Identifying Research Priorities for Cisco in Lake Ontario: A Workshop Summary Report

May 31, 2018
Cornell Biological Field Station at Shackelton Point
Bridgeport, New York

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Introduction

Historically cisco (*Coregonus artedi*), along with three deepwater coregonines, were the primary prey for top offshore predators such as lake trout and Atlantic salmon in Lake Ontario. Cisco also supported important commercial fisheries in Ontario and in several New York embayments where cisco historically spawned. By the mid-20th century, however, populations were severely depleted due to overfishing, spawning habitat loss, and competition with invasive alewife and rainbow smelt.

The last significant commercial catches in New York State were reported in the 1960s, with usually less than 100 lbs reported per year through the 1970s and 80s. Cisco are still caught as incidental bycatch in commercial whitefish fisheries during fall in the Bay of Quinte and in commercial yellow perch fisheries in Chaumont Bay. From 2009 to present, commercial catches of cisco in Chaumont were generally low but variable, ranging from 12 to 1806 lbs. The New York State Department of Environmental Conservation (NYSDEC) is not expanding commercial take of cisco and instead plans on retiring the remaining two commercial gill net fishing licenses in New York.

The Lake Ontario Fish Community Objectives[1] support improving the diversity of native prey fish, including coregonines. Currently alewife dominates the preyfish biomass in Lake Ontario and active rehabilitation may be needed to increase coregonine biomass. Reintroduction of bloater (*Coregonus hoyi*) in Ontario and New York is also part of sanctioned Lake Ontario Committee efforts and is being pursued by the United States Geological Survey (USGS), NYSDEC, and the Ontario Ministry of Natural Resources and Forestry (OMNRF) alongside cisco restoration. Experimental rehabilitation of cisco spawning populations in Irondequoit Bay and Sodus Bay is both a NYSDEC and USGS initiative, and actions from a draft plan are underway. The main objectives of the plan are to reestablish cisco at historic spawning locations and evaluate new methods for assessing and indexing their populations.

A workshop to discuss cisco research and rehabilitation in Lake Ontario was held on 31 May, 2018 at the Cornell University Biological Field Station at Shackelton Point in Bridgeport, NY. Over 30 attendees from a variety of state and federal agencies, universities, and conservation organizations were present. The goals of the workshop were to review the current knowledge of cisco ecology, summarize recently completed and ongoing research efforts, and to identify key research priorities to support cisco restoration in Lake Ontario. The outcomes of the workshop are presented below, organized by general topics. At the end of each topic, a summary of related research needs is presented. A participant-ranked list of the top research priorities is included at the end of this report along with responses to select survey questions related to these priorities.

[1] Stewart, T.J., Todd, A., LaPan, S., 2013. Fish community objectives for Lake Ontario. Report of the Great Lakes Fisheries Commission Lake Ontario Technical Committee.

Assessment

Survey methods

There is currently no targeted cisco assessment program in Lake Ontario. However, there are various programs that may provide information relating to population trends, and some of these have been operating for over six decades. These include the Canadian waters gillnet survey in the Eastern Basin (since 1958), the Canadian gillnet survey in nearshore waters less than 30m (since 1992), United States bottom trawl survey (since 1978), and reported commercial landings in both Canada and the US. Harvest data are available for much longer, back to the mid 1800s, although cisco and bloater catches were combined in reports through much of the time series. It is important to note that historical accounts suggest that cisco populations had already been in significant decline prior to detailed record keeping. The contemporary surveys suggest that cisco are most abundant in the eastern portion of Lake Ontario.

Existing programs have already incorporated new sites and seasons to expand our understanding of cisco throughout Lake Ontario. The spring bottom trawl program expanded to include Canadian waters in 2016 and in 2018 included several new Bay of Quinte sites. Fourteen cisco were caught at the Conway site in 2018, and 6 cisco were caught in a lower Bay of Quinte site.

Historically USGS have conducted annual fall surveys for benthic fishes using bottom trawls, which were joined by NYSDEC and OMNRF in 2015. However, cisco are not routinely encountered in these assessments. Cisco may be beginning their annual staging near spawning grounds at this time, although timing and location of staging is unknown. As adult cisco are pelagic, they are likely not susceptible or are undersampled by the benthic trawl surveys.

A summer assessment was attempted using hydroacoustics and midwater trawls in 2016-2018. This survey was designed with coregonines in mind and in particular to assess bloater, which have been stocked in Lake Ontario since 2012. This approach was successful at collecting cisco; unfortunately, no bloater were collected. Cisco were pelagic and mostly caught at depths around the metalimnion where water temperatures were 10-15°C. Some fish were caught in water temperatures as low as 6°C, and fish were also found in depths from the point where the metalimnion intersected the bottom out to approximately 100m depth. Cisco were often encountered in patches nearshore, suggesting that a targeted assessment in the nearshore might be efficient. However, cisco did not appear to stay in these nearshore patches very long, and their distribution and dispersal may be related to temperature and stratification. Thus, summer surveys with this new design may have limited temporal applications. In addition, there are no historical data from this survey with which to compare.

For the last 15 years cisco have been successfully captured on spawning shoals in Chaumont Bay using Oneida style trapnets. The purpose of these efforts was to collect gametes to raise and stock cisco in locations where they were found historically. However, targeting spawning aggregations of cisco could provide an opportune time to estimate population size, but there are some limitations. For example, even though cisco are concentrated on spawning shoals, the weather and lake conditions at this time of year (late November and early December) make it challenging for the smaller boats that are needed for this type of work. In addition, although researchers suspect most cisco spawning is occurring in a few discrete places (Chaumont Bay and Bay of Quinte) these are still large areas to sample with limited time and opportunity. Despite these potential limitations, the nearshore of the eastern basin of Lake Ontario may be a good place to focus sampling and assessment efforts. If spawning aggregations can be used to estimate population size, experimenting with gear and timing of surveys in these areas may provide some of the best opportunities to adequately assess population trends at this time.

Research Needs: A primary research priority that was identified during the workshop was the need to develop an annual survey that specifically targets and effectively assesses cisco abundance in Lake Ontario. This assessment might be accomplished with a summer midwater trawls, suspended gillnets, hydroacoustics, or perhaps a different strategy. A new survey design was suggested that would capitalize on the cisco staging period (pre-spawning aggregation) earlier in October or November, potentially reducing exposure to weather and lake conditions that constrain surveys during spawning time. Although some recent successes have been realized, it is still unclear what gear and timing would be most effective for this type of assessment.

Long-term trends

Combining information from multiple long-term data sources in Lake Ontario provides some idea, but still an incomplete picture, of cisco population trends over the last several decades (Figure 1). Following declines in the early part of the time series (1960s-1970s) there was a period of increased cisco abundance in the late 1980s and early 1990s, followed by another decline in the 2000's. Each time series shows an indication of increased abundance in the most recent years (2015-2017), following what appears to be a strong recruitment event. Trawl surveys indicate a strong year class of cisco in 2014 and also a 2015 cohort. The gillnet trend (Canada only) lags behind the trawls due to gillnet mesh sizes having low selectivity for small sizes.

Historical commercial fishing data show large amounts of cisco harvested up to the early 1950s, with a declining trend continuing until the 1980s when the commercial fishery diminished to its current level (Figure 1). Variability in harvest to research survey relationships since 1950 can be explained by changes in the commercial fishery and differences in the spatial extent of the two programs. The three research survey programs described above show significant correlations despite differences in spatial extent, which provides confidence in using data collected from general assessment programs to describe long term trends in cisco abundance.

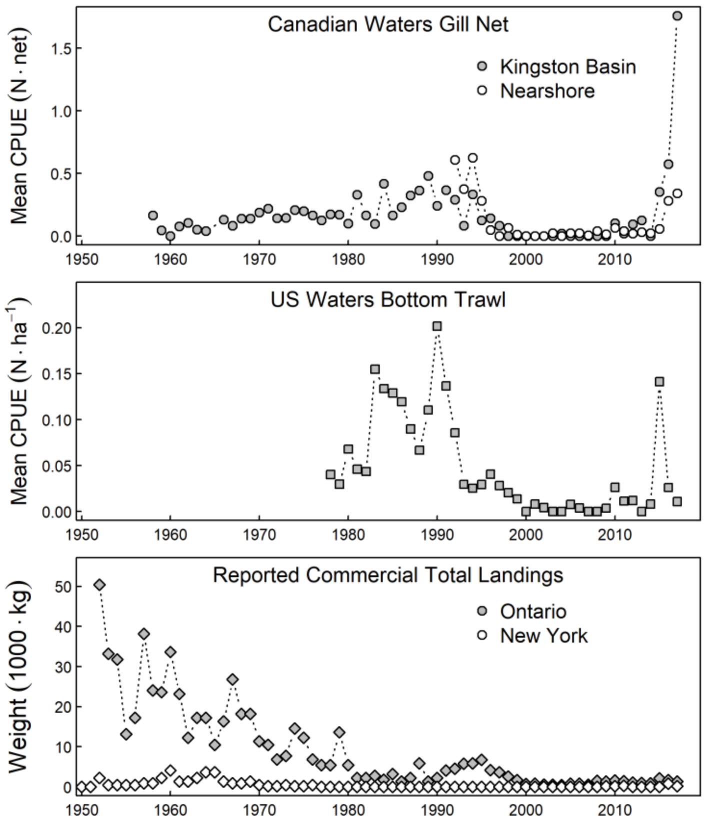

Figure 1. Lake Ontario cisco catch per unit effort (CPUE) for various sampling programs. Reproduced with permission from Weidel et al. (in review)[2].

Sampling efforts and historical accounts indicate that there is a relatively consistent concentration of cisco in the eastern portion of Lake Ontario. Cisco are very rarely encountered in the western basin. Variability in catch locations based on sampling data from 1987 to 2017 indicate that cisco distribution has the potential to expand and contract in other areas of the lake, but it is difficult to attribute these patterns to movement by individuals (straying or shifts in distribution) or as an artifact of the low capture probability of cisco with the currently used survey methods.

Juvenile "black box"

Very little is known about cisco behavior, distribution, and impediments from the time the larvae can no longer be caught in larval tows (~30mm TL) and when they recruit to spawning populations at approximately age 2-3. Not only is this a critical life stage that may affect year class strength, but this is also the time when cisco are most susceptible to predation by large predators such as lake trout. As one of the commonly stated rationales for cisco restoration is to

[2] Weidel, B., J. Hoyle, M. Connerton, J. Holden, and M. Vinson. In review. Lake Ontario cisco dynamics based on long-term surveys. Proceedings of the 13th International Coregonid Symposium, Ashland WI. Special issue, Advances in Limnology.

provide a larger native prey base for lake trout and Atlantic salmon, it is critical to better understand this life stage. At both this workshop and the cisco assessment workshop in Ashland, WI in September 2017, the development of assessment techniques for sampling juvenile cisco was identified as a key research priority. The juvenile stage has been referred to as a "black box." Great Lakes researchers have successfully sampled egg, larval, and adult stages, but cisco between age-1 and recruitment are not well represented in our current sampling methods. The Michigan Department of Natural Resources is attempting to collect young of year cisco in Lake Michigan using bottom trawls. Juveniles are occasionally caught in bottom trawls in the Bay of Quinte (see Assessment, above), and have been caught in small-mesh gillnets in Chaumont Bay.

Research Needs: As little is known about the ecology and distribution of juveniles, almost any study concerning these topics would be useful. In order to effectively study juveniles, however, new survey methods must be developed that can reliably capture them. Experimenting with trawl or net style, location and time of year may be necessary.

Food Web and Ecology

There are some data and anecdotal evidence that can be used to get a sense of the potential role cisco played in the Lake Ontario food web in the past. Based on historical accounts it was likely that the largest component of fish biomass in Lake Ontario (as well as the other Great Lakes) was represented by cisco. Cisco can exhibit rapid growth, potentially escaping the gape limit of predators within the first year or two of life. Variability in growth among individuals, across space, and through time make it challenging to distinguish at what age or size cisco may no longer be available as prey to most predators. There is also evidence going back several decades indicating that cisco are not merely planktivores. Cisco can grow large, exceeding 40 and 50 cm, and alewife and "fish remains" are sometimes observed in cisco gut contents. Thus, the functional role of cisco within Great Lakes food webs may change with ontogeny.

Research Needs: Workshop participants cautioned that many of the research priorities listed here need to be considered in the context of dynamic factors that may differ across space and change through time. These factors included but were not limited to life stage (ontogeny), season, morphology, foraging behavior, species assemblages, predator-prey interactions, environmental conditions, habitat suitability. Because of the many unknowns, it is important to identify research priorities that help managers meet fisheries objectives.

Cisco diet throughout life stages, with a focus on larval and early life stages, and its role as a potential driver of year class strength was identified as a research priority. This includes seasonal variation and the possibility of diet match-mismatch through space and time. As cisco is a highly plastic species, the potential for plasticity in diet and all other life history characteristics should be considered.

One of the primary motivations driving cisco restoration in Lake Ontario is to provide a more diverse native prey fish base for predators such as lake trout and Atlantic salmon. Potential predators (fishes, birds, humans etc.) and which prey species (alewife, cisco, lake whitefish, rainbow smelt etc.) offer the most accessibility and overall quality as forage for these predators should be considered. The dynamic nature of predator-prey interactions through space and time, and how shifting environmental conditions such as climate may affect these interactions, represent big-picture research objectives to understand the lake system as a whole and not just the role of an individual species within the system. Modeling may be able to shed light on many of these questions, including those related to community dynamics, ecology, population dynamics, and climate effects. Existing data that may be available for comparisons and modeling should be identified. In order for this to be successful, clear communication and cooperation among agencies should be fostered. In order for models to be useful and informative, sample sizes needed to properly parameterize the model should be identified, as well as the feasibility of collecting the various types of data that may be included. Finally, the ability of the lake to support stocks of both native coregonines and alewife as a forage base is unknown, and may be complicated by interspecific interactions.

Spawning Populations and Habitat

Before their collapse in the late 1800s and early 1900s, cisco spawned in various bays and nearshore areas in both the eastern and western basins of Lake Ontario. Hannah Schaefer (USGS Ann Arbor) has created a map of these historical spawning locations from Goodyear et al. (1982) and other sources (Figure 2). Today, there are two known spawning populations in Lake Ontario; one on the Canadian side in the Bay of Quinte, and one on the American side in Chaumont Bay. In Chaumont Bay, cisco spawning is concentrated on shallow, rocky shoals comprised of fractured bedrock[3]. Ellen George (Cornell University) presented results from an egg mat study in which genetically confirmed cisco eggs were found on similar shallow rocky areas near Fox Island, Tibbets and Dablon Points, and in Henderson Harbor. Peak densities of cisco eggs near Horse Island in Henderson Harbor are comparable to densities found in Chaumont Bay in 2014. As these sites have not been monitored in the past, it is unknown whether these represent new spawning areas that have recently become recolonized or if they represent remnant spawning populations that have remained undetected until now. Although adult cisco have been caught in trap nets in Irondequoit Bay, Sodus Bay, and North Pond, no eggs have been collected in those locations. Additionally, as most of the work on spawning habitat has been conducted in New York waters in and around Chaumont Bay, little is known of spawning behavior or location in the Canadian Bay of Quinte.

[3] George, E.M., Stott, W., Young, B.P., Karboski, C.T., Crabtree, D.L., Roseman, E.F., Rudstam, L.G., 2017. Confirmation of cisco spawning in Chaumont Bay, Lake Ontario using an egg pumping device. J. Great Lakes Res. 43, 204–208. doi:10.1016/j.jglr.2017.03.024

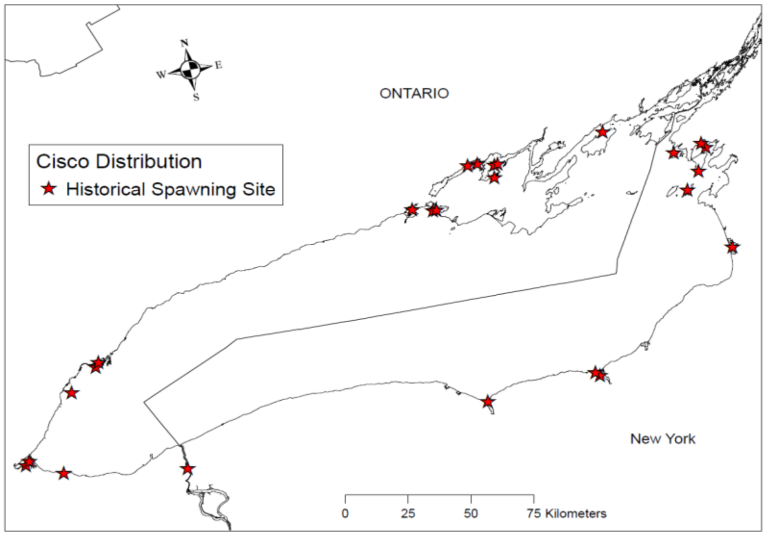

Figure 2. Historical cisco spawning sites in Lake Ontario. Reproduced with permission from H. Schaefer[4].

Two spawning habitat models are being developed for cisco in the Great Lakes. Hannah Schaefer (USGS GLSC Ann Arbor) is constructing a habitat suitability model for cisco and lake whitefish in Lakes Ontario and Erie. The model is based on historical sites from Goodyear et al. (1982), and factors include distance from tributaries, ice onset date, ice cover duration, substrate type, and fetch distance. Matthew Paufve (Cornell University) is constructing a spawning substrate occupancy model based on egg pumping work conducted in lakes Michigan and Superior, where a marked contrast was observed relative to cisco spawning habitat and behavior in Lake Ontario. Jory Jonas (MI DNR) reported that an alternate spawning strategy has been observed in Lake Michigan, with cisco spawning near the surface over 100 ft of water.

The U.S. Fish & Wildlife Service (USFWS) Lower Great Lakes Fisheries and Wildlife Conservation Office is conducting an acoustic telemetry study on cisco spawning movements in the Eastern Basin of Lake Ontario. This study is addressing spawning site fidelity, rate of return of spawners in following years, and range of fish movement during the non-spawning seasons.

Grant Scholten (USGS Tunison Laboratory of Aquatic Science) is conducting experiments on chemical imprinting behavior in hatchery reared cisco. Fish are being exposed to several potential homing chemicals, then their behavior is evaluated in a double arm chamber experiment. USGS Tunison has also posted informational signs at NYSDEC boat launches around the eastern basin of Lake Ontario. Anglers are encouraged to contact USGS if they catch a cisco.

[4] Schaefer, H. Predicting spawning habitat for lake whitefish (*Coregonus clupeaformis*) and cisco (*Coregonus artedi*) in the Lake Erie and Lake Ontario regions using classification and regression tree (CART) and random forest models. Master's thesis submitted to the University of Michigan, 2018.

Research Needs: A major goal that arose during group discussion and the post-workshop survey was the need to re-establish spawning populations in embayments. However, the habitat in sites such as Sandy Pond and Irondequoit Bay are predominantly soft substrate, not exposed rock. The group highlighted the importance of understanding how plastic cisco are in spawning habitat choice in order to make the best decisions on habitat restoration or alteration in these embayments. Several participants mentioned the possibility of experimental habitat restoration, either by adding rocky habitat or cleaning silted-in habitat, similar to the experimental reefs constructed in the Detroit River and Grand Traverse Bay, Lake Michigan. Also, although we have a general idea of what preferred habitat may look like, what constitutes "suitable" spawning habitat? Is there a measure of impactedness? Additionally, is there a minimum effective spawning population size to ensure successful reproduction?

As only one spawning population has been extensively studied for habitat choice (Chaumont Bay), more research is needed on spawning habitat and behavior in other Lake Ontario populations. The contemporary spawning locations and habitats of the Bay of Quinte population is largely unknown. Also, the existence of other ecomorphs and spawning strategies in other lakes (e.g., lakes Michigan and Superior) brings into question whether there may be other spawning strategies present in Lake Ontario as well.

Several of our major early life history questions could possibly be answered using genetic tools. For example, identification of spawning sites or other habitat areas could be investigated with eDNA. However, the group highlighted the importance of understanding the limitations of eDNA, and to make sure it was being applied appropriately. Follow up studies would have to be performed to demonstrate that the activity of interest (e.g., spawning) was indeed occurring at locations with positive eDNA hits. Other questions approachable with genetics included the influence of parental groups on future offspring success, and the experimental measurement of genetic versus plastic (environmental) trait variation.

Early Life History

Identification of eggs and larvae

Identification of larval coregonines remains a problem in Lake Ontario. Cisco and lake whitefish larvae are not distinguishable using common metrics such as myomere counts, total length, or pigmentation patterns[5]. Genetic identification remains our best option for reliable identification of eggs and larvae, but is costly and time consuming. USGS Tunison is looking at morphometric differences between cisco, lake whitefish, and hybrid larvae raised in the hatchery to attempt to identify any differences. They are also using landmark analysis to try and develop a meristics

[5] George, E.M., Hare, M.P., Crabtree, D.L., Lantry, B.F., Rudstam, L.G., 2017. Comparison of genetic and visual identification of cisco and lake whitefish larvae from Chaumont Bay, Lake Ontario. Can. J. Fish. Aquat. Sci. 75, 1329–1336.

key for adults. However, the concern was raised that coregonines raised in hatcheries often show significantly different morphometrics and meristics than their wild counterparts.

The Cornell group is developing markers for positive ID of cisco/lake whitefish F1 hybrids, but those results were not presented at this workshop.

Research Needs: Developing an affordable, simple, and field-ready method for reliably identifying eggs and larvae to species was one of the primary research priorities identified at this workshop. Although the barcoding method used in George et al.[3,5] and other papers is useful, it can be expensive on a large scale, does not identify hybrids, and is not accessible to groups without a dedicated genetics lab. Although the type of tool that would be best to develop was not identified, we agreed that some sort of genetics-based, potentially field-friendly tool should be a top research priority.

Year class strength & recruitment drivers

Larval cisco densities have been known to fluctuate in abundance by an order of magnitude from year to year (E. George, Cornell Univ.) The drivers of these fluctuations are not well known. Predation by alewife and rainbow smelt on cisco larvae has been implicated in the collapse or reduction of cisco populations in other areas of the Great Lakes. However, no alewife were observed in acoustic or gillnet surveys in Chaumont Bay in 2014 or 2015 during the time larval coregonines were present, although the concern was raised that only two years of data may be insufficient to fully answer this question. In Chaumont Bay, larval cisco prefer small cyclopoid copepods early in the season (1-2 weeks after hatching), then switch to larger cyclopoids and cladocerans as they overcome gape limitation (approximately 2-3 weeks after hatching; E. George, Cornell Univ.). USGS Oswego is launching a project to assess larval coregonine distribution at a lakewide scale. Not only will this project help researchers hone in on potential unknown spawning sites, but will hopefully help identify predictors of larval distribution. Factors being considered include distance from overwintering alewife, morphometry, substrate type, distance from historical spawning locations, total phosphorus, wind speed and direction, time, temperature, and depth. Sampling for this project began in April and May 2018, with over 1200 samples collected by a variety of partner agencies.

Another important predator on cisco larvae may be rainbow smelt (*Osmerus mordax*). There are several publications suggesting that rainbow smelt have affected cisco recruitment and even extirpated cisco from systems as a result of predation on larvae. However, alewife currently dominate the biomass in Lake Ontario and rainbow smelt represent a relatively small proportion of catches during standard sampling surveys. Thus, perhaps there are other, more important drivers at work. Comparisons of cisco abundance indices across lakes suggest that larger, landscape-scale drivers may be influencing cisco populations with bottom trawl data from lakes Ontario and Superior showing similar declines in cisco relative abundance beginning in the 1990’s. Further, preliminary analyses of year class strength indices in lakes Ontario and Superior show synchrony between strong year classes despite the more than 300-mile distance between the two systems and their inherent differences (B. Weidel, USGS Oswego).

Hannah Lachance (University of Vermont) summarized the results of a pilot study that looked at the effect of changes in light on development, survival, and gene expression in cisco eggs and larvae. The goal of this study is to examine the role that climate variables such as ice cover play in early life history stages. Briefly, the light treatment hatched earlier and had high larval mortality compared to the dark and control treatments. So far the gene expression results seem to be corresponding with observed physiological differences.

Research Needs: A primary research priority identified during the workshop was the need to establish an effective index of recruitment. There are still many unknowns about what drives the wide swings in cisco year class strength. Work in other lakes and on other species (e.g., lake whitefish) suggest that winter conditions and other environmental variables may control year class strength. The group identified the need to look at variability across different scales; for example, lake-wide, temporal year-to-year, just the eastern basin, etc. Several other sources of variation other than the environment were also mentioned. For example, does the presence of predatory alewife in the nearshore, which may be dependent on winter and spring conditions, affect year class strength? What is the key bottleneck stage that determines year class strength, and does this change from year to year? A major theme that arose from this discussion was the need to stop looking for the "silver bullet," or the one thing that always controls year class strength. The group thought that in reality it was more likely a "series of gauntlets," where variation from year to year could affect any or several of the potential threats (for example ice cover, alewife presence, zooplankton abundance/quality, etc.) that in concert could interact to determine year class strength. The group stressed the importance of not focusing on a single life stage, but linking success through all stages of development to form a more complete picture of what drives success. By understanding this complex system more fully, we may be able to forecast the effect of climate change on cisco in Lake Ontario, which was also identified as a future research need. It was mentioned that this may be accomplished in part by using controlled experiments in the hatchery, as discussed above (ex. Effect of ice cover on egg/larval development).

It is not known whether match-mismatch dynamics is affecting larval survival and year class strength in Lake Ontario. Daily otolith growth rings may be used to back-calculate hatch date to inform questions of match-mismatch and hatching triggers such as ice-out and degree days.

Population Structure and Genetic Diversity

Recent genetics work has focused on assays of selectively neutral markers to measure the strength of recent genetic drift and inbreeding resulting from recent population size reductions, and to test for population subdivision among spawning aggregations. Matt Hare (Cornell University) presented patterns of microsatellite variation in both lake whitefish and cisco samples from Lake Ontario, the latter including Chaumont Bay and Bay of Quinte spawning aggregations, summer midwater trawl samples, and a time series of samples from Bay of Quinte going back to 2003. All cisco samples had similarly high levels of heterozygosity and allelic richness, both comparable to that found in a single population sample of lake whitefish. There were no patterns supporting a recent genetic bottleneck or inbreeding. Tests for population subdivision did not reject the null hypothesis of spatial homogeneity, suggesting that population connectivity is sufficient to maintain similar allele frequencies. However, it was noted that a low level of exchange, e.g. 10 per generation, can maintain this genetic homogeneity and it therefore does not necessarily indicate demographically meaningful levels of connectivity. With all cisco samples combined the contemporary effective population size (based on within-sample allelic correlations) was on the order of $N_e = 5000$ with an infinite upper 95% confidence limit, further attesting to the weak influence of genetic drift in these populations. Therefore, the sampled cisco populations appear to have not been compromised genetically and are likely to have a strong capacity for adaptive response to environmental change.

Research Needs: Diversity at neutral markers such as microsatellites, useful for inferring historical demography, will be insensitive to functional genetic consequences of fisheries selection or other forms of selection potentially leading to local adaptation. Genomic scale analyses would be more useful for testing hypotheses about selection, local adaptation, and other functional genetics questions in addition to providing more statistical power to detect subtle population subdivision.

Hatchery Supplementation

Fall fingerling cisco were stocked into Irondequoit Bay annually from 2012-2016 and into Sodus Bay beginning in 2017. These fish were raised at the USGS Tunison Laboratory with gametes from wild fish caught in Chaumont Bay. In the fall of 2017 USFWS Lamar also began raising cisco at their facility for stocking into Lake Ontario.

Meredith Bartron outlined ongoing work at the USFWS Lamar office to monitor genetic diversity in cisco and bloater broodstock from Lake Ontario used for hatchery-based supplementation. Microsatellite-informed parentage analyses have been used to document variable amounts of reproductive skew among males contributing to a spawn.

Research Needs: One major question to come out of the discussions was how we could use hatcheries to inform our knowledge of wild populations. For example, the hatchery is a great resource for setting up controlled experiments, especially using early life history stages such as eggs and larvae. However, the concern was raised that because cisco are such a variable and plastic species, hatchery findings may not always be applicable to wild fish. An example of this was shown in the afternoon general discussion, when morphometric results from two separate hatcheries showed more similarities between bloater and cisco raised at the same hatchery than cisco from two hatcheries (the “tank effect”). We need a better understanding of the differences between cisco development in the hatchery and the wild, and future studies should take care to think critically about how and when hatchery results may not be transferable to wild populations.

The ideal type of experiments to be conducted in hatcheries would be controlled experiments that can most effectively contribute to the restoration effort. For example, USGS Tunison work on imprinting, or experiments that help identify genetic variation contributing to fitness-related traits, that can then be assayed in wild populations.

This discussion was similar to discussion on using lake whitefish as a proxy species for cisco. As a close relative of cisco, available knowledge on lake whitefish could be very helpful when no similar experiments have been conducted on cisco. However, the concern was raised that the lake whitefish population is on a different trajectory than cisco in Lake Ontario, with high lake whitefish population levels appearing to alternate with cisco high population levels. How are these species different, and how can we tease apart the differences to better inform our understanding of cisco population dynamics?

There was interest in developing an assessment of the cisco stocking program. What would success of the stocking program look like? It was suggested that success would be a cisco population ready to expand and assume a larger role in the Lake Ontario preyfish base in the event of future food web changes. However, can an assessment of the stocking program collect meaningful data that would determine if the stocked fish are surviving and adding to the population? We decided that without accurate information about the size or condition of the existing lake-wide cisco populations it will be difficult to assess the contributions from the stocking program.

Other research priorities related to hatchery supplementation included developing a consistent method to distinguish stocked from naturalized fish, moving towards marking of all stocked fish, and assessing the survival of stocked fish. Additionally, stocking methods could be designed around assessments to address the question of whether stocked fish are homing, i.e. returning to spawn, at their stocked location. Although some cohorts of stocked fish are marked with calcein, no stocking location-specific marks have been implemented. Finally, beyond initial survival there is some question as to whether life history traits and success later in life is different in hatchery versus wild origin individuals. A cost-benefit analysis of rearing practices may help focus and refine hatchery efforts in the future.

Further Considerations

Research Needs: Several other research priorities emerged outside of the above categories. Currently, cisco restoration efforts have existed within the lens of restoring a native prey base to Lake Ontario. However, it may be beneficial to conduct a socio-economic assessment in order to predict how the fishing economy, both recreational and commercial, may be affected by a resurging cisco population. If restoration is successful to the point that a new recreational fishery arises, public outreach, education, and collaboration may be prudent to promote responsible use of the new fishery and gauge public interest. Additionally, the issue of contaminants arose during discussion, with the question of how cisco may act as a vector for bioaccumulation and biomagnification of persistent pollutants. This could have impacts both on the food web as well as any future fisheries that may develop. Climate change, which was mentioned during multiple discussions and in several contexts, has the ability to affect many of the goals and research objectives mentioned here and should be considered for all questions and life stages.

Formation of a cisco task group: There was some interest in forming a task group dedicated to furthering the stated priorities and goals of this workshop. This task group would function under the Lake Ontario Technical Committee, would be responsible for coordination, communication, and project management of research ventures in the future. The group may also be responsible for methods standardization in the event that a lake-wide assessment survey is created. Finally, it could serve as a central body for unifying the various goals and objectives that may exist across multiple stakeholder groups, as well as defining appropriate metrics of success for restoration efforts.

Summary of Research Priorities

At the end of the workshop, participants were asked to identify and vote on top research priorities for cisco in Lake Ontario. Research priorities are ranked here based on the number of votes for each category. High priority items are generally considered to be those that are immediately necessary to successfully continue cisco research efforts in Lake Ontario; lower priority items, while still important, may be more applicable in the long term or have a narrower research scope. Finally, participants were asked to answer three questions in a post-workshop survey about research priorities, with a focus on what knowledge gaps they felt could be overcome in the near future.

Ranking of Top Research Priorities

High (>10 votes):

- Quick, easy, affordable, and field-ready genetic identification tool for coregonines.
- Determining what suite of factors (climate, interspecies interactions, etc.) are the major drivers of year class strength and recruitment.
- Developing an effective, targeted, and cooperative lakewide assessment strategy for cisco.

Medium (5-10 votes):

- Evaluation and cost benefit analysis of stocking success and performance of stocked fish.
- Determining spawning habitat preferences and assessing the potential need for habitat restoration.
- Adult behavior, including seasonal movements and natal homing.
- Interspecies interactions with alewife, rainbow smelt, etc. at all life stages.

Low (<5 votes):

- Small scale intensive study of in-hatchery success rate, from fertilization to hatching.

- Re-establishment of historic spawning populations.
- Determine if other spawning strategies such as offshore/deepwater spawning exist.
- Larval fish development and ecology, including diet, growth, hatch dates, and developmental plasticity under differing environmental conditions.
- Predator-prey interactions with chinook salmon, Atlantic salmon, lake trout, etc. and the lake's ability to produce salmonids based on a majority cisco diet as compared to an alewife dominated system.
- Juvenile assessment and filling in the juvenile "black box" knowledge gap.
- Socio-economic analysis of future recreational and commercial fisheries development.
- Investigation of smaller systems, such as Keuka Lake, to provide insight into knowledge gaps for Lake Ontario.

Survey Results

What do you feel is the largest information/data gap that remains to be addressed to support cisco restoration in Lake Ontario?

- Multivariate analysis of year class strength.
- Species identification of larvae.
- Distribution of adult and juvenile cisco, and status of spawning stocks, throughout Lake Ontario.
- Basic early life history information.
- Assessing performance of hatchery supplementation.

What do you feel is the largest barrier that remains to cisco restoration in Lake Ontario?

- Presence of alewife and/or rainbow smelt.
- Monetary support and lack of appreciation or valuation of cisco.
- Identifying what we don't know, and experimentation and research to address unknowns.
- Species identification of larvae.
- Lack of priority for cisco-targeted surveys.
- Producing and assessing performance of hatchery stocks.

What is one barrier that you feel can be overcome?

- Species identification of larvae.
- Targeted, lakewide, multi-agency collaborative assessment of adult, juvenile, and spawning cisco distributions.
- Disparate goals, poor communication, and perception that cisco are not valuable economically and ecologically.
- Stocking and experimentation to improve recruitment.
- Habitat restoration and enhancement.