirpated and depleted native species. The TLAS research is the focus of this report but succeeds as a collaborative effort with several other facilities and agencies (Ontario Ministry of Natural Resources and Forestry [OMNRF] White Lake Fish Culture Station [FCS], U.S. Fish and Wildlife Service [FWS] Allegheny National Fish Hatchery [ANFH], FWS Northeast Fishery Center [NEFC], not shown in figure 1).

[1]U.S. Geological Survey.

[2]New York State Department of Environmental Conservation.

[3]U.S. Fish and Wildlife Service.

[4]Ontario Ministry of Natural Resources and Forestry.

The Coregonine Research Program at TLAS includes a diverse array of research projects. An emphasis of the program is improved production and field assessments of juvenile bloater and cisco released experimentally to support restoration in Lake Ontario. Re-establishing and (or) rehabilitating coregonine populations as components of the Lake Ontario fish community is a high priority for United States and Canadian fisheries management agencies, and TLAS research is carried out in part to support fish community objectives of the Lake Ontario Committee (Stewart and others, 2017). This research is part of a broader effort throughout the Great Lakes to restore or conserve native coregonine fishes. The TLAS research program is conducted in collaboration with scientists from other laboratories and agencies, particularly the NEFC and FWS Lower Great Lakes Fish and Wildlife Resources Office; the USGS Lake Ontario Biological Station; the New York State Department of Environmental Conservation (NYSDEC) Lake Ontario Unit, regional offices, and hatchery system; and the OMNRF Glenora Station and White Lake FCS. Funding for this research is largely provided by the Great Lakes Restoration Initiative. Coregonine restoration research has been a major focus of the TLAS program for most of the last decade and is designed to determine the success of restoration methods. The feasibility of re-establishing bloater and cisco populations in Lake Ontario is being tested with notable successes discussed herein, including the first successful rearing of bloater; successful releases of these two native species into Lake Ontario; and collections of returning adults or surviving juveniles. We discuss culture and release methods, post release field evaluations of experimental fish, and additional research needs. A brief history of the program is provided, with an emphasis on our results for the last 2 years (2019–20).

Methods

Fish culture and other methods used to conduct research on native coregonine restoration at TLAS are described below.

Study Area and Conservation Hatchery

Lake Ontario is a deep Great Lake and losses of native species have left the deep waters depleted of fish life (Bronte and others, 2017; Stewart and others, 2017). Also, overharvest and other factors have left coastal Lake Ontario embayments that historically supported large spawning populations of cisco without native coregonines. Cisco collection sites and Lake Ontario cisco and bloater release sites are about 120 kilometers (km) from Cortland, New York, where the TLAS facility is located (fig. 1). The TLAS facility can rear tens of thousands of fish for experimental research and has an ultraviolet (UV) treatment facility constructed in 2012, which treats effluent and protects the local drainage basin from possible exposure to fish diseases. Most water in this flowthrough system is provided to a variety of tanks and raceways by wells and maintains a constant temperature of approximately (~) 9 °Celsius (°C) year-round. Oxygen and other dissolved gases are monitored, and additional oxygen can be added as needed.

Annual Cycle of Rearing, Release, and Evaluation—Bloater

Bloater restoration in Lake Ontario is a collaborative multiagency research project with close coordination among the NYSDEC, FWS, OMNRF, and USGS. The annual cycles of fish production, release, and evaluation include egg collection; care from spawn through development, hatch, and juvenile growth; experimental release; and field evaluation of surviving juveniles, returning adults, and wild production of eggs and larvae. There are two sources of bloater eggs for the Lake Ontario restoration project. The first is from wild bloater collected from Lake Michigan at spawning time by the FWS Jordan River National Fish Hatchery in Elmira, Michigan. The other (and presently the primary) egg source is from the bloater brood stock derived from those wild collections and maintained at the OMNRF White Lake FCS, Sharbot Lake, Ontario (and a few other Canadian hatcheries).

Fish are cared for using standard hatchery practices (Piper and others, 1982; Wedemeyer, 2002); a specific methods and procedures manual for coregonine culture was recently completed (Chalupnicki and others, 2024). Eggs are cared for at White Lake until eye up (that is, when the embryo has developed eyes that are visible though the chorion [eggshell]). Some eyed eggs are transferred to TLAS and some to other facilities (for example, NEFC or ANFH, Warren, Pennsylvania). Disease-free certification (provided by NEFC or NYSDEC) is required for care and release of bloater from wild stock or for bloater eggs transferred across the international border. Skilled fish culture staff at TLAS monitor bloater egg development weekly and standard fungal treatments are administered three times per week until hatch. Feed is provided in quantities that maximize growth for the water temperature and water volume and flow rate in each tank. Fish growth and survival are measured biweekly from hatch to stocking. A systemic mark is used to color the bones and identify the cohort source. Marking has involved single or double marks with oxytetracycline (OTC) or calcein administered either in feed (OTC) or via an immersion bath (calcein) at 2 months post-hatch (and 3 months for a double mark; table 1); a single mark is standard for bloater. At release, bloater fingerlings range from 75 millimeters (mm; 3 grams [g]) to 105 mm (8.5 g) and yearlings range from 97 mm (11.0 g) to 121 mm (13.0 g), depending on the temperature at which they were reared. Bloater have been consistently released offshore into deep waters of Lake Ontario (2012–20 and continuing) either from a haul tank on a research vessel (that is, USGS R/V *Kaho*) or from a stocking truck on a landing craft. Bloater fingerling stocking has

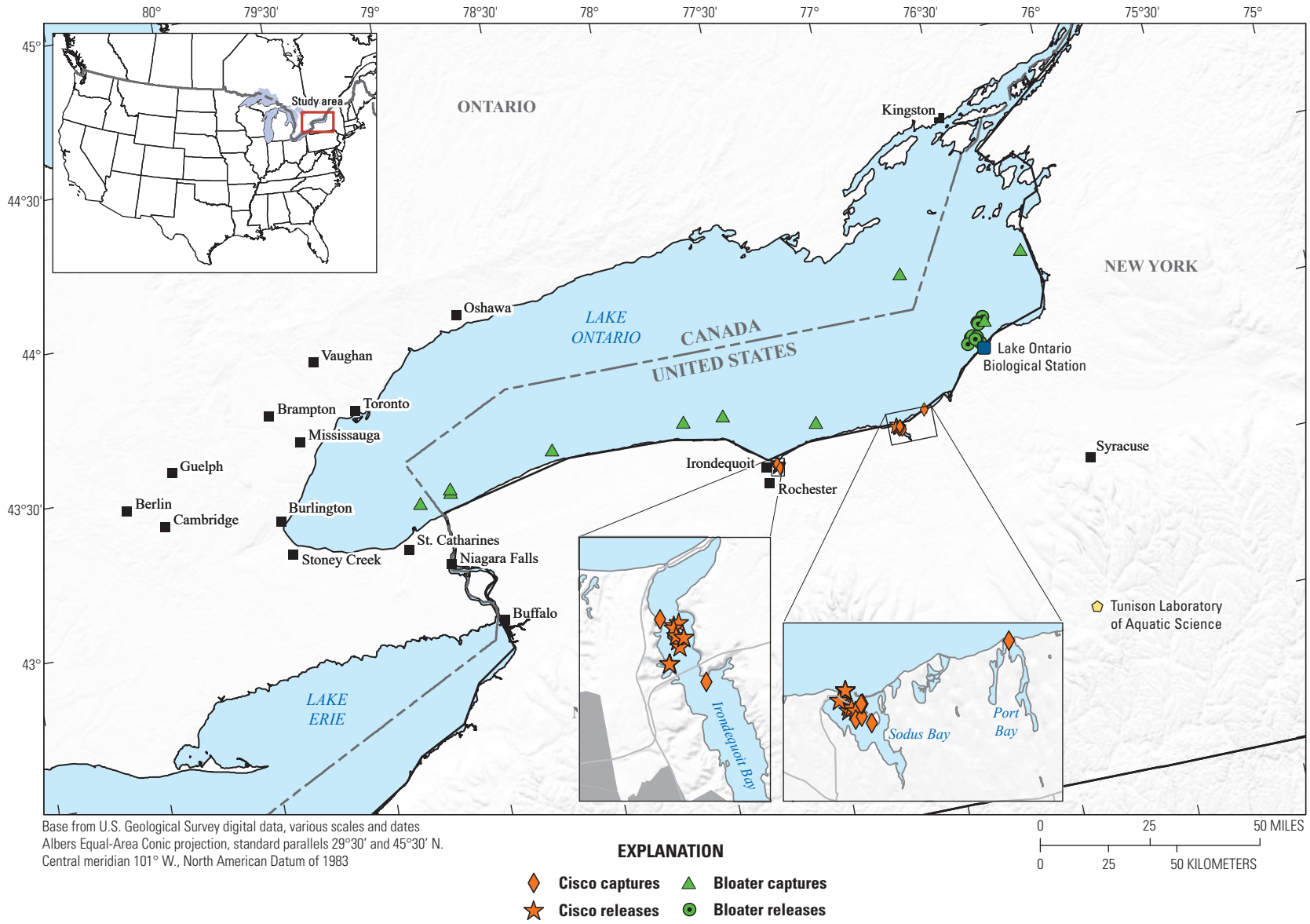


Figure 1. Map of experimental release locations and recapture sites for cisco (*Coregonus artedi*) and bloater (*Coregonus hoyi*) in Lake Ontario and its embayments. An additional bloater captured by Ontario Ministry of Natural Resources and Forestry trawls off Rocky Point is not shown.

usually been early in November and bloater yearling stocking is in mid-May. Recapture of released fish has been done using bottom trawls during annual USGS–NYSDEC–OMNRF fish surveys (Weidel and others, 2022).

Annual Cycle of Rearing, Release, and Evaluation—Cisco

Cisco restoration in Lake Ontario embayments that historically supported large spawning aggregations has been a collaborative multiagency research project with close coordination among field crews and spawning teams from the NYSDEC, FWS, and USGS. In late November, adult cisco are collected from Johnson, Middle, and Herrick Shoals in Chaumont Bay, Lake Ontario using Oneida-style trap nets (a box trap net with long wings projecting laterally from the mouth and a conical codend) soaked for 24 hours (hr). These adults are transported via an insulated and aerated haul tank on a truck to TLAS where eggs are spawned manually, usually within 24 hr. Tissue samples from spawned fish are sent to NEFC for disease screening. Eggs and fish are reared using standard hatchery practices like those applied to bloater culture. Eggs are cared for at TLAS until the eyed stage and disease-free certification is acquired. Some eyed eggs are then transferred to other facilities, such as NEFC or NYSDEC hatcheries. Cisco egg development is monitored weekly and standard fungal treatments are administered three times per week until hatch. Feed is provided in quantities that maximize growth for the water temperature and water volume and flow rate in each tank to produce fish most likely to survive well after release into the wild. Fish growth and survival are measured biweekly from hatch to stocking. Also, a systemic mark is used on cisco to color the bones and identify the cohort source and release site. Marking has involved single or double marks with OTC or calcein administered either in feed (OTC) or via an immersion bath (calcein) at 2 months post-hatch (and 3 months for a double mark; table 2). At release, cisco fingerlings range from 87 mm (4.4 g) to 133 mm (17.5 g) depending on the temperature at which they were reared.

Table 1. Bloater (*Coregonus hoyi*) eggs spawned, hatch rate, and juveniles released by United States facilities and those recaptured from Lake Ontario. The spawn year or stocking year of recaptured fish has not been determined; numbers are total collected within the year indicated in the release year column.

[--, not applicable data; OTC, oxytetracycline; OTC TM200, OTC-laced feed made by BioOregon; OTC TM400 ppm, OTC-laced feed made by BioOregon; calcein 5,000 ppm, calcein immersion at a concentration of 5,000 parts per million; WL, eggs from White Lake Fish Culture Station, Sharbot Lake, Ontario, Canada; ppm, parts per million]

Spawn year	Eggs spawned	Release year	Spring release	Fall release	Fish recaptured	Hatch (percent)	Mark
2012	32,784	2012	--	1,211	0	47	OTC TM200
2013	69,584	2013	--	7,241	0	48	OTC TM400 ppm
2014	97,716	2014	--	19,663	0	46	calcein 5,000 ppm[a]
2015	326,950	2015	--	62,584	1	73	calcein 5,000 ppm[b]
2016	616,832	2016	--	149,250	0	51	calcein 5,000 ppm[b]
2017	324,652	2017	--	97,368	1	75	calcein 5,000 ppm
2017–18	269,089[c]	2018	18,632[d]	103,396	4	43 (WL), 81 (wild)	calcein 5,000 ppm
2018	229,055	2019	17,295	--	3	20	calcein 5,000 ppm
2019	721,547[e]	2020	11,153	--	--[f]	55	calcein 5,000 ppm

[a]OTC at 600 ppm was applied first but failed create a persistent mark.

[b]Alizarin Red S 5,000 ppm was applied first but failed to create a persistent mark.

[c]Of these eggs, 19,296 were wild eggs.

[d]Yearlings released in 2018 were from the 2017-year class, while fall fingerlings were from the 2018-year class; 3,988 of fingerlings were from wild eggs

[e]171,738 were wild eggs; 316,705 were green White Lake eggs; and 233,104 were eyed White Lake eggs.

[f]The COVID–19 pandemic limited deepwater surveys that might have recaptured more bloater in 2020.

Table 2. Cisco (*Coregonus artedi*) eggs spawned, hatch rate, and juveniles released and those recaptured from Lake Ontario. The spawn year or stocking year of recaptured fish has not been determined; those numbers are simply the total collected within the year indicated in the release year column.

[--, missing or not applicable data; OTC, oxytetracycline; OTC TM200, OTC-laced feed made by BioOregon; OTC 400 ppm, OTC-laced feed made by BioOregon; calcein 5000 ppm, calcein immersion at a concentration of 5,000 parts per million; calcein Double 5,000 ppm, calcein immersion at a concentration of 5,000 ppm twice, 1 month apart to create a double mark; OTC Double, feed made by BioOregon with OTC mixed in, fish fed regiment twice (1 month apart) to create a double mark; ppm, parts per million]

Spawn year	Adults spawned	Eggs spawned	Release year	Irondequoit Bay	Sodus Bay	Fish recaptured	Hatch (percent)	Mark
2011	22	100,530	2012	9,968	--	--	45	OTC TM200
2012	28	198,356	2013	8,937	--	0	21	OTC TM400 ppm
2013	61	308,513	2014	144,973	--	0	54	calcein 5,000 ppm[a]
2014	35	209,207	2015	91,723	--	0	77	calcein 5,000 ppm[a]
2015	99	429,161	2016	--	22,575	1	51	calcein 5,000 ppm
2016	245	723,251	2017	--	408,783	4	68	calcein 5,000 ppm
2017	389	972,770	2018	241,694	278,980	0	70	calcein 5,000 ppm
2018	209	540,595	2019	--	384,906	4	92	calcein Double 5,000 ppm
2019	209	752,144	2020	--	239,244	7	85	OTC Double
2020	38	103,800	2021	--	--	--	--	--

[a]OTC at 600 ppm was applied first but failed to create a persistent mark.

Cisco were released into target embayments (specifically Irondequoit Bay or Sodus Bay) from 2011 to 2020 from either a stocking boat (operated by NYSDEC) or from shore directly out of the stocking truck (provided by either FWS or NYSDEC). Cisco fingerlings were stocked in late October or early November. However, because of limited capacity, summer releases have also happened in early July when fish were about 68 mm (2 g). Recapture of released fish and returning adults was done using trap nets or gillnets deployed in the experimental embayments; as many as an additional five cisco annually have been caught and photographed by anglers in the past three years. Egg and larval collections were done annually within the experimental embayments (Sodus Bay and Irondequoit Bay) to detect any wild reproduction from 2015 to the present; collections were expanded to reference sites (Port Bay and Little Sodus Bay) in 2018 and continue to the present. Egg blocks were deployed in December in randomly selected locations on presumed-appropriate habitat (based on the presence of relatively clean, gravel-cobble substrate). Ichthyoplankton tows were used in late April to sample larvae that may have been near the surface after the estimated hatch date (mid-April). A multi-agency effort sampled larval coregonines from numerous Lake Ontario embayments in spring of 2018, including Irondequoit Bay, Sodus Bay, Port Bay, Little Sodus Bay, Chaumont Bay, Henderson Bay (fig. 2), and Sandy Pond. The TLAS focused on Chaumont Bay (continuing a 17-year index sampling survey [2016 and 2017 missing]) with additional sampling in Little Sodus Bay, Port Bay, Sodus Bay, and Irondequoit Bay (the latter two being the experimental cisco release sites). Each year, larvae were sampled during a week in late April to early May. Seven to 20 sites were sampled within each bay using paired 1.0-meter (m) diameter x 3-m cone length ichthyoplankton nets with 500-micrometer (µm) mesh. Each net haul was at the surface for 5 minutes at 1,000 revolutions per minute (rpm) and distance travelled was recorded by global positioning system track (McKenna and Johnson, 2009; fig. 2). Contents from both nets were transferred to the same jar and preserved in 90 percent ethanol. Samples were then processed at TLAS.

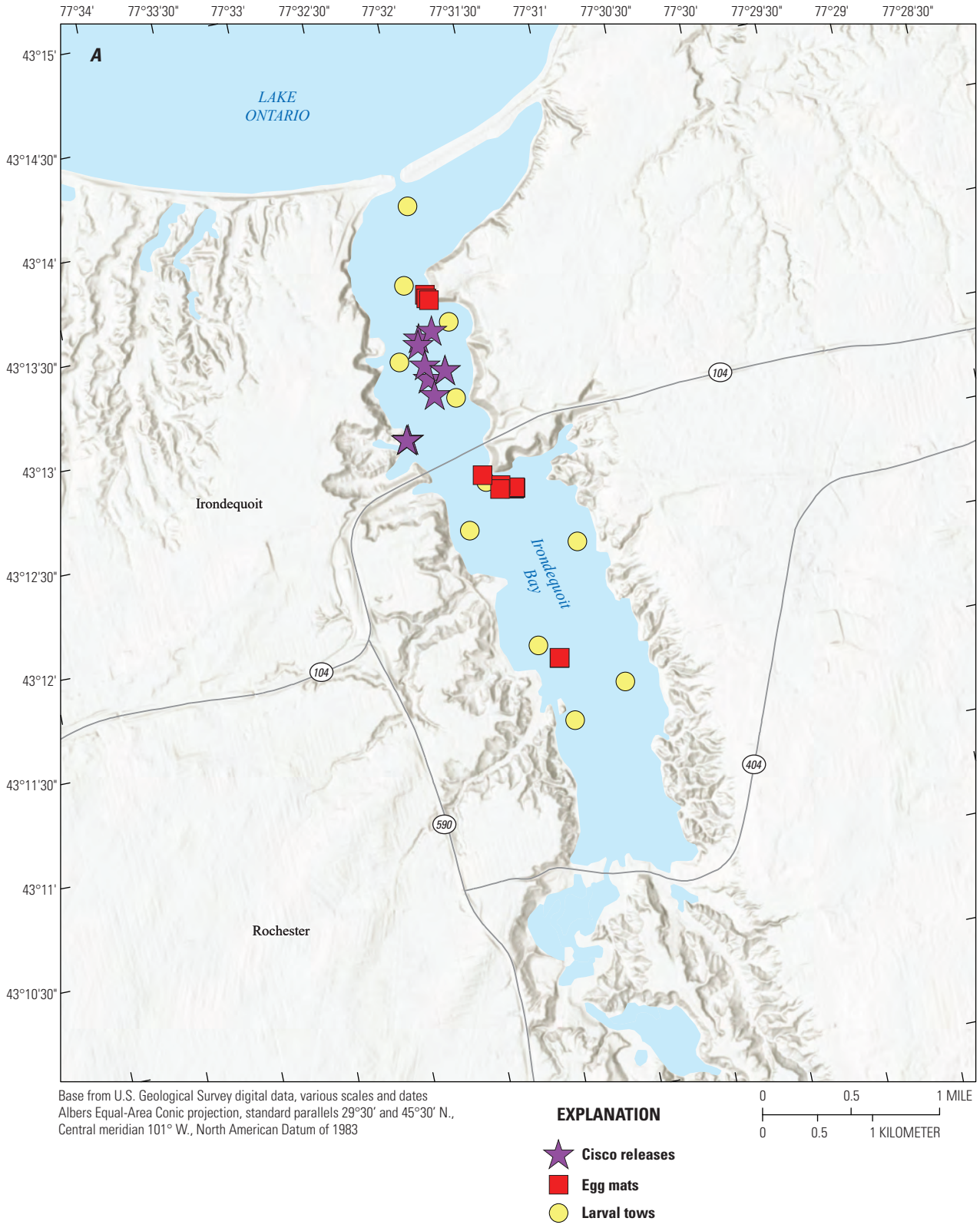
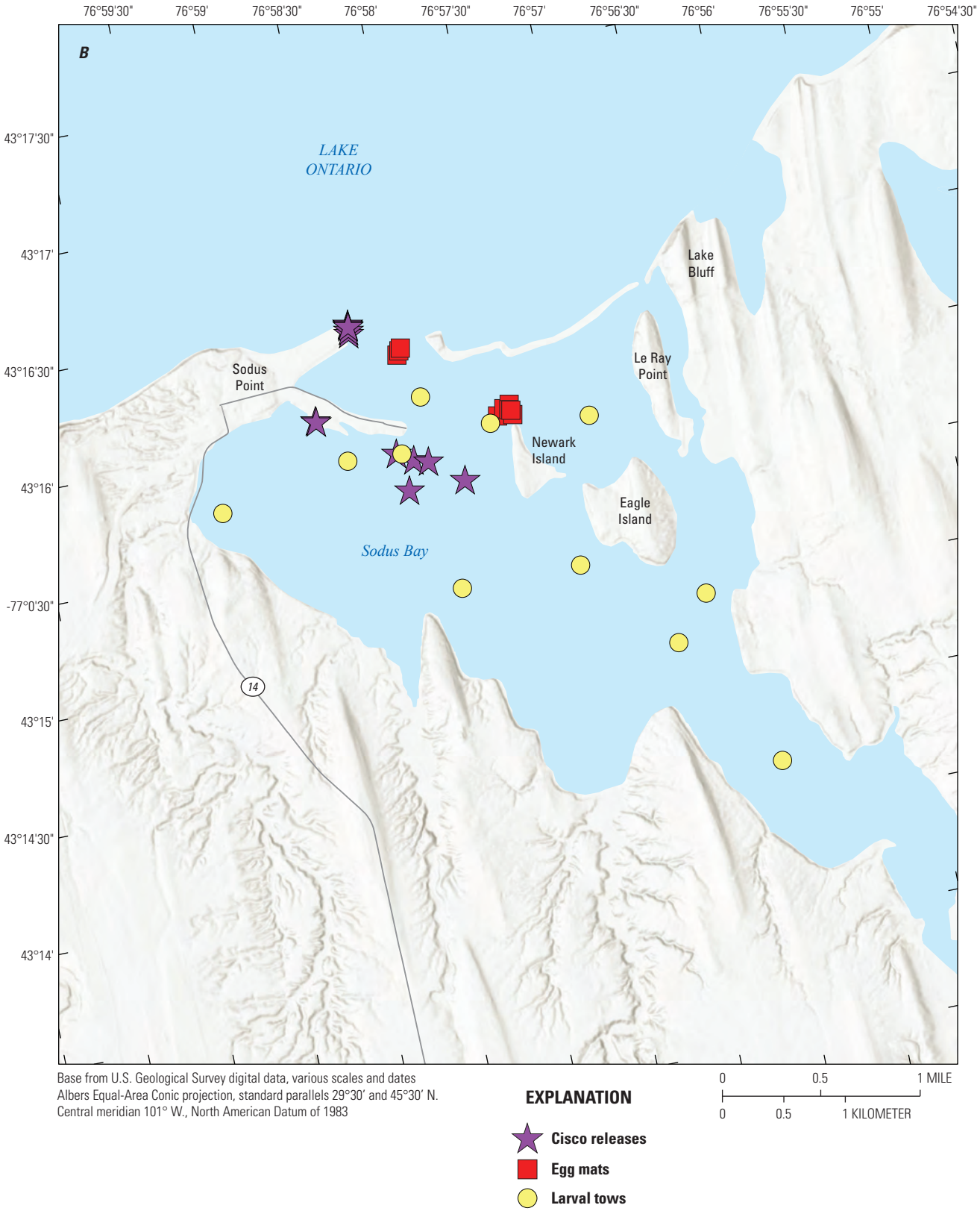


Figure 2. Cisco (*Coregonus artedi*) release sites (purple stars), and sampling locations for egg mats (yellow circles) and larval ichthyoplankton tows (red squares) within Lake Ontario embayments. *A,* Irondequoit Bay. *B*, Sodus Bay. *C,* Port Bay. *D,* Little Sodus Bay. *E,* Chaumont Bay. *F,* Henderson Bay. Coregonine egg collection in Little Sodus Bay is denoted by a four-point star.



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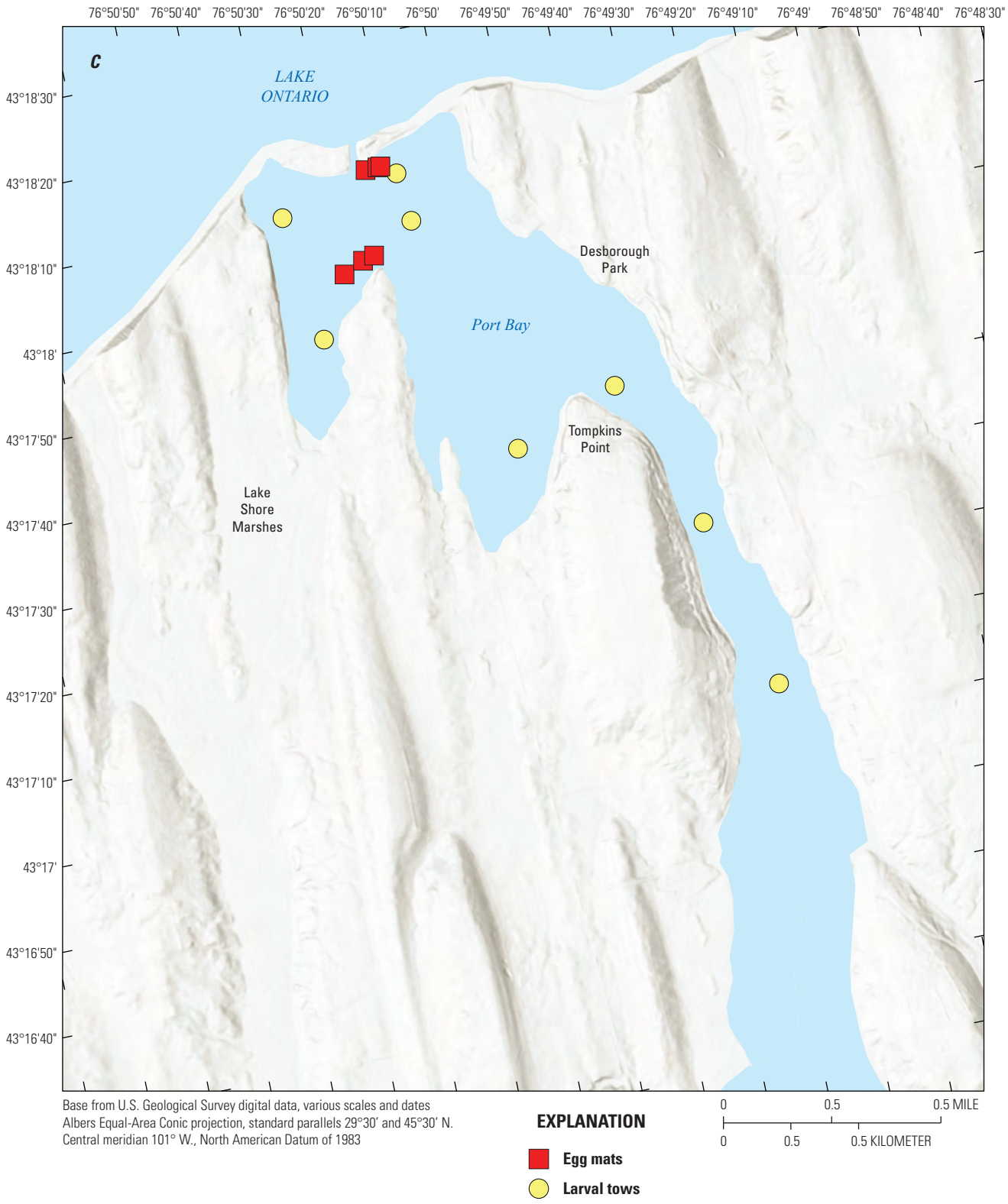

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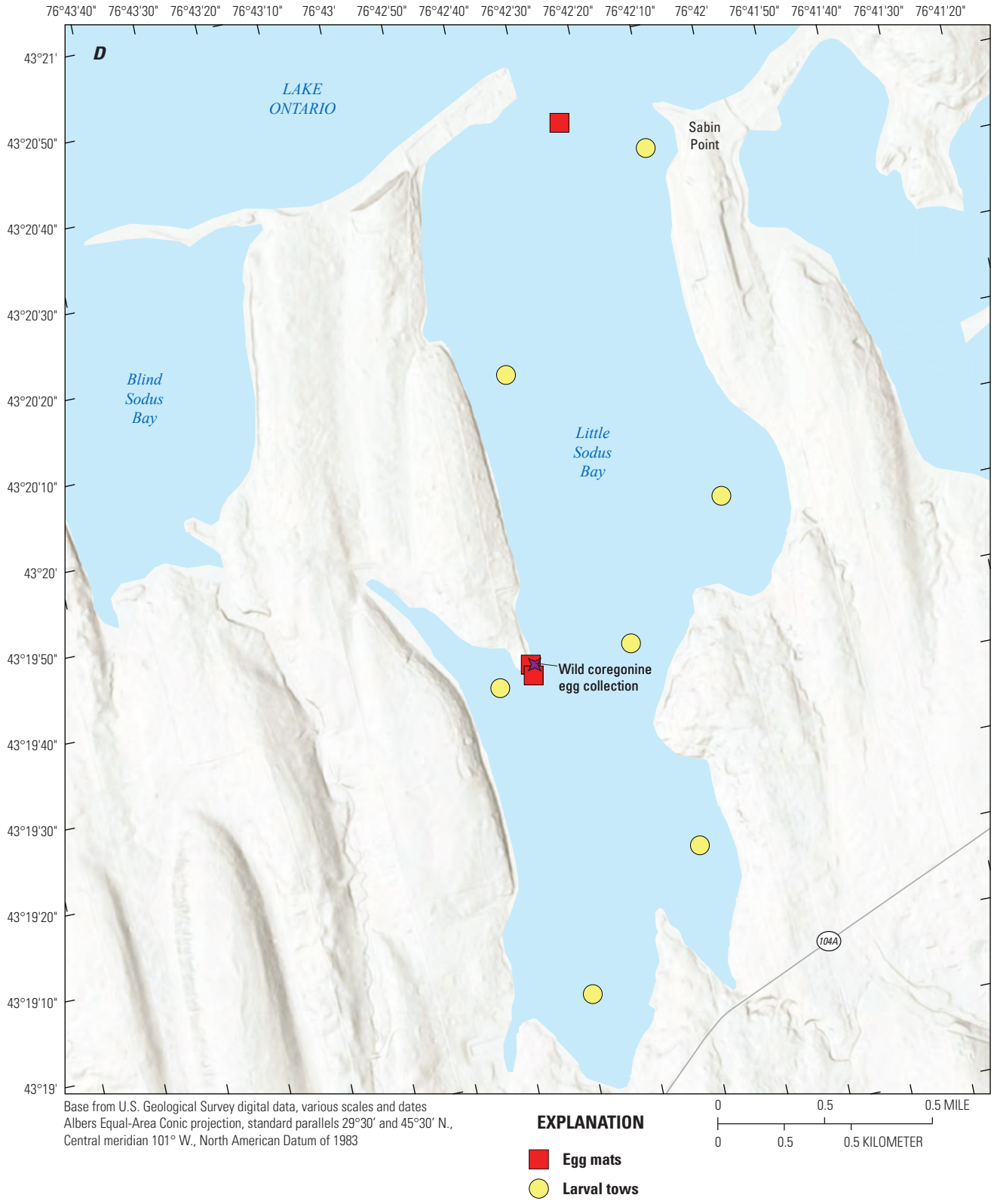

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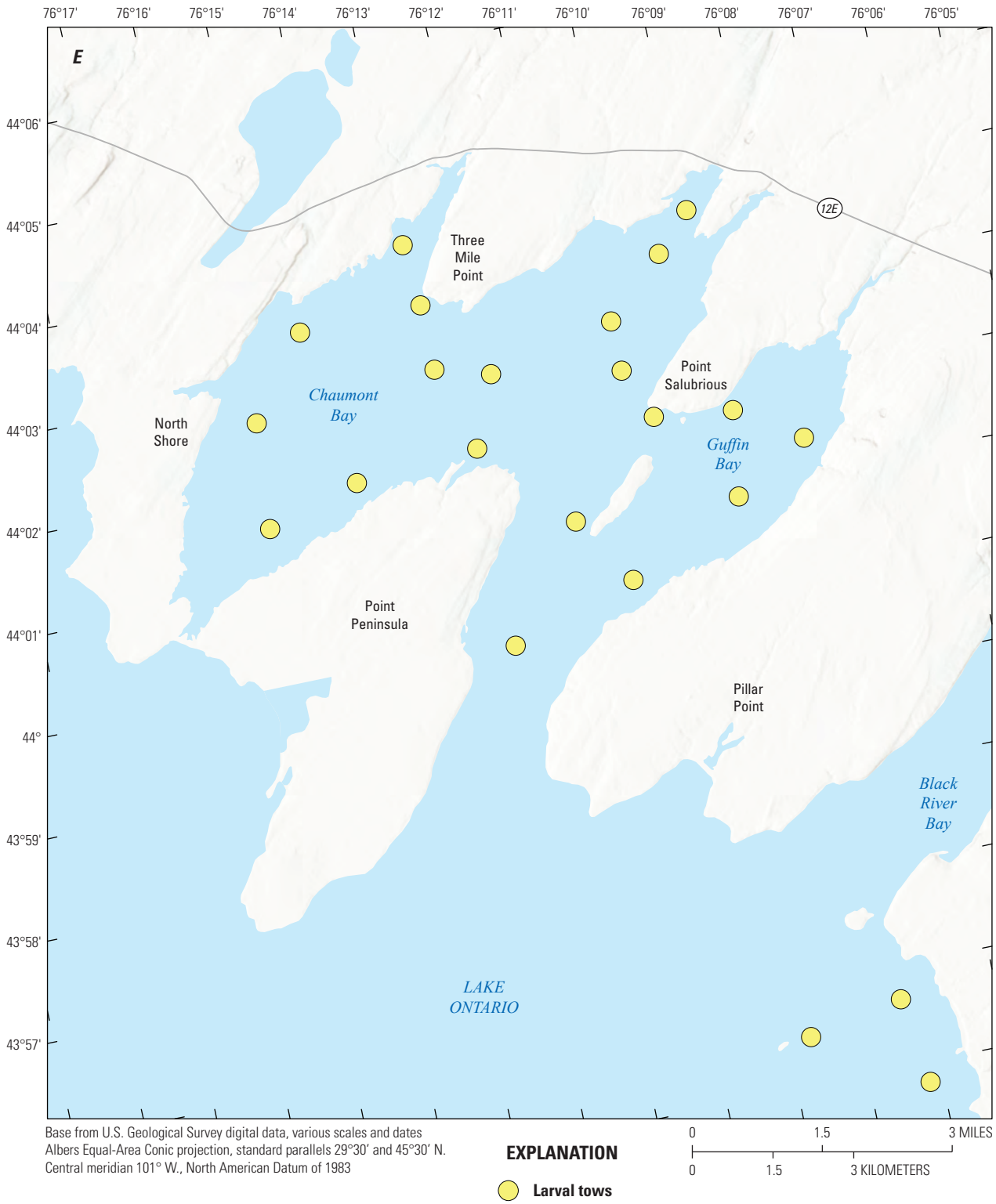

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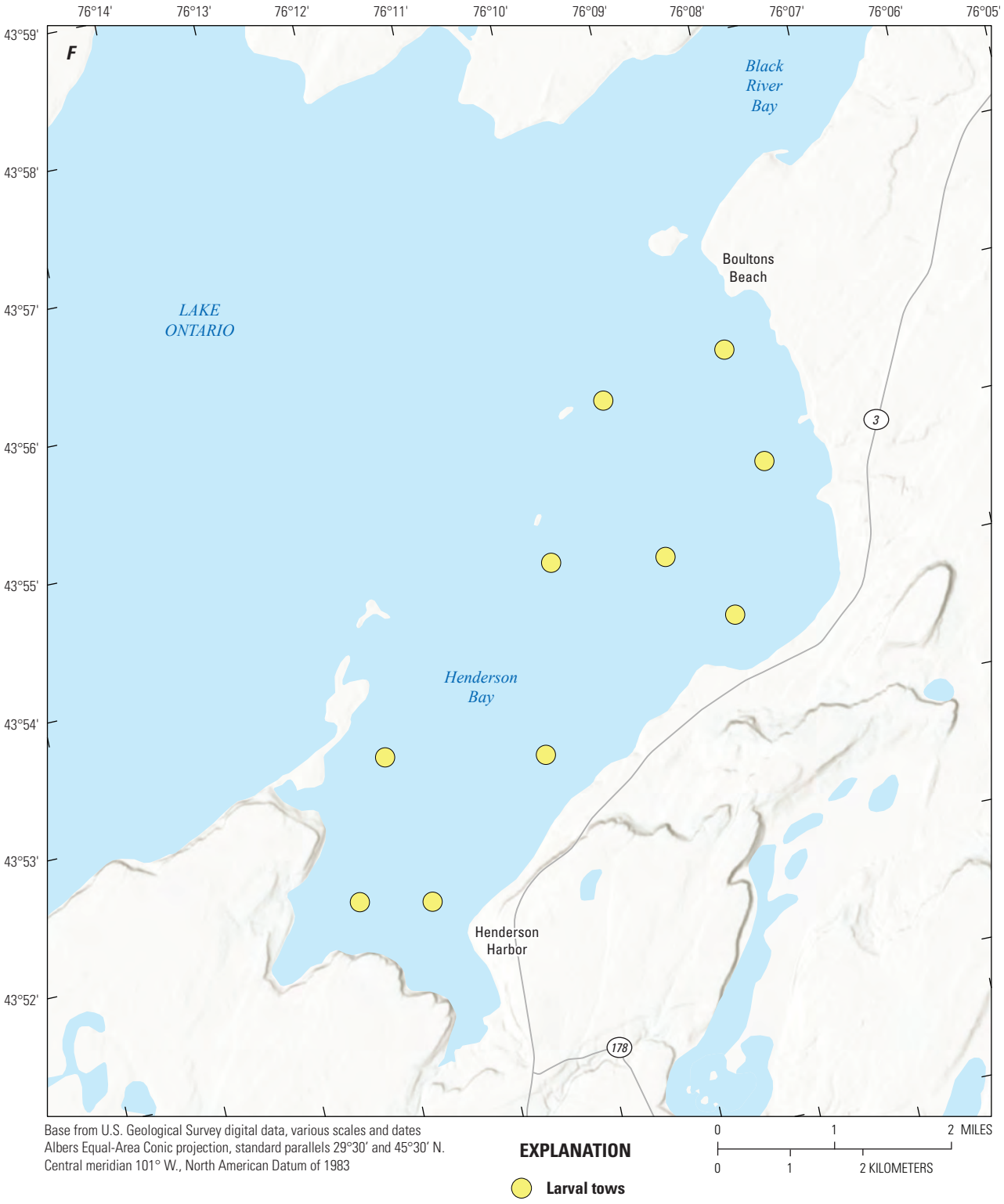

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Results

Cultured Production and Experimental Releases—Bloater

Bloater egg production was from the wild Lake Michigan source from 2012 until 2018, producing as much as ~600,000 eggs. However, few wild eggs were collected in 2018 (~19,000; table 1). An additional collection happened in 2020 and consisted of ~72,000 eggs reared for Lake Ontario (fig. 3). Egg production from the OMNRF White Lake Hatchery brood stock began in 2018 and continues to the present; distribution to United States facilities (TLAS, NEFC, and FWS ANFH) has ranged from ~250,000 to nearly 700,000 eggs annually. Hatch rates for eggs from wild fish have been higher than that of brood stock eggs, but bloater egg quality from both sources was generally poor in 2020. Of the 171,738 wild green eggs received by TLAS (lot 1: 86,778; lot 2: 42,480) from the FWS Jordan River National Fish Hatchery in 2020, only 70 percent (120,217) survived to the eyed stage. The NEFC received 108,139 of these eyed eggs for experimental rearing. The remaining 12,078 were raised at TLAS. TLAS also received two shipments of eggs from the OMNRF brood stock cohort in 2020: 316,705 as green eggs (2013 year class (YC): 25,750; 2014 YC: 290,955) and 233,104 as eyed eggs (2013 YC: 74,740; 2014 YC: 158,364). After 431 temperature units (daily thermal units), ~174,187 and 128,207 of those eggs (~55 percent) hatched, respectively (table 1). A directed experiment was completed in 2023 to investigate a possible nutritional deficiency in the cultured brood stock that may be related to egg quality (Sweka and others, 2024).

At TLAS, fry and juvenile survival increase with time after hatch, and mortality is typically less than 0.1 percent/day/tank when the fish reach ~0.15–0.25 g at around 2–2.5 months post-hatch (depending on water temperature and density of fish per tank). Biweekly measurements of fish growth from hatch to release, displayed a typical power function pattern (Chalupnicki and others 2024). In 2020, calcein was

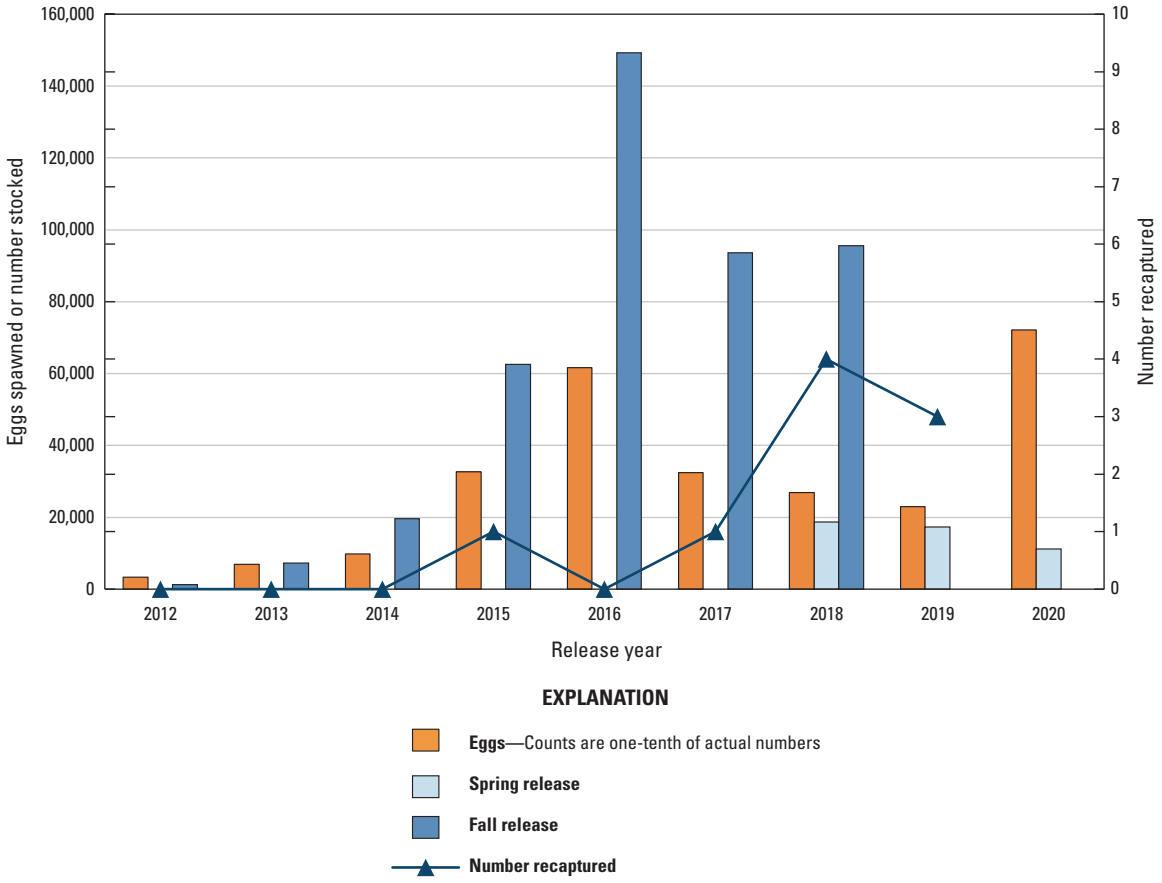

Figure 3. Egg production (that is, eggs from hatchery, wild brood stock, or both) and experimental releases of fall fingerling and spring yearling bloater (*Coregonus hoyi*) reared at Tunison Laboratory of Aquatic Science, U.S. Fish and Wildlife Service Northeast Fisheries Center, and (or) Allegheny National Fish Hatchery into Lake Ontario (indicated on a $\log_{10}$ scale with the left vertical axis), and recaptured bloater. Two of the three bloater recaptured in 2019 were from Canadian releases (no calcein marks); all others have had marks indicating they were cultured in the United States. The COVID–19 pandemic restrictions reduced sampling effort to recapture bloater in 2020.

unavailable, so bloater were marked with a manufactured feed containing OTC mixed in to provide identification of release year. They received a single mark at 10 months post-hatch with medicated feed manufactured by BioOregon.

Experimental releases of bloater fall fingerlings happened in 2012–18 and ranged from ~1,200 to nearly 150,000 (table 1; fig. 3). However, yearlings are suspected of having greater survival after release into the lake at a time of abundant food (spring) (Holeck and others, 2020). Therefore, yearling spring releases ranging from ~11,000 to 18,000 occurred 2018–present. In 2020, a total of 11,153 spring yearling bloater (2019 YC) were released into Lake Ontario off of Oswego, N.Y., in ~100 m of water depth using a NYSDEC-chartered landing craft. Since the beginning of restoration research, the total number of bloater released from U.S. facilities into Lake Ontario is 476,117. Approximately, 150,000 TLAS-produced bloater were released in spring of 2021 and 2022.

Cultured Production and Experimental Releases—Cisco

The cisco egg-take from Chaumont Bay spawners increased steadily from 2011 to a peak of nearly 1,000,000 eggs in 2017 and then was reduced to align better with experimental release targets (table 2; fig. 4). In November 2019, a total of 752,144 eggs were spawned from adult cisco collected from Johnson and Herrick Shoals in Chaumont Bay. At that point, 192,178 eggs were transferred to the NEFC, 26,816 to the NYSDEC Bath FCS, and 26,397 to the NYSDEC Oneida FCS. The remaining 641,506 eyed eggs developed at TLAS, and 545,280 hatched (85 percent) after 376 temperature units. The FWS NEFC also received 75,000 of these fry in mid-February. The cisco egg-take in 2020 was minimal and only intended to satisfy the most basic partner needs; a total of 38 adult cisco were collected from Chaumont Bay. The 15 females and 23 males spawned at TLAS produced 103,810 eggs. Like bloater, juvenile cisco survival at TLAS increased with time after hatch, and mortality was typically less than 0.1 percent/day/tank when the fish reach ~0.15–0.25 g at around 2–2.5 months post-hatch (depending on water temperature and density of fish per tank). Biweekly measurements of fish growth from hatch to release displayed a typical power function pattern (Chalupnicki and others, 2024). Because calcein was unavailable in 2020, cisco were marked with OTC to provide indications of release year; they received OTC marks at 2 and 3 months post-hatch via medicated feed manufactured by BioOregon.

Experimental releases of cisco happened in Irondequoit Bay 2012–15 and in 2018 and ranged from ~9,000 to 240,000 fall fingerlings (and one 2018 August release). Experimental releases happened in Sodus Bay 2016–20 and ranged from ~22,000 to 500,000 fall fingerlings (most 2017 fish were released as summer fingerlings). In 2020, 178,744 fall fingerling cisco were shore stocked into Sodus Bay by TLAS and 60,500 fall fingerling cisco were shore stocked into Sodus Bay by NEFC. The total release of cisco into Irondequoit Bay to date is 497,295 and into Sodus Bay is 1,576,182.

Recapture of Released Fish and Larval Production

Bloater were recaptured from Lake Ontario each year from 2015 to 2019, except for 2016, for a total of nine fish (Weidel and others, 2022). Collection locations were widely distributed throughout Lake Ontario. Because of the COVID–19 pandemic, open lake surveys capable of collecting bloater were limited and assessments of adult cisco returning to the experimental embayments in 2020 were not possible. Cisco have been recaptured from experimental release sites or adjacent embayments each year during 2015–19 (except for 2017; table 3), for a total of 16; these fish had OTC or calcein marks indicating their hatchery origin. There were also annual reports from ice fishermen of adult coregonines collected (as many as 30 in a season) from Port Bay, Irondequoit Creek, and other embayments. However, whether they were experimental fish released into Sodus or Irondequoit Bays has not been determined. Naturally produced larval coregonines have been consistently found in Chaumont Bay each spring since 2004 (McKenna and Johnson, 2009). Since 2018, coregonine larvae have also been collected from six other Lake Ontario embayments, including greater than 300 from Sodus Bay (experimental cisco release site) and Henderson Bay (adjacent to Chaumont Bay; table 4). Some of the Chaumont Bay larvae have been genetically identified as cisco and others as lake whitefish (McKenna and others, 2020). Some of those from other embayments have also been genetically identified as cisco (Brown and others, 2023). Egg traps have been deployed in six experimental embayments and the known spawning area in Chaumont Bay. Thousands of eggs have been collected in Chaumont Bay, but only two have been collected from a different embayment (that is, Little Sodus Bay).

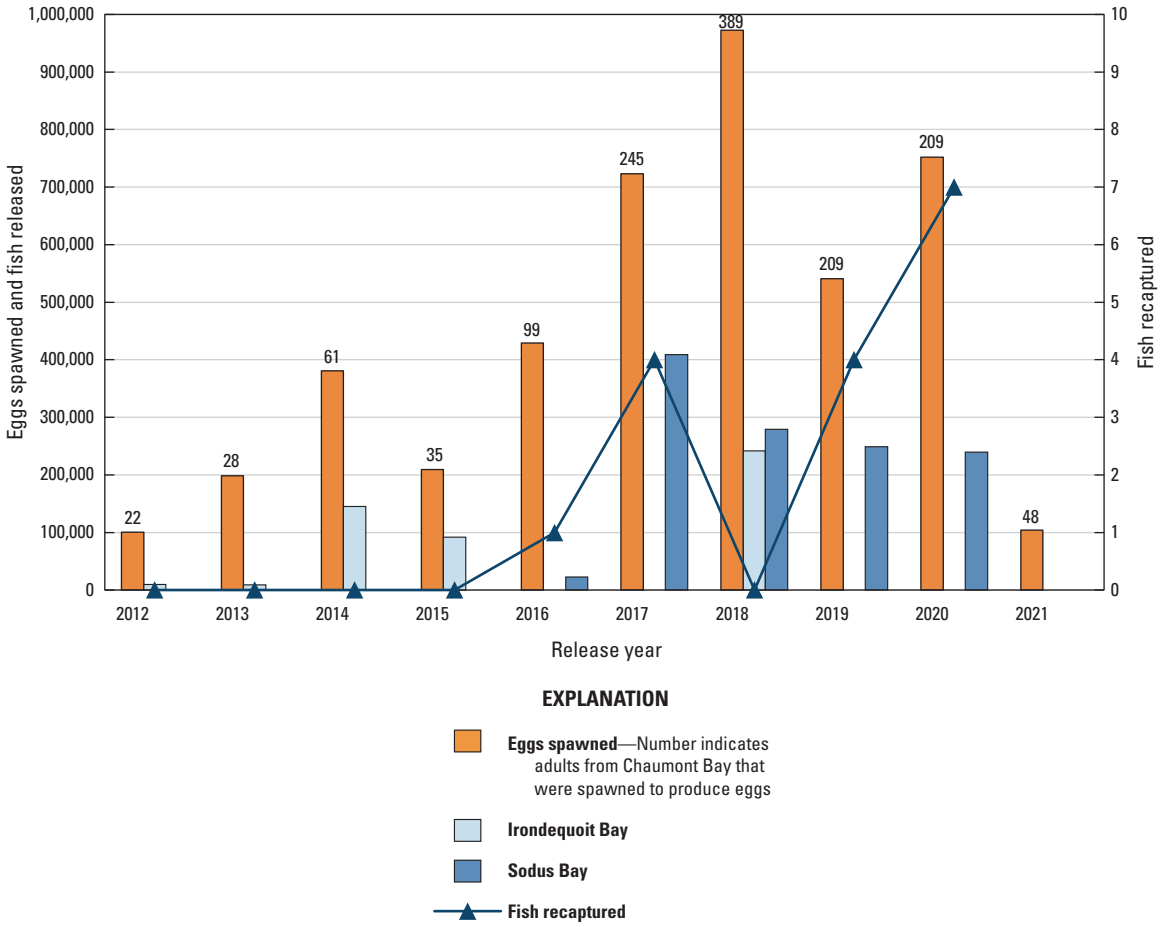

Figure 4. Adult cisco (*Coregonus artedi*) collected from Chaumont Bay, Lake Ontario, and spawned at Tunison Laboratory of Aquatic Science (numbers above egg bars), fertilized egg production, experimental releases of fall fingerlings reared at Tunison Laboratory of Aquatic Science and U.S. Fish and Wildlife Service Northeast Fishery Center into Irondequoit and (or) Sodus Bay, and recapture of cisco. The COVID–19 pandemic prevented sampling to recapture cisco in 2020.

Table 3. Recaptures of cisco (*Coregonus artedi*) from experimental embayments by spawn year. See figure 1 for locations of embayments.

[--, missing or not applicable data]

Year	Stage	Irondequoit Bay	Sodus Bay	Port Bay
2015	Adult	--	1	--
	Juvenile	--	--	--
2016	Adult	4	--	--
	Juvenile	--	--	--
2017	Adult	--	--	--
	Juvenile	--	--	--
2018	Adult	--	1	--
	Juvenile	1	1	1
2019	Adult	--	7	--
	Juvenile	--	--	--

Table 4. Spring larval coregonine collections by embayment since the start of experimental releases in Lake Ontario. See figure 1 for locations of embayments.

[--, missing or not applicable data]

Year	Irondequoit Bay	Sodus Bay	Port Bay	Little Sodus Bay	Sandy Pond	Henderson Harbor	Chaumont Bay tows	Chaumont Bay shore seine
2017	0	0	--	--	--	--	--	--
2018	0	7	0	--	--	--	2,148	34
2019	3	0	1	99	1	379	7,462	257
2020	0	316	0	0	0	8	4,182	31

Discussion

Although there are positives and negatives (and an extensive literature) about releasing cultured fish into natural environments, stocking remains an important tool for restoring extirpated species (Tudge, 1992; Miller and others, 2004; Trushenski and others, 2010, 2018; Baillie and others, 2015, for example). The quality of cultured fish and their release methods are likely to affect postrelease survival and restoration success. With the collaboration of numerous partners, the TLAS coregonine restoration research program has substantially advanced the science of artificially rearing coregonines and the evaluation of experimental releases of cultured coregonines into Laurentian Great Lakes systems. Determining the feasibility of re-establishing bloater populations, increasing the number of cisco spawning populations, and developing effective restoration methods for native fishes in Lake Ontario has been a major focus of TLAS for most of the last decade. Notable successes of this collaborative research program include, rearing of two native coregonines; several studies on their basic life histories, marking, and release; and evaluating re-establishment by recapture of returning experimental adults and surviving juveniles, and detection of wild production. This work has resulted in hundreds of thousands of bloater and cisco being reared at TLAS, NEFC, and OMNRF and released into habitats previously occupied by these species in Lake Ontario. Some of the directed research that was required for these successes is briefly described below.

There remain challenges to rearing sufficient numbers of coregonines for successful restoration in Lake Ontario. Capture of mature cisco from Chaumont Bay for acquisition and fertilization of eggs has been reliable for the past decade (2010–present). However, fertilized bloater eggs have been difficult to acquire from the wild Lake Michigan population and the supply of eggs from cultured brood stock has been limited. The hatch rate of fertilized cisco eggs has been high (greater than 85 percent) but that for bloater has been variable and often lower. However, our standard hatchery procedures generally provide effective care for cisco and bloater, and survival after hatch was generally high and mortality was very low after 8–10 weeks of growth. Once past the first-feeding stage, bloater and cisco growth followed typical power response curves with weight increasing faster than length for at least the first 7–9 months. Technical discoveries of this research are being used by the ANFH, the NYSDEC hatchery program, and other facilities for large-scale production to support native species restoration in Lake Ontario and other Great Lakes. The growth, morphology, genetics, and other aspects of the culture process for bloater and cisco are being further investigated and refined.

The potential development of fish disease is a major concern for any fish culture facility (Piper and others, 1982; Wedemeyer, 2002). The TLAS UV treatment system was constructed to protect the local drainage basin from any disease that may arrive at the station within wild fish or eggs. Until the NEFC (Lamar, Pa.) UV system was completed last year, TLAS was the only facility in the region that could receive wild eggs or fish. In addition to water treatment, disease testing provided by the NEFC fish health group and NYSDEC fish disease control unit is a critical part of the restoration effort, ensuring disease-free fish for the experimental field releases. Ironically, a human disease issue, the COVID–19 pandemic, limited much of the field evaluation activities in 2020. However, established TLAS biosecurity protocols have helped to protect people as well as fish, and bloater and reduced cisco production for the restoration program continue.

Distribution, Survival, and Recapture After Release

Recapture numbers have been low but are encouraging given the number released and the low probability of detection in the main lake, as well as the fact that most of the year classes have yet to mature and return to spawning sites. To date, nearly 500,000 bloater have been released into Lake Ontario by USGS and FWS, and a similar number (555,000) have been released by OMNRF. Nearly 500,000 cisco have been released into Irondequoit Bay and nearly 1.4 million into Sodus Bay. These may seem like large numbers of fish, but Lake Ontario is an enormous water body (the 13th largest in the world), with an area of nearly 19,000 square kilometers (km^2) and a water volume of greater than $1.6x10^{12}$ cubic

meters (m^3; U.S. Environmental Protection Agency, 2021). If all the bloater released to date were spread uniformly throughout the entire volume of Lake Ontario, there would be ~1 bloater for every 1.6 million m^3. It would require ~110 standard trawls to collect a single bloater. However, not all these fish have been released into Lake Ontario at the same time and the number surviving in the lake is likely to be much smaller in any one year. Greater than 1,000 trawls would have been required in the year with the first bloater recapture (2015). Despite the low probability of collection, the trawl survey has recaptured nine bloater and as many as four in a single year. This tells us that not only are the bloater surviving in Lake Ontario for at least months after release, but also that they are probably not uniformly distributed. They have been recaptured at widely different locations throughout the lake. Similarly, for cisco, which are generally a shallow water species, the likelihood of recapture is low. If all the cisco released into the experimental embayments were spread out uniformly within the waters of Lake Ontario shallower than 30 m deep (a total volume of $6.7x10^{10}$ m^3), we would expect one cisco for approximately every 32,000 m^3. Also, cisco are collected with gillnets and trap nets, which are passive gear occupying small areas of the embayments, and yet 16 cisco have been recaptured from Irondequoit Bay, Sodus Bay, and Port Bay. Additionally, several anecdotal reports of cisco catches from ice fishermen (as many as 10 at a time with about a dozen fishermen reporting) suggest that cisco may be more prevalent in the experimental embayments than indicated by the trap net and gillnet catches.

Tunison Laboratory Research: Present and Future

Research at TLAS supports the Lake Ontario Committee objectives and partner needs in a variety of ways. In addition to the broader field experiments and associated fish rearing done at TLAS, numerous directed studies were required to successfully produce a sufficient number of high-quality fish for the field experiments and to effectively release and evaluate the re-introduction of coregonine fishes into Lake Ontario. These include determining the proper feed (size and composition) for each life stage of bloater and cisco in the laboratory, determining optimal water flow and water quality (for example, dissolved gases and temperature) for best growth and survival, developing effective marking techniques that provide identification of the producing facility and year class of recovered fish; evaluating the best release locations and conditions; assessing postrelease survival, quantifying returning adults, and detecting wild egg and larval production.

Rearing

Water Quality

As with most fish, relatively high flows (size-appropriate) are best for coregonine growth, because they quickly deliver nutrients and oxygen to the fish and remove waste (Timmons and Ebeling, 2010). Dissolved gases vary and low oxygen or high nitrogen stress fish and may threaten survival. Extensive degassing methods using, aeration and oxygen injection techniques, are used to provide optimal water quality and flow for each life stage. At TLAS, the well water is pumped to the top of a 4.6-m high head tank and cascades through a set of baffles to the tank bottom, removing much of the nitrogen gas. Oxygen may also be directly injected into the system at several points. Oxygen demand increases as the fish grow or at high fish densities. Data on gas concentrations and ratios are being collected and analyzed to better characterize tolerances of cisco and bloater and the effects of gas concentrations on their growth. Temperature also is a critical environmental factor of fish growth and survival. While the TLAS water remains constant at ~9 °C, temperature varies at other facilities and temperature effects are being investigated.

Diet and Growth

Researchers at TLAS and OMNRF were the first to successfully rear bloater, overcoming numerous challenges. The first year of rearing bloater was particularly difficult and one of the first issues was survival past the first feeding stage. After close investigation of first-feeding bloater, a TLAS scientist discovered that the mouths of these tiny fry were too small to eat the smallest commercial feed or typical live *Artemia* spp. (brine shrimp) and only the smallest juvenile brine shrimp could be consumed (H.G. Ketola, TLAS, oral commun., 2011). Very fine commercial feed is now available and young bloater thrive in the laboratory at first feeding stage and beyond. It also is clear that, although coregonines are members of the Salmonidae family, they are not salmon or trout. However, most available feeds for coldwater fishes were developed for salmon and trout (some developed at the Tunison Laboratory of Fish Nutrition) (Hardy, 1998). TLAS scientists and those at the NEFC and OMNRF stations experimented with several different feeds. The commercial Otohime brand worked best for the early life stages, presumably because it contains a high proportion of crustaceans; Otohime is not available in Canada, but krill-supplemented feeds are being tested. Nutritional issues are suspected in the poor egg (and sperm) production by the OMNRF broodstock bloater, and a large, collaborative experiment among TLAS, NEFC, and OMNRF to identify the cause(s) of that deficiency was recently completed (Sweka and others, 2024).

Marking

The ability to identify cultured fish once they have been released into the wild is critical for field experimentation. Unique marks distinguish cultured fish from any wild fish that may already exist in the system and can also identify particular source facilities of cultured fish, the year class of the fish, and other factors, such as what rearing or release techniques were used. Marking is vital for the Lake Ontario coregonine research, particularly for cisco, where wild populations still exist in the Eastern Basin of Lake Ontario. TLAS and NEFC developed effective color marking of bones that persists for years and will identify experimental fish for field evaluations of survival, habitat use, and other aspects of cisco and bloater ecology (Chalupnicki and others, 2016). Initial marking of cisco was done with OTC applied to the fish in an immersion bath but a successful mark could not be verified. Calcein, which impregnates bones with a dye that fluoresces green, was determined to be durable and was used in all subsequent years, except 2020 when the chemical was unavailable. OTC mixed in feed was successfully used in 2020 to mark bloater and cisco. There can be many combinations of treatments and sources of experimental fish, and additional marking options would allow for more complex experimental treatments. Dyes fluorescing other colors than calcein green have also been tested but exhibited lesser degrees of effectiveness (M. Chalupnicki, TLAS, written commun., 2014); more research is needed. Genetic samples have been collected from all cisco and bloater used to produce fish for experimental releases, and parentage analysis may be used to identify the progeny of any of these fish that are recaptured from Lake Ontario.

Release and Postrelease Survival

Fish experience stress from the transport process to reach the release site (Tacchi and others, 2015). The degree of that stress is likely related to the time needed to travel to the release site and water conditions in the transport tank. Transport crews stop frequently enroute to measure oxygen concentration in the transport tanks and to ensure that aeration systems are working. The NEFC and TLAS are doing experiments on transport-induced stress by measuring cortisol levels. At the release site, fish are transferred to a stocking boat for release offshore or are drained from haul tanks directly into water at the release site. Cisco have been released by both methods into Irondequoit Bay and Sodus Bay. Bloater have been hauled by boat offshore of Oswego and released into deep waters of Lake Ontario. More research is needed on the effects of these transport and release methods.

Evidence of released cisco dispersal is provided by fish collected with trap nets and gillnets deployed in the experimental embayments in late October or early November, approximately 2 weeks after release. Only a single cisco has been collected at that time. Dispersal from the release site appears to be rapid and diver observations (eight dives from 2017 to 2020, in Sodus Bay and Keuka Lake) have noted immediate local dispersal after release. More research is needed to determine if released fish remain within the experimental release embayment or swim out to Lake Ontario shortly after release. These same nets are redeployed in early December to collect adults returning to Irondequoit Bay, Sodus Bay, Port Bay, or Little Sodus Bay (the latter two serving as reference sites where no fish have been released). In 2019, American Fisheries Society standard multimesh gillnets were deployed for the first time. Thus far, all captured cisco have had calcein marks indicating that they were fish raised at either TLAS or NEFC and released into either Irondequoit Bay or Sodus Bay. These data are being collected to estimate survival and habitat use of released fish. More intensive sampling over different substratum types is needed to better characterize adult returns and their habitat use, particularly if fish are returning to spawn.

Wild Egg and Larval Production

The increased number of locations where coregonine larvae have been collected compared to an earlier survey (McKenna and Johnson, 2009) is encouraging, but the productivity of these species is notoriously variable and weather dependent (Christie, 1963; Lawler, 1965; Bonsall, 2017). The increase coincides with the experimental releases of cisco into Irondequoit Bay and Sodus Bay. However, more genetic analysis is needed to determine whether the larvae are cisco or lake whitefish and if they are offspring of cultured fish or wild fish from other areas of Lake Ontario (for example, Chaumont Bay). As mentioned in the “Marking” section above, genetic parentage analyses may be used to determine the ultimate origin of recaptured fish.

Habitat

The habitat quality within experimental embayments is a critical aspect of coregonine restoration research. Habitat must be of appropriate character and quality for each stage of a species’ life cycle and of sufficient extent for that species to persist (Matthews, 1998). Spawning and nursery habitats are important for two critical stages within coastal embayments, and the amount and condition of those habitats are poorly known within our experimental embayments (or other Great Lakes embayments; Klumb and others, 2003). Initial substratum characterizations have been done (M. Chalupnicki, U.S. Geological Survey, oral commun., 2022) but must be improved and characteristics of appropriate spawning habitat must still be determined for cisco, bloater, and other coregonine fishes.

Other Coregonine Species

At least one other coregonine species, kiyi, has been extirpated from Lake Ontario but exists within the Great Lakes Region. *Coregonus reighardi* (shortnose cisco) was considered

extinct until 2023 (Eshenroder and others, 2016; Ackiss, U.S. Geological Survey, oral commun., 2023). In 2021, a collaboration among USGS, the Little Traverse Bay Bands of Odawa Indians and Sault Ste. Marie Tribe of Chippewa Indians, FWS, and others resulted in successful spawning of kiyi collected from Lake Superior, but only hybrid crosses with bloater were successful. Some of those hybrids are being reared at TLAS for research on their genetics and fertility. Efforts continue to acquire kiyi and other Great Lakes coregonine species that might benefit from research done at TLAS and other facilities of the broader collaboration.

Conclusions

Adding fish to an area is one of the few tools available to managers to restore extirpated or depleted populations. Conservation hatcheries conduct the research needed to evaluate the efficacy of fish releases as a conservation or restoration management tool, as well as reveal the ecology and life histories of native species. TLAS and other conservation facilities operate at the scale of the natural environment that is appropriate for conservation needs, providing hundreds of thousands of fish for the experimental fieldwork required to support effective restoration of native fish species. Our observations of progress toward historic food web components in Lake Ontario, supported by large scale releases of cultured fish, are encouraging. However, numerous other investigations are needed to determine the efficacy of experimental releases of bloater and cisco in Lake Ontario (such as Klinard and others, 2020). It seems likely, for example, that predators will consume the experimentally released fish (Klinard and others, 2021; Kraus and others, 2024). A related cisco re-introduction experiment in Keuka Lake, one of the large Finger Lakes in Central New York, has documented released cisco in the diet of *Salvelinus namaycush* (lake trout) (Koeberle and others, 2024). It will also be important to know in what proportion the cultured fish are consumed (relative to other available prey) and whether consumption of the re-introduced fish improves native predator conditions or populations. Effectiveness of releases targeted to specific habitats or areas also depends upon fish staying in or returning to the areas near the release sites, and the homing abilities of coregonine fishes have not been determined. Other information needs include determining the number of released fish sufficient to maintain recovery, the genetic diversity of wild and cultured fish, whether increased availability of native forage fishes aids restoration of native predators, and the sensitivity of recovering populations to environmental fluctuations and long-term (decadal or longer) changes. Evaluations of cisco returning to experimental release sites and bloater persistence as a function of additional releases continue to inform our understanding of restoration potential and methods.

Summary

Supplementation of fish to an area is an important tool for fishery managers. Conservation hatcheries conduct the research supporting effective use of supplementation and improve our understanding of the ecology and life histories of native species. Restoration of native species is expected to improve the diversity of forage for salmonid predators and ecological function in Lake Ontario. The Coregonine Research Program at TLAS encompasses a diverse array of research, with an emphasis on improved culture methods and field assessments of experimentally released juvenile coregonines, supporting restoration of native coregonines to the Laurentian Great Lakes. This collaborative research, carried out by numerous agencies to support the Fish Community Objectives of the Lake Ontario Committee (funded by the Great Lakes Restoration Initiative), is developing new and innovative techniques to raise native coregonine fishes to life stages suitable for survival in Lake Ontario. TLAS and other conservation facilities operate at the scale of the natural environment that is appropriate for conservation needs, providing fish for the experimental fieldwork required to support effective restoration of native fish species. Rearing and release of hundreds of thousands of experimental coregonine fishes into Lake Ontario shows progress toward restoring historic food web components. However, evaluation of the successes of that research for native species restoration requires numerous other investigations to determine the efficacy of hatchery supplementation, including issues noted in the “Conclusions” section.

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