Evaluation of survival and Reproductive Success of Cultured Cisco (*Coregonus artedi*) in West Central Lake Huron

Lake Huron Technical Committee

March, 2023

Lake Huron Committee
Great Lakes Fishery Commission

Background and Rationale

Prior to its population collapse during the middle of the Twentieth Century, Cisco (*Coregonus artedi*, formerly known as Lake Herring) were the most abundant pelagic fishes in Lake Huron, found "out of virtually every port on Lake Huron, in the North Channel, and Georgian Bay" (Koelz 1929). Spawning aggregations of Cisco were historically concentrated around Saginaw Bay, Thunder Bay (Alpena, MI), the Les Cheneaux Islands, and along the Bruce Peninsula (Goodyear *et al*. 1982). Cisco were the dominant coregonine species harvested in Lake Huron during the early part of the Twentieth Century, with most of the production coming from Saginaw Bay during a spawning-focused fishery (Berst and Spangler 1973; Baldwin *et al*. 2009).

Fishery yields of Cisco declined rapidly in Lake Huron after the 1940s and by 1970, Cisco were a minor component of the Lake Huron fish community (Eshenroder and Burnham-Curtis 1999; Fielder 2000; Dobiesz *et al*. 2005). Similar patterns were observed throughout the Laurentian Great Lakes, and only in Lake Superior (Stockwell *et al*. 2009) have Cisco stocks exhibited substantive recovery. Several factors were hypothesized to have contributed to the collapse of Cisco stocks in the Great Lakes, including competitive and predatory effects of invasive Alewife (*Alosa pseudoharengus*) and Rainbow Smelt (*Osmerus mordax*), overfishing, and eutrophication (Smith 1968; Smith 1970; Christie 1974; Eshenroder and Burnham-Curtis 1999).

The current distribution of Cisco in Lake Huron is limited to northern Lake Huron, in the Les Cheneaux Islands, North Channel, and Georgian Bay (Dobiesz *et al*. 2005; Ebener 2012). Cisco are no longer observed in Saginaw Bay (Fielder and Thomas 2014) and are rarely observed in the main basin (Figure 1). Lake Huron's pelagic prey base, composed principally of Alewives and Rainbow Smelt, largely collapsed in 2004 (Riley *et al*. 2008) and the pelagic prey fish biomass remains low (Roseman *et al*. 2016; O'Brien *et al*. 2017). Following the collapse, a near immediate response was observed in native fish stocks, including an increase of Walleye (*Sander vitreus*) numbers (Fielder et al. 2007) and an increased contribution of wild Lake Trout (*Salvelinus namaycush*) (He *et al*. 2012). Bloater (*C. hoyi*) abundance increased during the mid-2000s and by 2010 Bloater biomass dominated an otherwise depressed prey fish community in the main basin (Riley *et al*. 2012). In contrast, Cisco, while still encountered in fisheries and surveys executed in northern areas of the lake (Ebener 2012), remain nearly absent from surveys targeting the pelagic fish community in the western main basin (O'Brien *et al*. 2017).

The current condition of the Lake Huron ecosystem presents an opportunity to test the ability of Cisco to reestablish self-sustaining populations in an altered foodweb. As a result, the Lake Huron Technical Committee (LHTC) developed a recovery guide (LHTC 2007) for Cisco in Lake Huron based, in part, on the recommendations of Fitzsimons and O'Gorman (2006). Principle among their conclusions was that the lack of spawning stocks in areas where Cisco were extirpated was the fundamental impediment to recovery. Implicit in the recovery guide was a need to attempt restorative stocking experiments, particularly in historically important locations where Cisco once thrived.

The LHTC recovery guide offered seven key justifications to pursue restoring "*Lake Herring (Cisco) to a significant level,"* which remains an unmet objective for Lake Huron (DesJardine *et al*. 1995). These include (1) enhanced resiliency of the prey base through diversification; (2) promotion of a thiaminase-free prey form; (3) restoration of a native prey form better adapted to the local environment and climate; (4) establishment of a larger body-sized prey form to promote more-energetically efficient growth in piscivores, including lake trout; (5) promotion of a pelagic prey form to better support consumptive demand by pelagic predators; (6) establishment of a prey buffer (likely via juveniles in nursery habitats) for nearshore species such as Yellow Perch (*Perca flavescens)* in Saginaw Bay; and (7) promotion of a prey form that offers potential as a recreational and commercial species.

As a result, the LHTC has recommended to the Lake Huron Committee (LHC) that successful Cisco restoration in Saginaw Bay and the main basin of Lake Huron will not be achieved until spawning stocks return to Saginaw Bay. The LHC strongly supports Cisco recovery efforts and concurred with the LHTC recommendation that a stocking and assessment program offers the best option to hasten the recovery of Cisco in the western main basin of Lake Huron and Saginaw Bay.

Donor Stocks

The need for genetic conservation is an important component of any fisheries restoration effort (Philipp *et al*. 1993; Busack 1995). Importation of Cisco gametes from outside Lake Huron for hatchery production would likely introduce traits and behaviors in cultured progeny that are not consistent with existing wild stocks. If successfully established, these cultured variants of Cisco could displace or interbreed with wild Cisco, increasing the risk for outbreeding depression. After considerable discussion, the LHC directed that these recovery stockings proceed first with fish sourced from Lake Huron before consideration be given to sources from outside the basin. If stocking northern Lake Huron Cisco proves unsuccessful, as informed by the "Indicators" described in this document, then the Lake Huron Committee will reevaluate this Cisco stocking project and decide if Lake Huron-sourced culture and stocking should continue or whether consideration should be given to transitioning to a source from outside the Lake Huron basin.

Goal

The goal of this study is to determine if it is feasible to reestablish a self-sustaining population of Cisco in the main basin of Lake Huron, with emphasis on Saginaw Bay.

Objectives

1. To assess whether cultured Cisco can survive to maturity in Lake Huron.
2. To determine if cultured Cisco, once mature, will home to the focal stocking area(s) for spawning purposes.
3. To detect whether natural reproduction results from mating of cultured Cisco.
4. To determine if any resulting wild Cisco progeny also mature, home, and successfully reproduce indicating the potential for recovery beyond cultured fish.
5. To evaluate dispersal of cultured Cisco from the focal stocking areas.

Methods

Overview

One million (±20%) Cisco fingerlings have been requested from the U.S. Fish and Wildlife Service (USFWS) hatchery system each year for ten years, equating to a stocking rate of roughly 3.33 fish ha^{-1} based on the surface area of Saginaw Bay. Stocking rates of up to 10 fish ha^{-1}per year (~3 million fingerlings) would, assuming 50% mortality from age-0 to age-1, produce a weak to moderate year-class in Lake Superior (Rook at al. 2013). Fielder and Olds (unpublished data) determined that long term recovery success from stocking may occur at even low stocking densities and that stocking rates primarily drive the magnitude and speed of recovery. Additionally, their modeling efforts estimated that large year classes, such as those historically produced in Saginaw Bay, were not necessary to reach current recovery objectives. It should be noted that evaluating the study objectives would likely be easier at higher stocking rates due to the increased likelihood of encountering fish relative to lower stocking rates. Future increases to the stocking density would be made depending on availability of gametes, production capacity, and LHC approval.

Wild gametes will be collected from Les Cheneaux Islands and Drummond Island vicinity in northern Lake Huron. Gamete collection will occur during the fall as Cisco move into shallower habitats to spawn. Spawning fish will be collected using short set (<2 hour) small mesh gillnets (50.8mm – 104.6mm bar) with gametes collected after fish are removed from the net. Captive brood lines will be created from equalized lots from Les Cheneaux Islands and Drummond Island regions and will be used to augment wild brood production when necessary to meet production targets.

Cisco will be stocked in Saginaw Bay annually during four stocking events during the spring (~500k fish) and fall (~500k fish) utilizing both shore and offshore stocking. All cultured fingerlings will be planted in outer Saginaw Bay near Whitestone Point on the northwest side of the bay (Figure 2). This location is thought to offer stocked Cisco access to more diverse thermal and physical habitat, lower predator densities and is closer to historic spawning areas than other inner-bay sites (Goodyear et al. 1982). Offshore stocking will be conducted via the USFWS' vessel, the *Spencer F. Baird* and will occur in the same vicinity as shore stocking; approximately 6 km from shore in 15 m of water (Figure 2). Shore and offshore stocking will occur as close in time as logistically possible and weather permitting. Due to the seasonal component of the stocking strategy, spring fish are expected to be smaller than their fall counterparts (spring mean TL 58 mm; fall mean TL 89 mm). During the spring and fall stocking events stocking will be coordinated so the receiving waters are within the preferred thermal range of juvenile Cisco (10-14 °C, based on published work and unpublished monitoring data) and will also consider logistic needs related to distribution and marking.

All stocked fish will be marked with differential Oxytetracycline hydrochloride (OTC) marks to allow managers to evaluate the relative success of each season/size stocking strategy. Batch marking cultured fish with OTC laced feeds is a proven technique (FDA 2017) and will allow for differential marks between fish released in the fall and spring each year. Spring fingerlings will receive a single OTC mark and fall fingerlings will receive two OTC marks. Due to the limitations of OTC marking and small release size of the hatchery Cisco, we are unable utilize any additional marks to evaluate the relative performance between shore stocked and offshore stocked Cisco. Gamete collection, culture, and marking practices for Cisco reared for this study are provided in a separate document (Lake Huron Cisco Propagation Plan, 2016, USFWS internal document).

Evaluation and Indicators

Both existing and new targeted surveys will be used to evaluate the plan objectives. Relative survival and the presence/absence of stocked and wild Cisco will be assessed by examining data from a suite of surveys and the collection of appropriate samples to determine origin and/or experimental lot. Relative survival of any future experimental lots (e.g. life stage or stocking location) will be evaluated based on a statistical comparison of catches within gears and among survey types. Because Cisco are currently extirpated from the study area, the presence of wild Cisco with genetic profiles similar to Cisco brood sources will be taken as evidence of natural reproduction resulting from the successful spawning of stocked Cisco, as opposed to immigration from outside wild sources. While beyond the scope of this evaluation plan, ancillary research projects, for example the application of acoustic predation tags in stocked fish or analysis of stable isotopes or other biochemical assays to determine trophic ecology, may offer further means to evaluate questions related to survival and life history. Dispersal from the focal stocking area(s) will be evaluated through an analysis of the recapture locations of marked fish.

Performance will be further evaluated by comparing the targeted gillnet catch rates of spawners with those achieved with similar gear in northern Lake Huron (Ontario Ministry of Natural Resources and Forestry, and USFWS, unpublished data), Lake Michigan (MDNR, unpublished data), and in Lake Superior (Stockwell *et al*. 2009). While it is not expected that rehabilitation stockings of Cisco will mimic abundances of extant Cisco populations composed of multiple cohorts, such comparisons nevertheless offer a benchmark for framing stocking efficacy.

The following indicator/benchmark timeline has been defined based on the expected sequence of outcomes based on the study objectives. These indicators will offer a means to assess the efficacy of the stocking program/strategies and guide decisions on whether alternative strategies should be employed.

By 2023: Evidence for survival of stocked fish
By 2025: Evidence for survival of stocked fish to maturity
By 2027: Evidence that mature fish are returning to the focal stocking area(s) for spawning

Targeted indicator surveys, as described below, are assumed to offer the best means to evaluate these benchmarks since they are focused on collecting Cisco and are conducted in the focal stocking areas. Non-targeted indicator surveys will further enhance the evaluation potential, particularly if cultured Cisco survive and move beyond the vicinity of Saginaw Bay.

<u>Targeted Indicator Surveys</u>:

Survey 1: Post-stocking survival surveys:
Timing/Scope: In conjunction with stocking events and during late summer/Outer Saginaw Bay
Gear(s): Various
Agency Responsibility: Lead by USFWS with support from partner agencies.

Objective addressed: 1 and 5
Methods: Targeted midwater trawl /acoustic (late summer) and small (1.5-2.0”) mesh gillnet.

Survey 2: Commercial Fishery monitoring:
Timing/scope: Alpena to Harbor Beach – Year round
Gear(s): trap-net
Agency Responsibility: USFWS & MDNR
Objectives addressed: 1, 3, and 5
Methods: Collect Cisco (especially juveniles) caught in commercial gear. Set up a work group that will coordinate with the commercial fishers and collect samples once they are encountered in commercial gear, especially the trap net fishery.

Survey 3: Targeted spawning survey, new
Timing/Scope: October – December /Saginaw Bay
Gear(s): gill net
Agency Responsibility: Lead by USFWS with support from partner agencies.
Objective addressed: 2-5
Methods: Short duration or overnight gillnet sets in original stocking areas to detect returning adults.

Survey 4: Early life history, existing
Timing/Scope: April-early June/Saginaw Bay
Gear(s): neuston net, beach seine or small bottom trawl
Agency Responsibility: Lead by USFWS with support from partner agencies.
Objective addressed: 3 and 5
Methods: Larval surveys conducted in targeted zones during peak larval emergence (April); age-0 surveys conducted in proximity to focal stocking areas (May-June).

Survey 5: Saginaw Bay Fish Community Survey (SBFCS), existing
Timing/scope: September/ Saginaw Bay
Gear(s): gill net, bottom trawl
Agency Responsibility: Michigan Department of Natural Resources (MDNR)
Objectives addressed: 1, 3 and 5
Methods: follow existing protocols

Non-target Indicator Surveys

All non-target indicator surveys will be utilized to address objectives 1, 3 and 5. These surveys, funded through existing agency programs, will follow established protocols

Survey 6: Lake Huron acoustic survey
Timing/scope: September/ lakewide
Gear(s): midwater trawl
Agency Responsibility: U.S. Geological Survey (USGS), USFWS, and MDNR.

Survey 7: Lake Huron bottom trawl survey

Timing/scope: October/main basin, primarily U.S. waters
Gear(s): bottom trawl
Agency Responsibility: USGS

Survey 8: Fishery monitoring
Timing/scope: year-round/lakewide
Gear(s): various
Agency Responsibility: MDNR (creel and commercial) and USFWS (head hunters from Fish Habitat Utilization Program)

Survey 9: Spring Lake Trout survey
Timing/Scope: late April-May/US main-basin waters
Gear(s): gill net
Agency Responsibility: MDNR

Data and sample collection standards

The collection of data and samples as detailed below will be completed for all Cisco encountered in the aforementioned indicator surveys. Agencies will collect these data from any Cisco encountered during monitoring activities, particularly where Cisco are undocumented or rare.

<u>Biological data</u>
Total length, weight, sex, maturity status, sea lamprey wounds

<u>Capture information</u>
Date, agency, effort ID, specimen ID, capture site LAT/LON, gear type, gear description, capture depth, station depth, temperature at capture depth (if available).

<u>Structures for aging</u>
Scales and otoliths should be collected from all Cisco encountered.

<u>Structures for assessing OTC marks</u>
After recording of required biological data, a section of the vertebral column, starting at the anterior margin of the adipose fin (Figure 3), will be removed to ensure adequate vertebrae are available for chemical mark detection. Whole samples will be wrapped in aluminum foil or other light-obscuring material, bagged and frozen as soon as possible. Vertebral specimens will be noted with date and location, agency, species, total specimen length, and a unique agency sample identifier on a waterproof tag and include with the sample. An inventory sheet will accompany bulk samples submitted for processing by MDNR/USFWS.

<u>Subsampling for assessing OTC marks in juvenile coregonines</u>
We anticipate that some surveys outlined in this document (e.g. midwater trawls) may capture large numbers of small, unidentifiable coregonids that may require OTC analysis. Due to the difficulty of accurately identifying coregonine species at total lengths <200mm and the finite number of structures that can be evaluated for OTC annually, a size based subsampling routine will be implemented to determine how many individuals should be submitted for OTC analysis

(table below). Subsampling fish from surveys with potentially high catch rates of small, unidentifiable coregonines will allow catches to be efficiently screened for the presence hatchery Cisco without overwhelming our OTC processing capabilities. The subsampling scheme for submitting individuals for OTC analysis is as follows:

Fish identification resolution	Size bin (total length, mm)	Maximum number of fish to subsample per sampling event (e.g. tow, trawl, gillnet set, ect…)
Coregonus	<50	None, fish this small can be assumed to be of wild origin and do not require OTC analysis.
Coregonus	50-75	20
Coregonus	75-125	20
Coregonus	125-200	20
Cisco	>200	All, fish this large should be able to be correctly identified to species and all Cisco should be evaluated for OTC marks.

Note: non-Cisco coregonines (e.g. Bloater, Lake Whitefish) greater than 200mm do not need to be submitted for OTC analysis.

Subsampling is only required if more individuals are captured than the maximum threshold listed in the table above for each size bin; otherwise all individuals should be submitted to MDNR/USFWS for OTC analysis. Additionally, individuals should be randomly selected when subsampling to avoid any size bias within each size bin. Subsampled individuals should be submitted for OTC analysis as whole specimens following the procedure outlined in the "*Structures for assessing OTC marks*" section above.

Tissue samples for genetic analyses

A thumb-nail sized section of fin tissue will be removed and placed in a scale envelope. Tissue samples will include collection date and location, agency, species, and a unique agency sample identifier on the envelope. Air-drying of the sample is adequate for preservation. An inventory sheet will accompany bulk samples submitted for processing.

Sample Processing and Analysis

Detection of OTC marks

Detection of OTC marks on vertebrae will be performed using fluorescence microscopy in accordance with established agency procedures. MDNR, USFWS, and other agencies that develop competencies with OTC mark determination will assist with detection analysis. Currently MDNR and FWS have the requisite equipment and expertise to assess chemical marks.

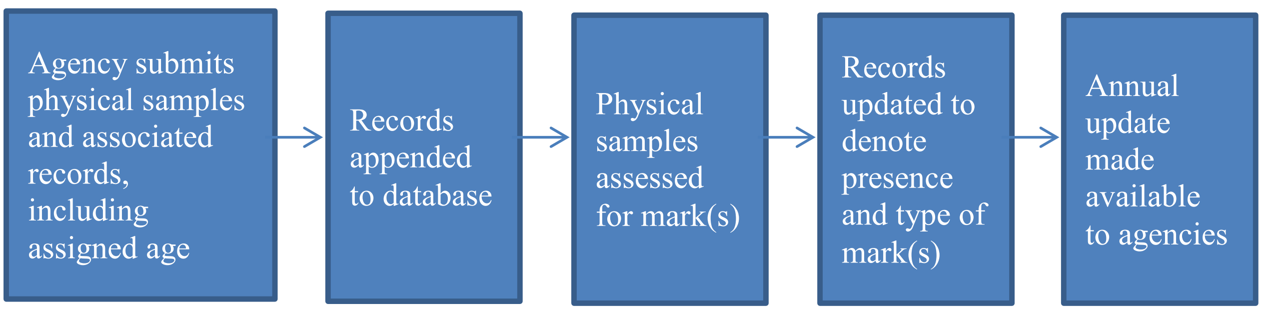
Aging

Cisco captured in the indicator surveys will be aged via agency-established protocols, though standardization of aging structures/practices is highly encouraged given that marking practices are not expected to allow differentiation of cohorts.

Genetic analysis
Processing of tissue samples to obtain genetic information will be performed at the USGS Great Lakes Science Center's Molecular Ecology lab. The Molecular Ecology lab is currently analyzing wild Cisco used for production and broodstock development to create a reference database that can be used to determine the lineage of wild Cisco encountered in the Saginaw Bay region. Microsatellite DNA loci and/or genomic analyses will be performed to evaluate the lineage of any untagged fish.

Capture Database

A project database and data management plan will be developed to track Cisco captured in the indicator surveys, utilizing the aforementioned required biological and capture data as database fields. The database will be maintained jointly between all agencies conducting OTC mark evaluation and populated annually with records for all Cisco submitted for evaluation of OTC marks. The USFWS Alpena Fish and Wildlife Conservation Office and the Alpena MNDR office will act as the co-leads on all OTC evaluation. As such, all recaptured Cisco should be submitted to one of those two offices. The database will be shared with submitting agencies to allow for joint analysis of catch/return rates. Workflow will proceed as follows:



Data analysis and metrics

LHTC member agencies will collaborate in data analysis and annual reporting as well as any journal manuscripts to stem from this work.

Funding

Collection of gametes and/or brood, and subsequent culture of the Cisco fingerlings will be provided and funded by the USFWS. Genetic analysis will be performed by the USGS Great Lakes Science Center Molecular Ecology Lab and funding for genetics analysis is to be secured by separate proposals. Surveys or analyses requiring additional funding outside of existing agency budgets, should be an LHC/LHTC priority for funding.

Reporting and Outreach

An annual progress report will be made to the LHC at the annual Great Lakes Fishery Commission Lake Committee Meetings. At least one peer reviewed publication is expected to result from this evaluation. Near the completion of the evaluation period, recommendations would be made to the Lake Huron Committee for any continued Cisco restoration strategies, including the future of any stocking and other management options for Cisco in Lake Huron. Stakeholder meetings will offer an opportunity to engage the public while providing a venue for disseminating material such as project brochures designed to help encourage public awareness and participation.

Schedule

	Year											
Activity	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Culture and stock Cisco												
Evaluate post-stocking survival												
Monitor for early life stages near focal stocking areas												
Monitor for post-juvenile Cisco in fisheries and SBFCS												
Monitor for spawning adults near focal stocking areas			pilot year									
Monitor for Cisco in non-target indicator surveys												
Conduct genetic analysis of any wild Cisco encountered												
Conduct genetic analysis of hatchery brood and production												
Report to Lake Huron Committee												
Final report and publication												

References

Baldwin, N. A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R.L. Eshenroder. 2009. Commercial Fish Production in the Great Lakes 1867-2006 [online]. Available from http://www.glfc.org/great-lakes-databases.php.

Berst, A.H., and G.R. Spangler. 1973. Lake Huron: the ecology of the fish community and man's effects on it. Great Lakes Fisheries Commission Technical Report 21.

Busack, C. A. 1995. Genetic risks and hazards in hatchery operations: fundamental concepts and issues. *In* American Fisheries Society Symposium Vol. 15, pp. 71-80.

Christie, W.J. 1974. Changes in the fish species composition of the Great Lakes. Journal of the Fisheries Research Board of Canada 31: 827-854.

Dobiesz, N.E., D.A. McLeish, R.L. Eshenroder, J.R. Bence, L.C. Mohr, M.P. Ebener, T.F. Nalepa, A.P. Woldt, J.E. Johnson, R.L. Argyle, and J.C. Makarewicz. 2005. Ecology of the Lake Huron fish community, 1970–1999. Canadian Journal of Fisheries and Aquatic Sciences 62: 1432–1451.

DesJardine, R.L., T.K. Gorenflo, R.N. Payne, and J.D. Schrouder. 1995. Fish-community objectives for Lake Huron. Great Lakes Fisheries Commission Special Publication 95-1.

Ebener, M.P. 2012. Status of whitefish and Ciscoes. In The state of Lake Huron in 2010. Edited by S.C. Riley. Great Lakes Fisheries Commission Special Publication 13-01: 29-35.

Eshenroder, R. L., & Burnham-Curtis, M. K. 1999. Species succession and sustainability of the Great Lakes fish community. *Pages* 145-184 *in* Great Lakes fisheries policy and management. *Edited by* W.W. Taylor and C.P. Ferreri. Michigan State University Press, East Lansing, Michigan.

Fielder, D. G. 2000. Lake herring spawning grounds of the St. Marys River with some potential implications for early spring navigation. North American Journal of Fisheries Management, 20:552-561.

Fielder, D. G., and C. Olds. In press. Identification of variables and their thresholds affecting the success of a Cisco reintroduction for reestablishing natural reproduction in Lake Huron. Journal of Great Lakes Research.

Fielder, D.G., J.S. Schaeffer, and M.V. Thomas. 2007. Environmental and Ecological Conditions Surrounding the Production of Large Year Classes of Walleye (*Sander vitreus*) in Saginaw Bay, Lake Huron. Journal of Great Lakes Research 33 (Supplement 1):118–132.

Fielder, D. G., and M. V. Thomas, 2014. Status and Trends of the Fish Community of Saginaw Bay, Lake Huron 2005–2011. Michigan Department of Natural Resources, Fisheries Report 03. Lansing, Michigan.

Fitzsimons, J., and R. O'Gorman. 2006. Status and assessment, research, and rehabilitation needs for Cisco in the Great Lakes. Canadian Technical Report of Fisheries and Aquatic Sciences 2638.

Goodyear, C. D., Edsall, T. A., Dempsey, D. M., Moss, G. D., & Polanski, P. E. 1982. Atlas of the spawning and nursery areas of Great Lakes fishes US Fish and Wildlife Service, FWS/OBS-82/52.

He, J.X., M.P. Ebener, S.C. Riley, A. Cottrill, A. Kowalski, S.K. Koproski, L. Mohr, and J.E. Johnson. 2012. Lake Trout Status in the Main Basin of Lake Huron, 1973–2010. North American Journal of Fisheries Management 32: 402–412.

Koelz, W. 1929. Coregonid fishes of the Great Lakes. Bulletin of the U.S. Bureau of Fisheries 1048: 297–643.

Lake Huron Technical Committee (LHTC). 2007. Strategy and Options for Promoting the Rehabilitation of Cisco in Lake Huron.

O'Brien, T.P., D.M. Warner, P.C. Esselman, S. Farha, S.J. Lenart, C.M. Olds, and K. Phillips. 2017. Status and Trends of Pelagic Prey Fishes in Lake Huron, 2017. U.S. Geological Survey Great Lakes Science Center, Ann Arbor, Michigan.

Philipp, D. P., Epifanio, J. M., & Jennings, M. J. 1993. Conservation genetics and current stocking practices: are they compatible? Fisheries 18:14-16.

Riley, S.C., E.F. Roseman, S.J. Nichols, T.P. O'Brien, C.S. Kiley, and J.S. Schaeffer. 2008. Deepwater demersal fish community collapse in Lake Huron. Transactions of the American Fisheries Society 137: 1879-1890.

Riley, Stephen & Roseman, Edward & O'Brien, Timothy & Fingerle, Amy & Mychek-Londer, Justin & George, Ellen. (2014). Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2011.

Roseman, E.F., Chriscinske, M.A., Castle, D.K., and Prichard, C.G. 2016. Status and trends of the Lake Huron offshore demersal fish community, 1976-2015. U.S. Geological Survey Great Lakes Science Center, Ann Arbor, Michigan.

Rook, B.J., Hansen, M.J., and Gorman, O.T. 2013. Biotic and abiotic factors influencing cisco recruitment dynamics in Lake Superior during 1978-2007. North American Journal of Fisheries Management 33: 1243-1257.

Smith, S. 1970. Species Interactions of the Alewife in the Great Lakes. Transactions of the American Fisheries Society 4: 754-765.

Smith, S. 1968. Species Succession and Fishery Exploitation in the Great Lakes. Journal of the Fisheries Research Board of Canada 25(4): 667-693.

Stockwell, J. D., M. P. Ebener, , J. A. Black O. T. Gorman, T. R. Hrabik, R. E. Kinnunen, W. P. Mattes, J. K. Oyadomari, S. T. Schram, D. R. Schreiner, M. J. Seider, S. P. Sitar, and D. L. Yule. 2009. A synthesis of Cisco recovery in Lake Superior: implications for native fish rehabilitation in the Laurentian Great Lakes. North American Journal of Fisheries Management 29: 626-652.

U. S. Food and Drug Administration (FDA). 2017. Approved Animal Drug Products (Green Book), Oxytetracycline for marking fish NADA 038-439 approved. Available from https://www.fda.gov/AnimalVeterinary/Products/ApprovedAnimalDrugProducts/

Figures

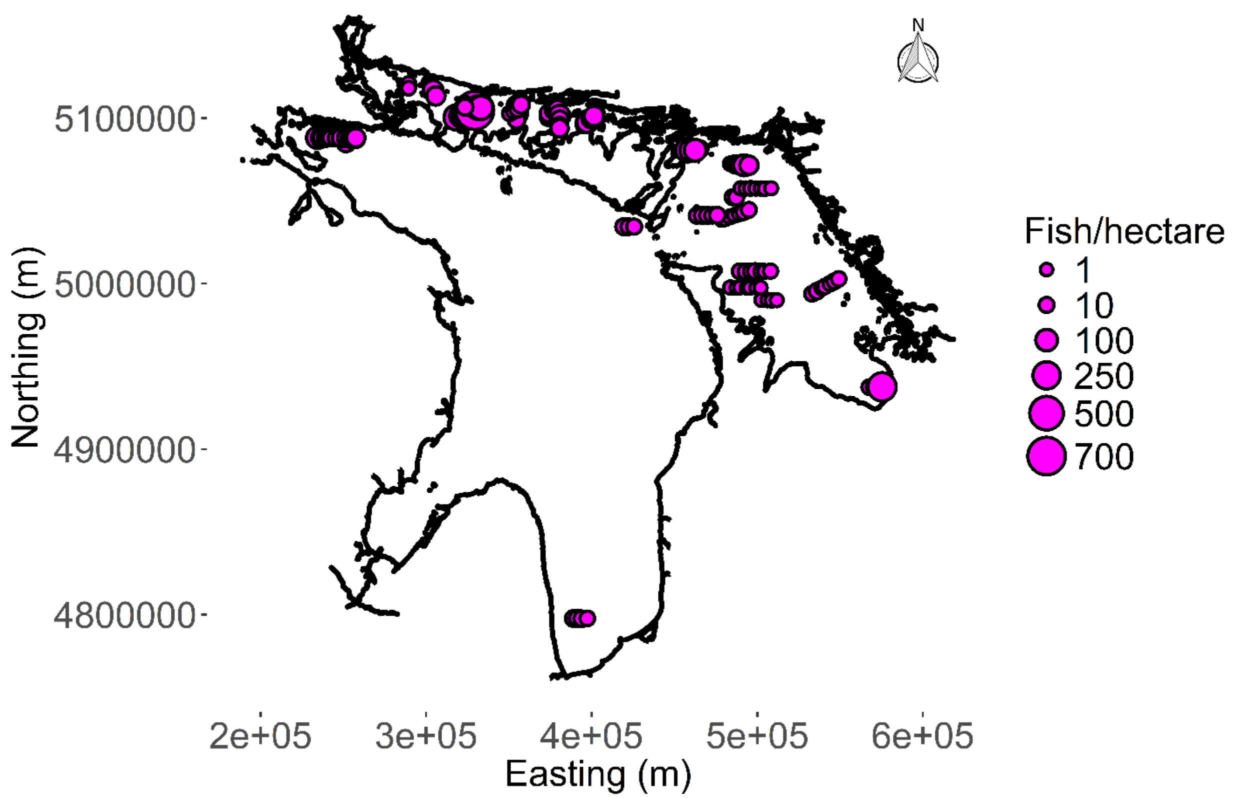


Figure 1. Geographic distribution of Cisco numeric density (mean) estimated from acoustic surveys during 2010-2017. See Figure 7 in O'Brien *et al*. (2017).

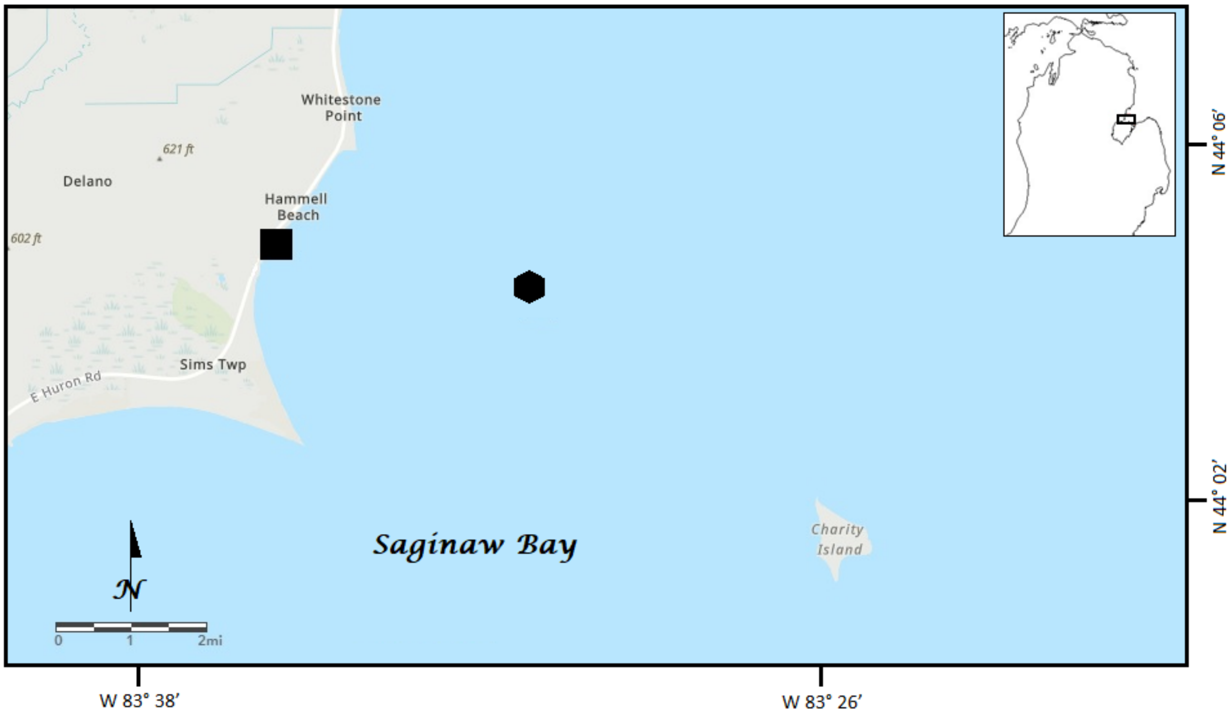


Figure 2. Cisco onshore (square) and offshore (diamond) stocking areas in Saginaw Bay.

Figure 3. Preferred landmark for sectioning of vertebral column on Cisco.