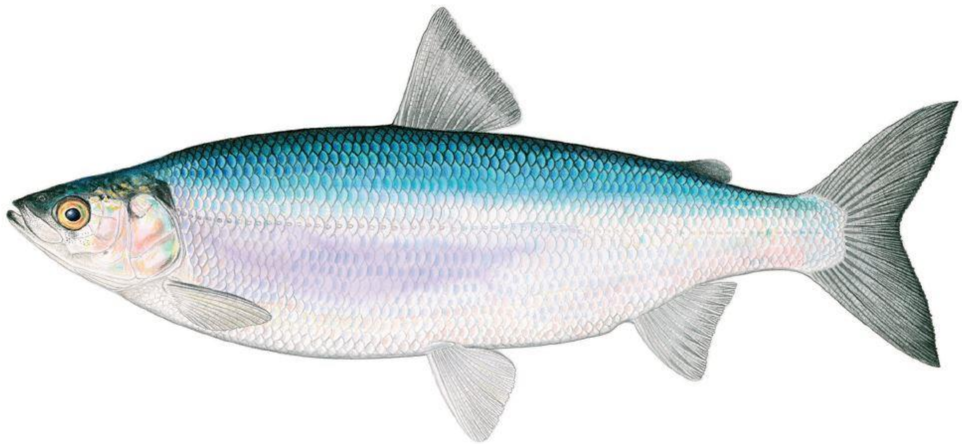
Impediments to the Rehabilitation of Cisco (*Coregonus artedi*) in Lake Erie



In fulfillment of a charge from the
Lake Erie Committee to the
Lake Erie Coldwater Task Group

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Cover image: Albus form collected by W. Koelz west of Port Stanley, Ontario, 16 December 1922, Univ. Mich. Mus. Zool. specimen 59375, STL 322 mm. from Eshenroder et al. (2016).

Abstract

Lake Erie Cisco populations are at a minute fraction of historical levels. The Lake Erie Committee has recognized the re-establishment of Cisco as desirable within their Fish Community Goals and Objectives and the Lake Erie Environmental Objectives. The Committee has thus charged the Coldwater Task Group with the completion of an impediments document that outlines the current state of knowledge of Cisco in Lake Erie and provides managers the necessary information to determine if achieving this goal is feasible in the current and future states of Lake Erie. This document explores the historical significance of Cisco in Lake Erie, their ecology, the current status of stocks, and the source of contemporary samples. Perceived risks, benefits, and impediments to rehabilitation are presented. Lastly, the results of a survey and general comments from both Lake Erie and upper Great Lakes biologists on perceived impediments and knowledge gaps is presented to provide additional guidance.

Introduction

Cisco, formerly known as Lake Herring (*Coregonus artedi*), played an historically important ecological role as the primary coldwater planktivorous prey fish in Lake Erie and once supported the largest commercial fishery in the Laurentian Great Lakes (Smith 1951). Strong Cisco fisheries existed in Lake Erie until 1925, when the population collapsed (Hartman 1972). A limited fishery persisted in Long Point Bay in the eastern basin until the 1950s (Oldenburg et al. 2007). Ciscoes are now considered extirpated in Lake Erie, although a few specimens have been observed over the past two decades, mainly by commercial fishers. The decline in the Lake Erie Cisco population, and in fact, the decline of practically all coregonid species throughout the Great Lakes in the early- to mid- 20th century, has been attributed to a variety of factors including: over-fishing, habitat loss and degradation, lake eutrophication, and interactions with non-indigenous species such as Rainbow Smelt (*Osmerus mordax*) and Alewife (*Alosa pseudoharengus*) (Christie 1973; Ebener 1997; Baldwin et al. 1979; Madenjian et al. 2008). Madenjian et al. (2008) proposed that an interaction between spawning habitat degradation and overfishing was the primary driver of Cisco collapse across the Great Lakes, excluding Lake Superior. However, the exact relative importance of each of these factors as drivers of population collapse and as limiting factors of Cisco population production remains unknown.

Cisco is recognized in Lake Erie's Fish Community Goals and Objectives (Ryan et al. 2003) as a rare species in need of protection, and mentions that their return as a dominant planktivore would be a desirable component of the fish community structure in the lake's eastern basin. Cisco rehabilitation is described in Lake Erie's Environmental Objectives as a potential mechanism to maintaining strong predation on pelagic zooplankton in order to achieve water clarity favoured by percids in the central basin and nearshore areas of the eastern basin (Davies et al. 2005). Based on literature reviews which informed Lake Erie's Lake Trout Rehabilitation Plan (Markham et al. 2008), it has been proposed that the rehabilitation of Cisco would have positive consequences for the successful rehabilitation of Lake Trout (*Salvelinus namaycush*) in Lake Erie by providing an alternate prey source for not only Lake Trout, but also Walleye (*Sander vitreus*) and other top predators. A larger prey fish relative to Rainbow Smelt and Alewife, Cisco may provide increased energetic gains to Lake Trout and other piscivores that result in enhanced growth and fecundity (Mason et al. 1998; Kaufman et al. 2009). Successful rehabilitation of Cisco has been considered critical for developing self-sustaining native salmonid populations in Lake Ontario (Bowlby et al. 2007). Lastly, Cisco re-establishment would alter the current planktivore community and result in a more stabilized coldwater food web (Madenjian et al. 2008).

As a precursory step to determining if Cisco restoration were feasible and the development of a management strategy warranted, the Lake Erie Coldwater Task Group (CWTG) was charged by the Great Lakes Fishery Commission's Lake Erie Committee (LEC) with preparing a document outlining possible impediments to Cisco rehabilitation given the current and anticipated future states of Lake Erie. Below we explore current and historical information available on Cisco population structure, ecology, and status in Lake Erie, and potential beneficial and detrimental impacts of Cisco rehabilitation. Rehabilitation impediments and knowledge gaps such as climate change, competition with existing invasive species, changes to the food web, changes in the Lake Erie fish community, and loss of critical habitats are then explored. The information in this document will provide managers with the information necessary to help inform potential next steps and management alternatives for Cisco rehabilitation in Lake Erie.

CISCO POPULATION STRUCTURE, ECOLOGY, AND STATUS

Population Structure

From a general literature review, James (2010) concluded that Cisco (*Coregonus*, subgenus *Leucichthys*) had been classified into as many as 39 different species due to their variation in life history, ecological characteristics, and phenotypic characteristics across their range. The phenotypic and ecomorphic variation has also resulted in some disagreement about the number of morphotypes that existed in the Great Lakes. Koelz (1929) described three morphotypes: a slender form (*Leucichthys artedi artedi*), a deep compressed form (*L. artedi albus*), and a deep bodied form (*L. artedi manitoulinus*). Eshenroder et al. (2016) describe various accounts of historic Lake Erie morphotypes, and generally agree with Koelz (1929) who proclaimed that the *L. a. albus* (deep compressed) morphotype was most common in Lake Erie although the *L. a. artedi* form also occurred. Recent multivariate analysis of Koelz's archived Great Lakes samples resulted in significant separation among the three morphs based on 15 body measurements and showed high classification success (>88%) for the morphs historically found in Lake Erie (Yule et al. 2013). Trautman (1957) also recognized two different "types" of Cisco in Lake Erie (*artedi* and *albus*); however, he concluded that *artedi* was most numerous in the deep eastern basin and *albus* was a more shallow-water form.

Within the *albus* and *artedi* forms in Lake Erie (Koelz 1929), multiple stocks may have existed. Historical evidence from Lake Erie suggests that some stocks of Cisco followed a migratory pattern, heading to the western basin in the fall to spawn and returning to the cooler, deeper waters of the eastern basin in the summer months (Goodyear et al. 1982). Goodyear et al. (1982) also noted that spawning occurred in the Long Point Bay area of the eastern basin. Specifically, spawning was reported on the east and west sides of Bluff Bar and along the south shore of Long Point, and the bay served as a nursery area. Oldenburg et al. (2007) deduced from Goodyear et al.'s (1982) spawning habitat maps and information on migration patterns that fish spawning in Long Point Bay were likely a separate spawning stock from the migratory stocks that spawned in the western end of the lake. Trautman (1957) also provided evidence for the existence of multiple spawning stocks where winter catches around the western basin islands were *albus* (which Trautman referred to as "intermediates"), in the central basin were *albus*, and east of Ashtabula were *artedi* and *albus*. Further mechanisms, beyond geographically distinct spawning aggregations, have allowed for the maintenance of Cisco stock structure within the Great Lakes such as discrete deep water versus shallow water spawners (see Stockwell et al. 2009).

Cisco Ecology

Spawning

Cisco are aggregate spawners. According to historical records, spawning areas suitable for Cisco were distributed throughout all three basins of Lake Erie, including the nearshore areas of the southern shore, the Bass Islands area in the western basin, the northern shore of the east-central basin, and the Long Point area in the east basin. The Long Point area was also identified as a substantial nursery area (Goodyear et al. 1982; Figure 1). The Maumee and Detroit Rivers also served as very important sources of larvae to Lake Erie. Cisco typically spawn in shallow, nearshore areas when autumn water temperatures decrease from 5°C to 2°C; usually within a two-week period in late November to early December. There is also evidence that Great Lakes Cisco may spawn pelagically over deep water (Scott and Crossman 1973). Spawning substrate includes clean, hard substrate in 1-20 m (3 – 66 ft) of water, but they are also reported to spawn over mud and vegetation (Goodyear et al. 1982; Scott and Crossman 1973). Stockwell et al. (2009 and references within) reported that Cisco have no specific type of preferred spawning substrate in Lake Superior. Based on commercial harvest data, Madenjian et al. (2011) surmised that Cisco heavily rely on just a few key spawning areas within a lake to sustain the population. Furthermore, Rook et al. (2013) proposed that evolutionary processes have resulted in spawning site fidelity in Cisco such that spawning habitats are linked to productive nursery areas via wind-driven processes (e.g., currents) that provide high juvenile survival.

Several studies have linked environmental conditions to reproductive success during incubation and early life stages. Miller (1952) suggested that year-class strength in Lake Whitefish (*Coregonus clupeaformis*) may be inversely correlated to wind strength, which may affect egg deposition, survival and retention on spawning reefs. Ventling-Schwank and Livingstone (1994) reported that bottom currents associated with winter storms were responsible for the offshore transport of coregonid eggs, plus silt and clay, into deeper waters which may affect egg mortality by transport into less suitable waters and by burial. Because of this, spawning sites that are protected from prevailing winds and associated currents, such as reefs and bays, may have greater success.

Eggs

Eggs are non-adhesive and settle into substrates for development during winter; no parental care is given. Eggs that settle into shallow and/or high energy wave areas are vulnerable to hydrodynamic processes (e.g., winter storm-induced waves), especially in winters with little or no ice cover, that result in erosional processes that may reduce localized egg survival. Conversely, Hardy (1994) indicated that strong year classes of Lake Whitefish were coincident with winters of early and prolonged ice cover. Hatching usually occurs from late March to May when temperatures are between 5°C and 6°C. The importance of the timing of emergence of Cisco larvae and food availability remains uncertain (i.e., the match-mismatch hypothesis; Cushing 1990). Evidence that Cisco can survive without foraging for up to a month after hatching (see Stockwell et al. 2009), as well as their successful recruitment in infertile lakes, suggests that post-hatch foraging should not be a limitation in Lake Erie.

Larval

Larval Cisco are usually found in shallow water, including protected bays, near the water surface in May and June (Anderson and Smith 1971; Selgeby et al. 1978; Hatch and Underhill 1988; Oyadomari and Auer 2004). Warm water temperatures in the upper 1-3 m are believed to trigger fast growth, but variation in water temperature across the lake can result in differential early growth (Kinnunen 1997). Cisco begin to move to deeper waters when nearshore water temperatures exceed 11°C (Oyadomari and Auer 2004) and at sizes exceeding 15 mm TL (Stockwell et al. 2009). In Lake Superior, growth and dispersal appear to be related to the temperature of the nursery area and currents (Oyadomari and Auer 2008). Scott and Crossman (1973) reported that Cisco move into deeper water in the summer months, moving below the thermocline. Edsall and Colby (1970) reported lower and upper lethal temperatures for age-0 Cisco at 0°C and 26°C respectively, and Wismer and Christie (1987) indicated a preferred temperature range of 9-14°C.

Recruitment

Great Lakes Cisco populations often exhibit highly variable recruitment, and Yule et al. (2008) found the Lake Superior spawning stock to be dominated by a few strong year classes with maximum ages that exceeded 20 years. Scott (1951) reported that small spawning stocks can produce some of the strongest year classes, whereas large spawning stocks can produce some of the weakest year classes. This could occur due to density-independent environmental conditions or by strong density-dependent mortality in the pre-recruit stage; the critical period is believed to occur between the egg and the end of the larval stage (Kinnunen 1997). Beyond the importance of adult spawning stock size, reproductive success and year class strength have been linked to environmental conditions. Stockwell et al. (2009) proclaimed that Cisco recruitment will be poor regardless of biological challenges (i.e., spawning stock size) without favorable environmental conditions. Important environmental drivers have included wind strength, ice cover, wave energy, and spring and summer temperatures; their relative importance may vary with life stage (e.g., Rook et al. 2013). Effects of environmental drivers may also vary with geographic location. For example, lake-wide synchrony in recruitment strength among multiple spawning stocks provides evidence of important regional environmental factors, whereas within-lake variation in recruitment strength among multiple spawning stocks can indicate localized impacts of environmental conditions and habitat quality (Rook et al. 2012; Rook et al. 2013).

Foraging

Cisco are primarily zooplanktivores as both juveniles and adults (Selgeby et al. 1994; Link et al. 1995; Hrabik et al. 1998), but their diet varies considerably, including *Mysis relicta* and *Diporeia hoyi (*hereafter referred to as *Mysis* and *Diporeia*, respectively), copepods, immature stages of aquatic insects, and eggs and fry of small cyprinids (Scott and Crossman 1973). Historically, Cisco in Lake Erie's eastern basin preyed heavily upon *Mysis*, whereas western basin Cisco preyed upon herbivorous cladocerans (Langlois 1954). Langlois (1954) stated that young Cisco are "absolutely dependent upon an abundance of zooplankton" during spring. Cisco selectively consume larger particles within the water column (Link and Edsall 1996) and, as a mid-trophic-level organism, provide a link between secondary consumers (i.e., zooplankton) and higher level predators (e.g., Lake Trout; Matuszek et al. 1990). At high abundances, selective feeding by Cisco can restructure the zooplankton community towards smaller-bodied individuals and change relative zooplankton taxa abundances (Rudstam et al. 1993). Current data from Lake Superior show that adult Cisco (> 260 mm) fed primarily on copepods during the spring, and both adult and juvenile Cisco largely fed on calanoid copepods and *Bythotrephes longimanus* (hereafter referred to as *Bythotrephes*) in fall (Kevin Keeler, University of Michigan, unpublished data). Limited diet information is available from ten contemporary Lake Erie samples of Cisco. Two individuals captured during April (1996 and 2011), in depths >=100 feet by fishers targeting coldwater species, had consumed small fish; Round Goby (*Neogobius melanostomus*) were included in the sample from 2011. Eight other individuals, captured during May-July at shallower depths (24-80 feet) had consumed Chironomidae larvae; one of these had additionally consumed *Bythotrephes* (Table 1).

Predation

Historically, Cisco was the main prey for Lake Trout in the eastern basin before both species collapsed in the 1950s (Markham et al. 2008). Currently Lake Trout primarily consume Rainbow Smelt and to a lesser extent Round Goby (Coldwater Task Group 2017). While the primary predator of Ciscoes is Lake Trout, they are also consumed by Rainbow Trout (Steelhead, *Oncorhynchus mykiss*), Northern Pike (*Esox lucius*), Burbot (*Lota lota*), Yellow Perch (*Perca flavescens*) and Walleye (Scott and Crossman 1973).

Age and Growth

Historical size structure data indicate differences between western basin and eastern basin maximum weights and lengths. This supports the conclusion that the Lake Erie Cisco population was comprised of multiple morphotypes. Trautman (1957) reported usual lengths for *artedi* as 279-381 mm and usual weights as 539-709 g; maximum lengths reached 508 mm and maximum weights reached 1361 g. Trautman (1957) reported usual lengths and weights for *albus* as 279-457 mm and 311-1361 g.; maximum lengths reached 635 mm and maximum weights reached 3629 g. Historical Lake Erie Cisco age distribution is unknown, however Van Oosten (1930) claimed that gill net catches in the mid-1920s (i.e., the period of severe collapse) were comprised primarily of age-2 and age-3 fish. It was implied that these fish were not captured as a spawning aggregation, but were schooled in response to environmental factors. Scott and Crossman (1973) reported that maturity can occur as early as age-2, but not until later ages at more northern latitudes (e.g., age-6 at Great Bear Lake). Cisco maximum age at Lake Superior has been estimated to exceed 20 years (Yule et al. 2008).

In 2014, a collection of historic Cisco scale samples from the mid-1900s (1949-1962) were located. Samples were collected from commercial fisheries at landing ports; thus, exact capture location, specifics of fishing gears, and how sample collection effort was distributed are unknown. However, samples did indicate a cross-lake distribution with highest number of samples coming from Wheatley, Ontario and Erie, Pennsylvania (Figure 2). Given that these samples were collected during the last period of Cisco commercial fishing in Lake Erie, they may provide valuable information to understanding population composition before the final population crash. For example, scales and affiliated information from scale envelopes may allow for analyses of genetic stock structure, sex ratio, size structure (acknowledging uncertainty regarding gear selectivity), and age structure (acknowledging bias in estimates from scales relative to otoliths at older ages).

Status of Cisco in Lake Erie

Contemporary Cisco observations are rare in Lake Erie. While agency fishery assessment programs have only captured 2 in the past 25 years, the Ontario commercial fishery has surrendered individual Cisco regularly since the 1990s (Figure 3). Since 1999, an average of two samples have been acquired annually, with as many as seven (1999) and as few as none (2009; the only year with no reports). These samples represent the only information available for understanding the current status and composition of Cisco in Lake Erie. Most of the reported fish were surrendered and were therefore available for biological sampling including lengths, ages, weights, and tissue for genetic analysis. Not all samples were retained and for those that were, repeated thawing and freezing rendered them inadequate for some morphometric analyses. Recognition of the importance of these samples and the variety and requirements of available analyses has resulted in the more careful handling, documenting, preservation, and long term archiving in recent years. A summary of sampling details and catch information from forty-six contemporary Lake Erie Cisco is presented in Table 1.

Contemporary observations have occurred lakewide, in all basins, from as far west as Pelee Island and as far east as Port Colborne. Most (n=24; 52%) of these fish have been captured in the waters associated with Long Point, ON, from May through October at a mean depth of 26.5 m (87 ft). It should be noted that the high catches in this area may be due to the ability of one commercial fisher to identify and report Cisco, and not necessarily due to an area of high concentration. Central Basin catches have occurred in June through August (one in November) at a mean depth of 21.3 m (70 ft), while the west central and western basin catches have occurred in fall (September) winter (December) and spring (March through May), but not in summer months.

Contemporary samples have been captured in both gillnet (mainly targeting Yellow Perch but also Walleye, White Bass (*Morone chrysops*) and Lake Whitefish) and trawl fisheries (targeting Rainbow Smelt), in depths from 7.3 – 47.2 m (median 22.6 m) (24 -155 ft (median 74 ft)). In gillnets set deep (>25m or 82 ft), Cisco have been captured concurrent with Lake Whitefish, Lake Trout, and Burbot whereas, for shallower gillnet sets, they have been captured in association with both cool and warmwater species: Rainbow Smelt, Yellow Perch, Walleye, White Perch (*Morone americana*), Gizzard Shad (*Dorosoma cepedianum*), Alewife, Freshwater Drum (*Aplodinotus grunniens*), and Emerald Shiner (*Notropis atherinoides*), among others.

Ages of the contemporary samples range from age-1 through age-7 with one age-9 and one age-12. The year of the highest reporting rate (1999) also saw the highest frequency of yearling fish (4 of 7). This 1998 year class continued to be the most commonly represented, in future years (Figure 4). Although some error may be associated with aging of scales from older individuals, this general time period (1998-2000), remains prevalent, suggesting that the last year of significant recruitment may have occurred ~16 years ago. Anecdotally, 1998 was also a year that the commercial fish processors commented on observing “herring” in fall catches as something out of the ordinary (J. Omstead, Omstead Foods, Wheatley, Ont. pers. com.).

Source of Contemporary Lake Erie Cisco

It is important to note that contemporary Cisco samples provide some understanding of the status and composition of Cisco *existing* in Lake Erie, without full knowledge of their origin. The question remains as to whether all or any of these fish: i) were produced in the upper Great Lakes and emigrated downstream; ii) were produced within Lake Erie by immigrants from an upper Great Lakes stock; iii) were produced within Lake Erie from a remnant Lake Erie stock; or iv) represent some combination of sources. Answering this question is important for informing decisions to stock for rehabilitation, including the choice of an appropriate source. Knowledge of successful reproduction within Lake Erie would also inform expectations of the success of rehabilitation actions such as stocking.

To approach this question, several attempts have been made to compare contemporary samples from Lake Erie to current and historic stocks of Ciscoes from the Great Lakes. In order to do this effectively, a comprehensive characterization of all possible source groups, both current and historic, would be necessary. Unfortunately, although there is some overlap in the individual fish examined, quite often comparisons were made between unique Lake Erie samples as well as to unique catalogues of information about source stocks. The analyses are outlined below:

<u>Genetic Analysis 1.</u> Nine contemporary (1990s) samples from Lake Erie, were compared with samples from the other Great Lakes (numbers and exact sources unknown), including archived Lake Erie specimens from 1955-65, using microsatellite markers. It was concluded that the *contemporary Cisco were genetically most similar to Lake Erie specimens from 1950s and 1960s, suggesting that a remnant of an original Lake Erie stock may exist* (Rocky Ward, USGS Northern Appalachian Research Laboratory, Wellsboro, PA, unpublished data). However, the next closest match was contemporary samples from Lake Huron, and the possibility exists that Lake Erie specimens from the 1950s and 1960s were comprised partially or entirely of immigrants from Lake Huron.

<u>Genetic Analysis 2</u>. (2017; ongoing) Thirty-seven contemporary samples (1990-2015) were made available for comparison to Great Lakes stocks using microsatellite markers. Comparisons were to be made to a database of Great Lakes Cisco genetic information which included contemporary samples from Lakes Superior, Huron, Ontario, and Erie (circa 1920s). A preliminary analysis using 9 contemporary Erie samples concluded that *none could be assigned with confidence to a source population, including 1920s Lake Erie*. Recognized deficiencies in this analysis include an incomplete set of reference groups as follows: only northern L. Huron spawning aggregations were included; no samples from 1950-60 Lake Erie were available (used in Genetic Analysis 1.); and no deepwater cisco samples (e.g. *C. hoyi*) were used, potentially significant given conclusions from Morphometric Analyses #2 (below).

<u>Morphometric Analysis 1</u>. (2013; ongoing). Yule et al. (2013) used data collected by Koeltz (1929; including both *C. albus* and *C. artedi* from Lake Erie) to refine a discriminant function

analysis (DFA) that could differentiate historic Great Lakes Cisco morphotypes. They subsequently analysed contemporary Cisco from Lakes Huron, Ontario, and Superior (the same populations used in Genetic Analysis 2). It was concluded that the *C. albus* form, the most prevalent Lake Erie form circa 1929, was represented by contemporary northern Lake Huron. A separate cluster analysis using the Koeltz (1929) measures and newly collected measures from contemporary Lake Erie Cisco (n=13), *found that the Erie fish were distinct; dissimilar from the historic Erie C. albus and C. artedi forms*. They were most similar to contemporary Lake Ontario Cisco from Chaumont Bay (D. Yule. USGS, Lake Superior Biological Station, Ashland, WI. Pers comm.). *Contemporary Cisco from northern Lake Huron such as the Drummond Island population were closest to the deep-bodied historic Erie form (C. albus).*

<u>Morphometric Analysis 2</u>. (2015) Twenty-two contemporary (2003-2015) Lake Erie Cisco were examined for 18 morphologic and meristic measures at the Royal Ontario Museum (ROM) in December 2015. Together with a similar set of data from nine contemporary (1995-1999) fish measured at the ROM in 2000, these data were used to inform a GLFC monograph entitled "Ciscoes of the Laurention Great Lakes and Lake Nipigon" (Eshenroder et al. 2016). These 31 fish and their classifications are listed in Table 1. The exercise resulted in the conclusion that most 25 of 31 fish examined could be classified as "swarm" Cisco, a form found in Lake Huron and described as a hybrid of deepwater forms of Cisco. Two of the fish were thought to be crosses between "swarm" Cisco and Lake Whitefish. Two were classified as *C. albus* and two as *C. artedi*, both described historically in Lake Erie but also present in Lake Huron.

Additional information is available to inform questions about immigration of Cisco into Lake Erie from the upper lakes. Recent surveys conducted in the Huron-Erie corridor have collected young coregonids (Coldwater Task Group 2014). Two larvae (12 mm TL) were collected in May 2010 and 1 in June 2011 in the St. Clair River (Edward Roseman, USGS, personal communication). Two of those coregonids were assessed using DNA barcoding techniques and determined to be Cisco, whereas the third was classified as an unidentified coregonid (Wendylee Stott, USGS, personal communication). In December 2011, 9 young coregonids were collected in floating fyke nets in the Livingstone Channel of the Detroit River just downstream of Wyandotte, MI (Justin Chiotti, USFWS, personal communication). Seven of those were subsequently verified as probable Cisco (Wendylee Stott, USGS, personal communication). Juvenile coregonids were collected in the Detroit River in December 2012, and Cisco larvae (n=22) and juveniles (n=39) were collected in the St. Clair River during 2013 (Edward Roseman, USGS, personal communication).

To summarize:

- Historically, Lake Erie Cisco populations were primarily composed of a compressed, terete bodied form (*C. albus*) with lesser representation from the subterete form *C. artedi* (Historic Morphometrics; Koelz, 1929).
- The *C. albus* form still exists in northern Lake Huron, and contemporary Lake Erie Ciscoes do not resemble this form (Morphometric Analysis 1).
- Thirteen percent of contemporary Lake Erie Ciscoes classify as *C. albus* or *C. artedi*, however most appear to be hybrid "swarm"- forms common to Lake Huron (Morphometric Analysis 2).

- Contemporary Lake Erie Cisco are most similar to historic Lake Erie Cisco circa 1955-65; they are secondarily similar to contemporary Lake Huron Cisco (Genetic Analysis 1).
- Contemporary Lake Erie Ciscoes do not resemble Contemporary Great Lakes Cisco populations examined to date nor do they resemble Lake Erie Cisco circa 1929 (Genetic Analysis 2).
- Ciscoes supporting the fisheries of the late 1950s may have been different than those supporting the fisheries in the late 1800s and early 1900s (Genetic Analysis 1 & 2).

In conclusion, a more complete picture of relationships between contemporary and historic populations will no doubt emerge as additional genetic analysis continues, and hypotheses are tested (e.g. genetic examination of coregonines from the Huron-Erie corridor and the inclusion of Lake Huron's deepwater forms as comparative groups). The entire exercise will benefit from a comparison of conclusions from different analyses applied to the same individual fish. Regardless, we feel that that evidence to date is sufficient to conclude that Cisco individuals currently recovered from Lake Erie are unlikely to represent an original historic archetype, specifically adapted to the lake. Rather they likely represent an amalgam of sources, morphotypes and possible hybridizations. While the presence of juvenile and larval coregonids in the Huron-Erie corridor provides a potential source to explain young Cisco recently recovered from Lake Erie, we cannot rule out the possibility of within-Erie production.

Potential Benefits and Detriments of Cisco Rehabilitation

Benefits

The benefits of rehabilitation of Cisco to Great Lakes planktivore communities were outlined at a workshop on Great Lakes Cisco (Fitzsimons and O'Gorman 2006). Those that could apply to Lake Erie include:

- ***Increasing diversity and resiliency of the prey fish community**:* A diverse prey fish community reduces predators' vulnerability to swings in prey fish abundance levels. Native Cisco co-evolved with Great Lakes predators creating a "harmonic community" that should be predictable and stable (Ryan et al. 2003). In contrast, Alewife, and to a lesser extent Rainbow Smelt, are shorter-lived, invasive species that did not co-evolve with native Great Lakes piscivores, and can experience massive winter die-offs. Thus, rehabilitating the Lake Erie Cisco population should increase ecosystem resiliency (see Holling 1973; Gunderson 2000), may help the lake return to its historical stable state stabilizing fishery harvests in the process. Furthermore, establishing and maintaining a diverse forage fish community is an objective identified in the Lake Erie Fish Community Goals and Objectives (Ryan et al. 2003).

- ***Reducing invasive Bythotrephes abundances:*** Lake Erie's food web has changed in past decades and invasive lower trophic level species have likely influenced trophic transfer. In particular, *Bythotrephes* (a predatory cladoceran) has become abundant (Bunnell et al. 2014) and been shown to alter Great Lakes zooplankton communities by selective predation on large herbivorous species (Barbiero and Tuchman 2004). Cisco have been shown to selectively feed on *Bythotrephes*. In Lake Superior, *Bythotrephes* constituted over 50% of Cisco diet composition in the fall (Kevin Keeler, University of Michigan, unpublished data). Restoration of Cisco may enhance top-down control of the invasive *Bythotrephes* and reduce zooplankton predation mortality by *Bythotrephes*.

- ***Providing a larger-bodied prey for piscivores:*** Cisco achieve a larger overall body size than both rainbow smelt and alewives, and large bodied prey items are essential for efficient and energetically advantageous feeding, especially Lake Trout (Mason et al. 1998) as well as many other Great Lakes piscivorous fish species (e.g., Walleye; Kaufman et al. 2009). Modeling of Lake Trout diets in Lake Superior concluded that the best growth in older Lake Trout occurs on a diet of Cisco (Mason et al. 1998). Growth and condition of Lake Erie Lake Trout has been satisfactory (Coldwater Task Group 2017) and having Cisco as a primary prey should not inhibit these traits. In fact, a larger prey item may provide further benefits to piscivores by enhancing foraging efficiency. Henderson et al. (2004) reported higher growth efficiencies and lower ingestion and activity rates for Walleye in lakes with Cisco as forage relative to lakes without Cisco where Yellow Perch was the primary forage. Increased energy from consuming high quality forage could be allocated to reproductive output and surviving Sea Lamprey (*Petromyzon marinus*) attacks (Lake Huron Technical Committee 2007). Introduction of Cisco at Lake Opeongo, Ontario, benefitted Lake Trout production via reducing cannibalism and increasing the number of recruits per mature female (Matuszek et al. 1990).

- ***Reducing thiamine deficiency:*** Thiamine deficiency in Great Lakes salmonids has been linked to diets dominated by Alewife and Rainbow Smelt (Honeyfield et al. 2005; Fitzsimons et al. 2009). When eggs are deficient in thiamine, it causes direct mortality just prior to and during emergence, and indirect mortality thereafter, due to reduced growth and impaired foraging and predator avoidance. The importance of thiamine deficiency to Lake Erie Lake Trout is not completely understood. Lake Trout consume more Rainbow Smelt than Alewife, and Rainbow Smelt have half the thiaminase activity of Alewife (Tillitt et al. 2005). Furthermore, Fitzsimons et al. (2009) reported that average thiamine levels were higher in Lake Erie Lake Trout whose primary forage was Rainbow Smelt than Lake Ontario Lake Trout that primarily ate Alewife. However, Fitzsimons et al. (2009) concluded that Lake Erie Lake Trout are still at risk for reduced reproductive success from thiamine deficiency despite their Rainbow Smelt based diet. Recent thiamine testing on female Lake Trout eggs collected on a small reef in the New York waters of Lake Erie near the mouth of Eighteen Mile Creek, New York, in 2010 and 2011, found average thiamine levels well above the lethal threshold of 4.0 nmol/g (2010=15.3 nmol/g, n=11; 2011=19.7 nmol/g, n=6; NYSDEC, unpublished data). Rehabilitation of Cisco, which are thiaminase-free, would provide an alternative Lake Trout prey resource and help ensure that thiamine deficiency does not become an impeding factor to Lake Trout reproduction.

Detriments

In addition to considering how Lake Erie's current ecosystem would support an attempt at Cisco rehabilitation (see "Impediments"; below), it is also important to consider the potential ecological impacts of a rehabilitated Cisco population on lower trophic levels and on other members of the fish community, including "new normal" naturalised species such as Rainbow Smelt and its related fishery.

- ***Competition and Impacts on the fishery:*** Potential competition between Cisco and Rainbow Smelt should also be thought of in terms of negative effects on smelt given that the Lake Erie Fish Community Goals and Objectives specifically include the objective of "sustainable harvests of Rainbow Smelt" in the central and eastern basins (Ryan et al. 2003). Evidence from Lake Superior would suggest that the problem of co-existence lies with the suppression of Cisco by Rainbow Smelt (Stockwell et al. 2009; Meyers et al. 2009; Meyers et al. 2014), however some thought should be given to whether this might play out differently in Lake Erie. Rainbow smelt currently have the highest commercial landings (by weight) of any species in Lake Erie, and negative impacts on this resource have the potential to cause economic impacts on the commercial fishing industry.

- ***Competition with Lake Whitefish and Burbot***: Lake Whitefish, historically co-existed with Cisco in Lake Erie, but are currently experiencing populations decline resulting from recruitment failure (Coldwater Task Group 2017). Competition with Lake Whitefish was considered as a possibility on Lake Huron, but it was noted that as adults they occupy different niches, pelagic and benthic, respectively (Lake Huron Technical Committee 2007). The possibility of planktivorous Cisco compounding the stress on two existing coldwater species which are currently experiencing poor recruitment (Lake Whitefish and Burbot) has been raised (See Survey Comment #3; Appendix 2). Martin and Fry (1972) described the effects of Cisco introduction to Lake Opeongo as generally positive towards Lake Trout but may have contributed to delayed maturity in Lake Trout, suppression of Yellow Perch and negative influences on the growth of young Lake Whitefish.

REHABILITATION IMPEDIMENTS AND KNOWLEDGE GAPS

It has been over sixty years since the last large year class of Cisco was produced in Lake Erie. During that time period, significant ecological changes have occurred; some are perceived to benefit Cisco rehabilitation, whereas others are perceived to impede rehabilitation. These ecological changes need to be considered within the context of Cisco life history and ecology (see Figure 5) in order to understand their potential impacts on rehabilitation success. Despite these changes, it is worth noting that Cisco have similar life history requirements (eggs, larvae, juveniles, adults) as Lake Whitefish, and it would seem logical that the same bottlenecks would affect both species. The reasons why Lake Whitefish have managed to persist in Lake Erie while Cisco have not are not clear, but the fact that ecological conditions present in the lake are still suitable to sustain a Lake Whitefish population is encouraging for the possibility of Cisco to recover. Below, we highlight ecological changes and uncertainties and discuss their potential to benefit or impede Cisco rehabilitation.

- ***Reproducing population in Lake Erie?*** While it is unlikely that contemporary Lake Erie Ciscoes represent a remnant stock, directly related to historic populations (see "Source…"; above), reproduction by non-remnant stock individuals (e.g. immigrants from the upper lakes) may still be taking place within Lake Erie. Evidence of successful reproduction would inform expectations of success for such rehabilitation actions as stocking. While other native coldwater species (e.g., Lake Whitefish and Burbot) increased in abundance in the 1990s and 2000s, this increase was not realized with Cisco (Ryan et al. 1999, Oldenburg et al. 2007), implying that if reproduction is occurring, the magnitude is not significant. Recent efforts by the USGS (Coldwater Task Group 2017) to capture Cisco near historic reefs in western Lake Erie during the fall were unsuccessful. A study is currently underway to sample coregonine larvae at historic spawning and nursery areas in Lake Erie, and this may provide further information on this question directly.

- ***Larval predation by invasive species:*** Alewife and Rainbow Smelt have been shown to prey upon larvae of native Great Lakes fishes. Effects of Alewife are not expected to limit Cisco recovery in Lake Erie because: 1) Lake Erie's Cisco population collapsed prior to Alewife invasion; 2) Alewife abundances in Lake Erie are relatively low compared to other Great Lakes; and 3) a review of Alewife effects on Great Lakes fish communities led Madenjian et al. (2008) to conclude that degradation of spawning habitat was much more influential on Cisco collapses than interactions with Alewife. In contrast, Rainbow Smelt levels may hinder Lake Erie Cisco rehabilitation efforts, especially in the eastern basin. Studies have shown that abundant Rainbow Smelt populations suppress Cisco populations through predation of larvae and juveniles, and are a major impediment to the recovery of Cisco stocks (Stockwell et al. 2009; Myers et al. 2009). The suppression of Rainbow Smelt through massive Lake Trout stocking was considered a critical component for recovery of Cisco in Lake Superior (Stockwell et al. 2009). Myers et al. (2009) used bioenergetics models to show that Rainbow Smelt consumption can account for up to 100% of larval Cisco mortality, depending on predator-prey overlap and predator feeding rate, in Black and Thunder Bays at Lake Superior. Furthermore, Rook et al. (2013) found Rainbow Smelt biomass to be a significant factor in Cisco stock-recruitment models for Lake Superior, but their importance varied by lake region as Rainbow Smelt densities varied. In Lake Erie, hydroacoustics sampling in the eastern basin from 2007 through 2016 indicated lower densities of yearling and older Rainbow Smelt-sized targets in the last five years (Forage Task Group 2017). However, densities have increased in recent years in central basin hydroacoustic surveys (Forge Task Group 2017). Densities of yearling and older Rainbow Smelt in Lake Erie's eastern basin trawl surveys remain high relative to other Great Lakes, averaging 343 and 620 fish/ha in Ontario and New York over the last 10 years, respectively (Forage Task Group 2017), compared to 159 fish/ha in Lake Superior trawl surveys (Vinson et al. 2016). Despite Rainbow Smelt abundance being drastically reduced in Lake Erie compared to abundance in the 1980s (Ryan et al. 1999), they are perceived to remain an impediment to Cisco restoration at the current population level. It is unknown if a Rainbow Smelt abundance threshold exists, below which the probability of Cisco rehabilitation success would dramatically increase.

- ***Forage availability and potential for competition with invasive species:*** Species invasions have resulted in changes to the food web and raised uncertainty about forage availability needed to support a Lake Erie Cisco population. Direct competition between Rainbow Smelt and Cisco for zooplankton may occur because both are zooplanktivores that feed on copepods and cladocerans in the Great Lakes. Selgeby et al. (1994) concluded that due to differences in diet composition and/or differences in spatial distribution that competition between Rainbow Smelt and Cisco was minimal at Lake Superior (but, see below). Another potential limitation is that *Bythotrephes* exhibit both lethal (via direct consumption) and nonlethal (e.g. shifts in zooplankton vertical distributions to higher densities within the hypolimnion) adverse effects on native zooplankton (e.g., *Daphnia retrocurva*) (Pangle et al. 2007). Decreases in crustacean zooplankton abundance in Lakes Erie, Huron, and Michigan coincided with *Bythotrephes* invasions (Barbiero and Tuchman 2004). In contrast, Cisco have also been shown to selectively feed on *Bythotrephes* (Coulas et al. 1998). *Bythotrephes* has been documented in the diet of contemporary Lake Erie Cisco (see current status, above). In recent investigations to evaluate the forage base available for Cisco at Lake Michigan, very high diet overlap was evident between Lake Superior Cisco and Lake Michigan Rainbow Smelt and Alewife (Kevin Keeler, University of Michigan, unpublished data). The comparisons between Lake Superior and Lake Michigan fish diets led to the conclusion that success of Cisco stocking for population rehabilitation in Lake Michigan may be limited due to seasonal competition with invasive planktivores. In Lake Erie, it is uncertain whether the current-day zooplankton community could support a Cisco population and whether interactions between Cisco and *Bythotrephes* would benefit or impede Cisco restoration. However, zooplankton communities are more similar now to patterns that existed in Lake Erie during 1928-1930 compared to the communities that were present during the height of eutrophication, especially through the 1950s and 1960s (Johannsson et al. 1999).

- ***Changes in the foodweb:*** Lake Erie's food web has changed drastically since the early 1900s when Cisco were abundant. There has been a loss of native species at multiple trophic levels (e.g., Sauger *Sander canadense,* Blue Pike *Sander vitreus glaucus, Mysis* and *Diporeia*) and species invasions at multiple trophic levels (e.g., Sea Lamprey, White Perch, *Bythotrephes*, and dreissenid mussels *Dreissena spp.*) that have led to food web uncoupling and destabilization. In particular, dreissenids have altered trophic transfer within Great Lakes food webs by shunting energy to the benthos and reducing transfer to the pelagic components of the food web (Hecky et al. 2004). A major shift in the zooplankton community (relative composition) following eutrophication (Johannsson et al. 1999) may have precluded any possibility of a resurgence of Cisco during the 1950s – 1960s. A specific concern for Cisco restoration is that *Mysis* are very rare now in the eastern basin (Johannsson et al. 1999) and Langlois (1954) claimed that *Mysis* was one of the most important food items to Cisco in the eastern basin. In contrast, Langlois (1954) highlighted the importance of mayflies (*Hexagenia spp.)* as prey items for Cisco in the western basin. Improvements in water quality have resulted in western basin *Hexagenia* nymph densities that are similar to densities from the 1930s-1950s (Schloesser et al. 2000; Krieger et al. 2007). Similarly attributed to nutrient abatement, calanoid density and biomass is currently higher than that of cyclopoids; once again reflective of the zooplankton pattern in the 1920s (Johannsson et al. 1999). Understanding how Cisco would fit into the current-day Lake Erie food web and how that may differ between basins remains unclear. Given the perceived niche overlap between these species, the apparent reduced carrying capacity of Rainbow Smelt likely reflects a similar, reduced carrying capacity potential for Cisco, if rehabilitation succeeds. Historic maximum commercial yields during their respective periods of dominance were comparable for these planktivores (Cisco 48.8 million lbs. in 1918; Rainbow Smelt: 43.6 million lbs. in 1982; Baldwin et al. 1979).

- ***Climate change:*** Lake Erie is at the southernmost edge of the Cisco range and Myers (1991, 2001) proposed that marine fish stocks near the edge of their range are increasingly sensitive to environmental influences on recruitment. Variation in year class strength appears to be a common trait of Cisco across the Great Lakes (Stockwell et al. 2009). Lake Erie is no exception, with periods of high abundance generally attributed to strong year classes (Scott 1951). Stockwell et al. (2009) suggested that Cisco recruitment is generally determined through density-independent forces, and without favorable environmental conditions, recruitment will be poor regardless of any biological challenges. Predicted climate changes to the Great Lakes region include increased air and water temperatures, increased precipitation, increased wind, decreased ice cover, and decreased dissolved oxygen (reviewed by Lynch et al. 2010).

  In the Great Lakes region temperatures are predicted to increase by 3-5° C during the 21st century based on current global greenhouse gas emission projections while average water levels in Lake Erie are predicted to decrease by approximately 0.4 m (Hayhoe et al. 2010). The influences of climate change on habitat availability and potential for Cisco rehabilitation in Lake Erie are not certain, but climate projections, modeling efforts, and field data suggest that suitable habitat for coldwater species would exist at least through the 21st century. For example, Lofgren (2014) used the Coupled Hydrosphere-Atmosphere Research Model (CHARM) to predict a 2-3° C increase in summer hypolimnion temperatures and potentially a 5° C surface temperature increase on average during 2043-2070 relative to 1964-2000 for Lake Michigan. Lofgren (2014) predicted an average maximum epilimnion temperature of approximately 18°C (in August) and average maximum hypoliminion temperature of approximately 11°C in October after lake turnover for Lake Michigan. Kao et al. (2014) incorporated Lofgren's (2014) temperature predictions in bioenergetics models to conclude that Lake Trout growth and consumption in Lakes Michigan and Huron would be affected by climate change; potentially positively with adequate forage availability. Kao et al. (2014) further concluded that behavioral thermoregulation would allow Lake Trout to occupy preferred water temperatures (e.g., 9° C; Bergstedt et al. 2012), but total area of available preferred habitat may be reduced or occur at deeper depths as a result of climate change.

  In Lake Erie, general predictions of water temperature increases and expected physiological and behavioral adaptations to those increases are not expected to preclude

Cisco rehabilitation. However, other factors (e.g., winter storm dynamics, ice cover) influenced by climate change will likely also be critical to recruitment and self-sustainability. Decreases in winter ice cover, late onset of ice cover, and increased potential for winter storms may drive adults off shallow spawning grounds (Scott and Crossman 1973) and negatively affect egg retention on substrates or decrease egg viability via erosional processes. Alternatively, warmer winter and summer water temperatures may increase egg development, enhance early spring primary production rates, and enhance Cisco growth rates. In the central basin, these same conditions may result in reduced juvenile and adult summer habitat if they exacerbate problems associated with hypolimnetic hypoxia (Fig 5). Recent modeling of climate change effects on Great Lakes Lake Whitefish recruitment (at a fixed spawning stock size) in the 1836 Treaty Waters predicted that some management units may experience increases whereas others would experience decreases; results varied with spatially-specific stock-recruitment relationships and projections of ice cover, warming, and wind speed (Abigail Lynch, Michigan State University, unpublished data).

- ***Loss of critical habitats:*** Loss of habitat was a factor that contributed to the demise of native Cisco stocks in Lake Erie and across the Great Lakes. Madenjian et al. (2008) stated that destruction of key spawning areas preceded population collapse by 10-15 years in Lakes Erie, Huron, and Michigan. Madenjian et al. (2008) highlighted that a Cisco population can rely on a single or very few spawning locations within a lake, and thus, populations are vulnerable if those few, key habitats are degraded and become unsuitable. Historically the Detroit River and its estuary were one of the major spawning areas for migrant Cisco in Lake Erie, and the channelization of the river coupled with removal of gravel forever changed its functionality as a spawning destination (Ryan et al. 1999). Cisco also spawned around the islands in the western basin, in nearshore areas around Cleveland, OH, and Erie, PA, and in Long Point Bay in the eastern basin (Goodyear et al. 1982). However, recent side-scan sonar surveys on historical Lake Trout spawning reefs indicated that habitat has been degraded in these areas, mainly due to dreissenid mussels (Gorman et al. 2010). Studies indicate that Cisco do not have a spawning substrate preference (Smith 1956; Goodyear et al. 1982; Scott and Crossman 1973), but often spawn over gravel or stony substrate (Scott and Crossman 1973). Juvenile Cisco key on rocks and vegetation in shallow protected bays during their first month following hatching (Oldenburg et al. 2007). Degradation of existing habitats is also of concern: changes in lake productivity, occurrence of abundant harmful algal blooms and proliferation of macroalgaes, benthic coverage by dreissenid shells, and other nearshore modifications. Unsuitability in the habitats associated with any of these critical stages has the potential to cause a recruitment bottleneck and would be difficult to isolate.

- ***Sea Lamprey mortality*:** Sea Lamprey are a known source of Cisco mortality. The presence of a Cisco population may lead to increased Sea Lamprey abundance due to an increase in prey availability (Young et al. 1996). Harvey et al. (2008) found that 25% of parasitic-phase Sea Lamprey in Lake Superior were attached to Cisco, and most of these were small, recently-metamorphosed Sea Lamprey. Stockwell et al. (2009) surmised that substantial increases in Cisco abundance may increase survival of young parasitic Sea Lamprey, and increase fecundity of spawning adults due to higher condition, consequently counteracting Sea Lamprey control efforts. Currently, adult Sea Lamprey abundance exceeds the management target for Lake Erie (Coldwater Task Group 2017), which may hinder the probability of successful Cisco restoration.

- ***Changes in fish community:*** The Lake Erie fish community has changed drastically since Cisco were abundant in the early 1900s. Increased abundance of visual feeders such as native Yellow Perch and invasive White Perch may impose significant predation on newly-hatched Cisco larvae and fry. Invasive bottom feeders such as Round Goby could exert predation pressure on the early life stages, possibly feeding on both eggs and larval fish. Steelhead is the most commonly stocked salmonid in Lake Erie (Coldwater Task Group 2017) and adults could exert predation pressure on a recovering Cisco population. Diet studies indicate that Steelhead are generalists, feeding on a wide variety of both fish and invertebrates, although fish make up the bulk of the biomass (Clapsadl et al. 2005). Although piscivore bioenergetics models for Lake Superior did not include Steelhead predation on coregonids, Negus's (1995) results indicated that Pacific salmonids (Chinook salmon, *Oncorhyncus tshawytscha; not currently stocked in Lake Erie*) could accentuate total coregonid consumption beyond just Lake Trout effects. In Lake Erie, Rainbow Smelt and Emerald Shiner are the most common fish species in Steelhead diets, indicating Steelhead may target pelagic species. Changes in the fish community since the time when Cisco were abundant may result in increased predation mortality on a recovering Cisco population.

- ***Commercial by-catch:*** Cisco are currently caught as by-catch in the commercial perch and smelt fisheries, although the catch-per-unit-effort is extremely low presumably due to low abundance. By-catch can be an important source of mortality to a recovering stock (Coggins et al. 2007) and the magnitude of Cisco by-catch in Lake Erie cannot be evaluated without better reporting.

- ***Disease vectors:*** Diseases in Great Lakes aquatic ecosystems have not received as much as attention as other drivers of abundance (e.g., fishing mortality); however, disease outbreaks have been show to impose large-scale mortality. Cisco are highly susceptible to viral hemorrhagic septicemia virus (VHSV) and they host parasites such as Cystidicola spp. and acanthocephalans, parasites for which population effects are uncertain (Faisal et al. 2013). Concerns about the susceptibility of Cisco to disease, their potential role in transmission, and introducing disease from a stocking program remain.

- ***Cost and logistics:*** Rehabilitating Cisco will require resources at a time when many agencies are constrained. Specific concerns include budgeting and staffing. If actions are initiated to move forward with Cisco rehabilitation, additional research dollars will be required, and additional monitoring and evaluation may be necessary. If a stocking program was determined as a priority management action, hatchery costs and the associated logistics would also need to be considered. The total costs of a Cisco rehabilitation program, trade-offs (e.g., required redistribution of monitoring efforts) to other management objectives, and potential feedbacks on existing fisheries are unknown and conjectures would likely vary among agencies. Costs would ultimately depend on the chosen management strategy and cannot be determined before defining alternative management actions and identifying the optimal strategy among those alternatives.

SUMMARY

This document fulfills a charge to Lake Erie's CWTG to report on the possible impediments to Cisco rehabilitation in Lake Erie. The LEC recognizes that rehabilitation of Cisco is a component of Lake Erie's Fish Community Goals and Objectives (Ryan et al. 2003) and is described in Lake Erie's Environmental Objectives (Davies et al. 2005) as desirable in order to achieve favorable conditions for percid production in the central and eastern basins. Furthermore, recovery of Cisco would provide diversification of Lake Erie's prey fish community and provide benefits to the ecosystem. There are many unknowns regarding the ability of present-day Lake Erie to sustain Cisco, including quality of spawning and rearing habitat, the effects of climate change on reproduction and recruitment, the availability of a niche for Cisco in Lake Erie food web, and competition with non-native species, especially Rainbow Smelt, that make recovery uncertain. After considering associated risks, if the decision were made to target Cisco rehabilitation, active reduction of Rainbow Smelt and stocking of reared Cisco are two potential approaches that would encourage recovery. Whereas the first approach (smelt reduction) is probably unacceptable because of potential detriments to both fisheries and key predators such as walleye, the second approach (stocking) might establish a background abundance of adult Cisco that could fill-in the pelagic niche following any natural or unplanned reduction in smelt abundance.

PERCEIVED IMPEDIMENTS SURVEY

A survey of biologists from Lake Erie and the upper Great Lakes graded the perceived impediments and priorities for informing knowledge gaps related to these impediments (Appendix 1). The wide range of responses highlighted uncertainties concerning the importance and potential for successfully addressing impediments to Cisco rehabilitation in Lake Erie. This survey characterized the most important impediment to Cisco rehabilitation was potential for larval predation by invasive species, whereas disease vectors and bycatch were less important. The major knowledge gaps from the survey identified a need for improving reporting of captured Cisco and a need for identification of the best brood stock source if stocking was identified as a management action, whereas developing models to estimate target spawning biomasses was not important at this time. The perceived feasibility of quantifying the current population status and ecological interactions between Cisco and the present Lake Erie community appeared ambiguous. Lastly, the survey allowed for comments and questions to be submitted for further consideration as the LEC considers initiation of Cisco rehabilitation (Appendix 2).

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Table 1. Individual measures and capture information for Lake Erie Cisco, 1990-2015.

ID	CLASSIFICATION	Year	Month	TL	FL	Sex	Gonads	AGE	Y-class	DIET	LAKE BASIN	FISHING GEAR	DEPTH	TARGET SPECIES	LANDED SPECIES
1		1990	Sep	260	234	F		1	1989		E	GN	127	FC	
2	*Artedi*	1995	Apr	443	410	F		9	1986		LP	GN	155	LWF	LWF; LT
3	*Albus*	1996	Apr	371	336	F	DEV	6	1990	SF; DM	LP	GN	135	LWF	LWF; LT
4	swarm	1999	Aug	153	137	F		1	1998		C	TR	69	RS	YP; WP; WAL; RS
5	swarm	1999	Aug	158	142	M		1	1998		C	TR	68	RS	RS; YP
6	swarm	1999	Summer	156	140	F		1	1998		C				
7	*Albus*	1999	May	323	291	M					**EC**		65		
8	swarm	1999	Aug	211	189	F		2	1997		LP	GN	85	LWF	LWF; BUR
9	swarm	1999	Sep	140	126	M		1	1998		LP	TR	100	RS	WAL; LWF; RS
10	swarm	1999	Sep		139	F		1	1998		LP	TR	100	RS	WAL; LWF; RS
11		2000	Sep	238		UK					WC		33		
12		2001	Oct	173	153	UK		3	1998		E	TR	140	RS	GS; RS
13		2002	Sep	170	153	F	DEV; EP	3	1999		LP	TR	101	RS	RS; CYP
14		2002	Sep	315	284	F	DEV; EP	3	1999		LP	TR	100	RS	RS; CYP
15		2003	Jul	301	271	UK		5	1998		C	GN	78	YP	YP
16		2003	Sep	222	203	M		1	2002		C	TR	75	RS	RS; WAL
17		2003	Sep	298	266	M		2	2001		C	TR	74	RS	RS; WAL
18		2003	Aug	278		F		4	1999		E	GN	102	CWS	BUR; WAL
19	swarm	2003	Jun	341	305	F	DOR	5	1998	CHIR	WC	GN	70	YP	YP
20	swarm	2003	May	298	271	M	DEV	4	1999	CHIR	WC	GN	24	WB	WB; WAL; SMB; WF; WP
21		2004	Jun			UK					LP	GN	100		
22		2005	Aug			F		6	1999		C	GN	60	WAL	WAL
23	swarm	2005	Jul	325	294	M					C		75		
24	swarm	2005	Jul	350	319	F					C		75		
25	swarm	2005	Jun	357	320	F		6	1999		C	GN	80	YP	WAL; YP;
26		2005	Dec	367	332	F	DEV; EP				WC	GN	70	YP	
27	swarm	2006	Mar	261	236	M	RUN				W	GN	32	YP	
28	swarm	2007	May	389	352	F	DOR	7	2000		LP	GN	125	LWF	LWF; BUR
29	swarm	2007	May	333	300	F	DOR	7	2000		LP	GN	30	YP; WB	WB; LWF; WP; YP; WAL
30		2008	Mar	464	420	M	SPENT	7	2001		WC	GN	70	WB	LWF; YP; WAL; WB; WP
31		2008	Mar	413	373	F	SPENT	7	2001		WC	GN	66	WB	WAL; WF; YP; WP; WB
32	swarm	2010	Jun	322	286	M	DEV	7	2003		LP	GN	50	YP	YP
33	swarm	2010	Jun	355	316	F	DEV	9	2001		LP	GN	50	YP	YP
34	swarm	2010	Jun	366	328	F	DEB	12	1998		LP	GN	50	YP	YP
35	*Artedi*	2010	Apr	438	396	F	DOR	9	2001		W	GN	38	WB	YP; WAL; WP; WB
36	swarm	2011	Apr	319	287	F	DOR	5	2006	GB	LP	TR	120	RS	RS
37		2011	Aug	250		UK					LP	TR	75	RS	RS
38	swarm	2011	Jul	262	236	F	DOR	4	2007		LP	TR	70	RS	RS
39	swarm	2011	May	308	277	M	DOR	6	2005	CHIR	LP	GN	35	YP	YP; WP; WAL; RS
40	swarm	2012	Nov	292	261	F		3	2009		C	GN	51	YP	YP
41	swarm	2013	Jul	277	249	M	DOR	5	2008	CHIR	LP	TR	70	RS	RS; ALE; EMS; FWD; RG; YP; RT
42	swarm	2014	May	330	295	F	DOR; EP				E	GN	74	YP	YP; WP; WAY; WB
43	swarm x LWF	2015	Jul	408	368	F	DEV; EP			BYTH, CHIR	E	GN	80	YP	YP
44	swarm	2015	Jul	309	279	M				CHIR	E	TR	70	RS	RS; LWF; WAL
45	swarm	2015	Jul	285	255	F	DEV; EP			CHIR	E	TR	70	RS	
46	swarm x LWF	2015	Jun	342	307	M				CHIR	E	GN	75	YP	YP

Classification types based on methods from Eshenroder (2016). Lengths: total (TL) and fork (FL) in mm. Sex: male (M), female (F), unknown (UK). Gonad Condition: developing (DEV), eggs present (EP), dormant (DOR), post spawn (SPENT). Age from scales. Diet: small fish (SM), dreissenid mussel (DM), Chironomidae larvae (CHR), *Bythotrephes longimanus* (BYTH). Lake Basin: west (W), west central (WC), central (C), east central (EC), Long Point (LP), eastern (E). Gear: gillnet (GN), trawl (TR). Catch Location: bottom (BOT), suspended in water column (SUS). Depth in feet. Species targeted and caught: Yellow Perch (YP), Walleye (WAL), Rainbow Smelt (RS), Lake Whitefish (LWF), Lake Trout (LT), Burbot (BUR), White Perch (WP), White Bass (WB), Gizzard Shad (GS), Smallmouth Bass (SMB), Alewife (ALE), Emerald Shiner (EMS), Freshwater Drum (FWD), Round Goby (RG), Rainbow Trout (RT), Cyprinid sp (CYP).

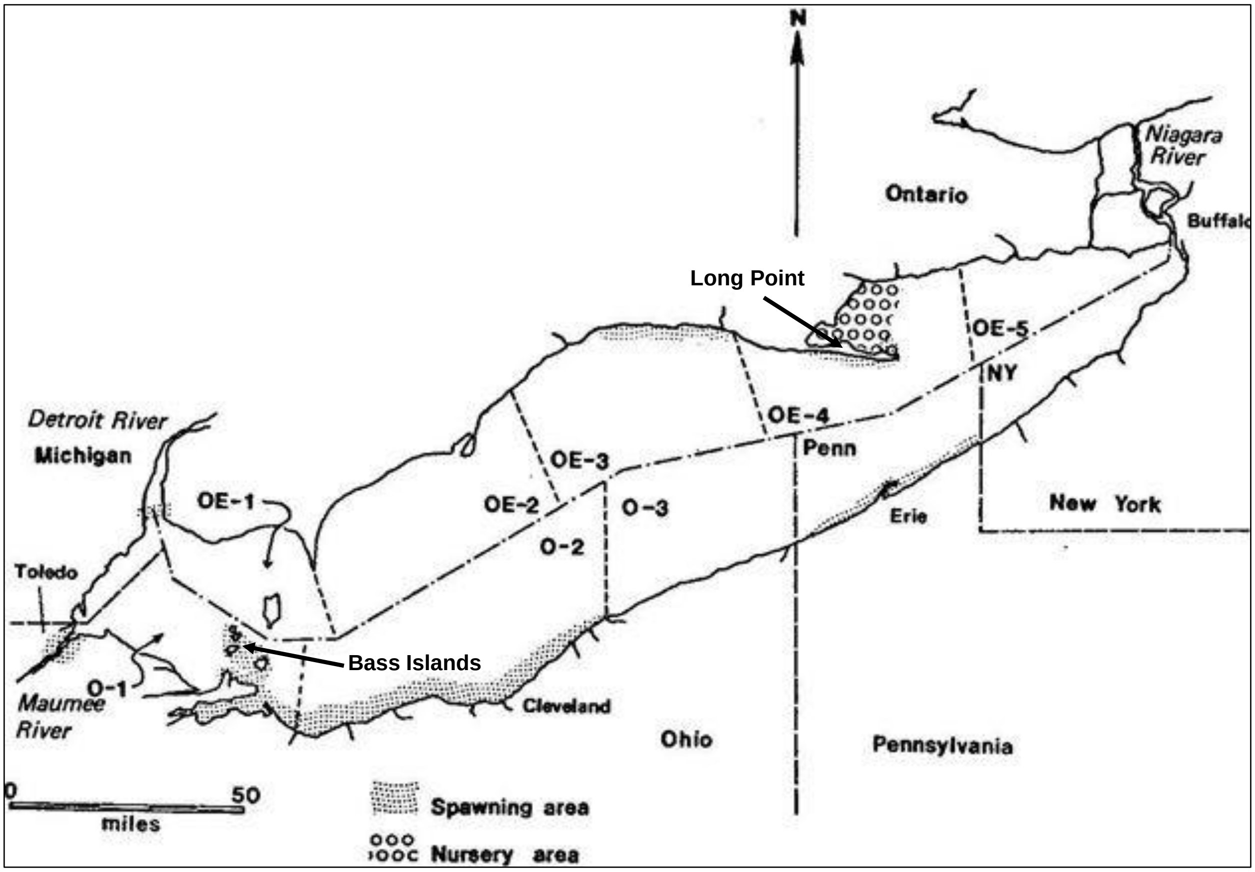


Figure 1. Historical spawning and nursery areas of Cisco in Lake Erie (from Goodyear et al. 1982). Dashed lines indicate boundaries of provincial and state management areas.

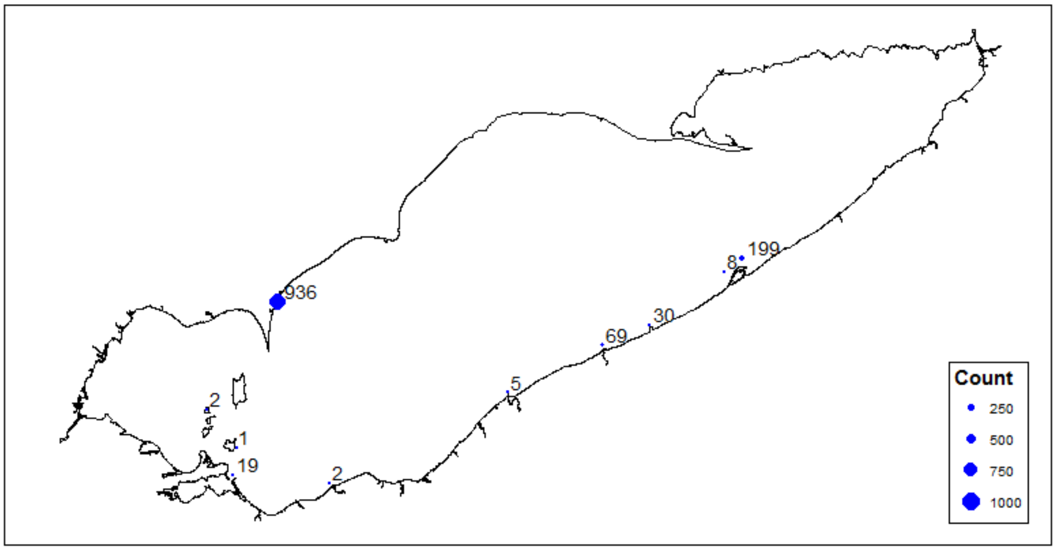


Figure 2. Number of newly found scale samples from Cisco that were collected at Lake Erie ports from 1949-1962, during the last period of intensive Cisco commercial fishing. Numbers indicate total number of scale samples collected by port. Sampling effort distribution and exact catch locations are unknown, and thus, this map should not be used to infer historical Cisco population distribution. This collection of scales was found in 2014 and is currently in possession of the USGS Great Lakes Science Center.

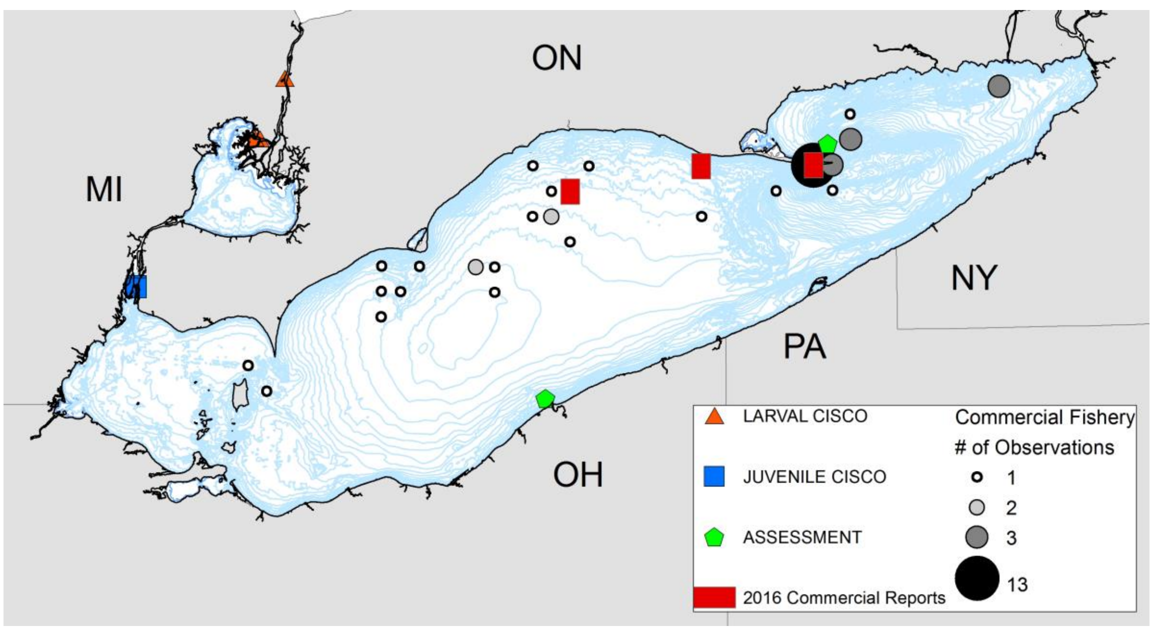


Figure 3. Cisco observations in Lake Erie and the Huron-Erie Corridor, 1995-2016. Commercial fishery observations are indicated with grey circles with size and shading indicating number of observations per 5' fishing grid. Locations of larval and juvenile Cisco observations (2010-11; USGS, USFWS) are indicated with triangles and squares, respectively. Locations of single observations from agency assessment surveys are shown with a green pentagon. NB – Three 5' grids from the 2016 commercial fishery indicate reported but unconfirmed observations. Source: Coldwater Task Group 2017.

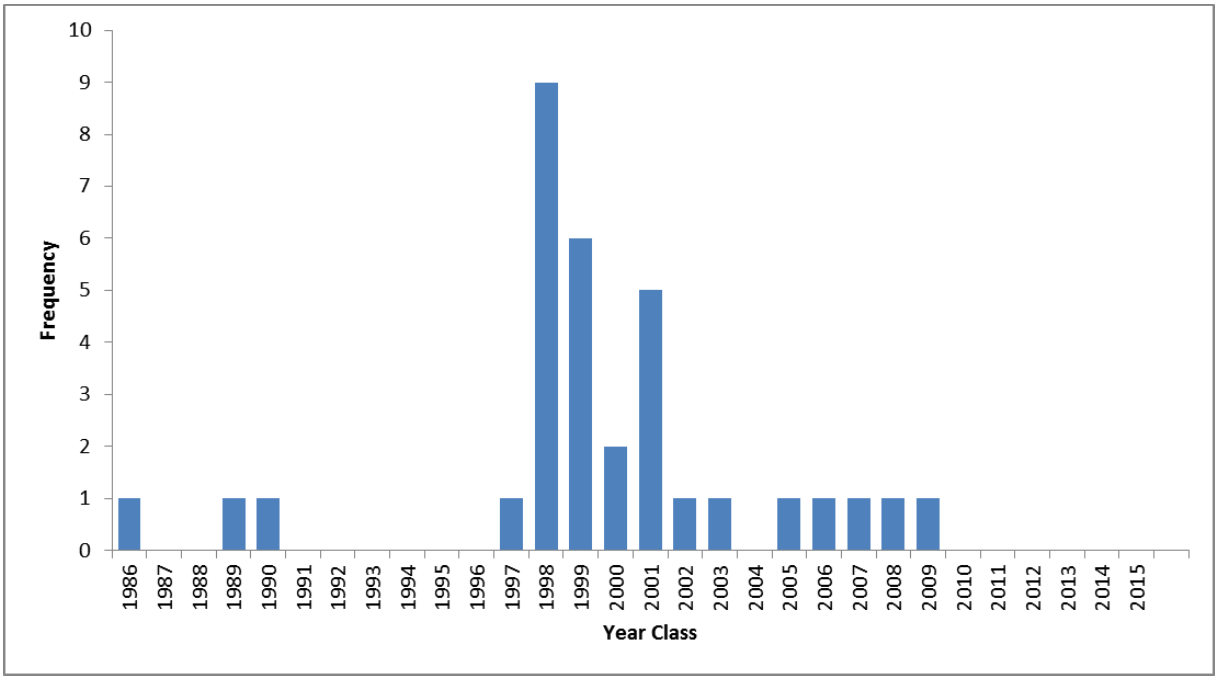


Figure 4. Frequency of individual year classes in composite collection of forty-six Cisco captured in Lake Erie between 1999 and 2015 using ages derived from scales.

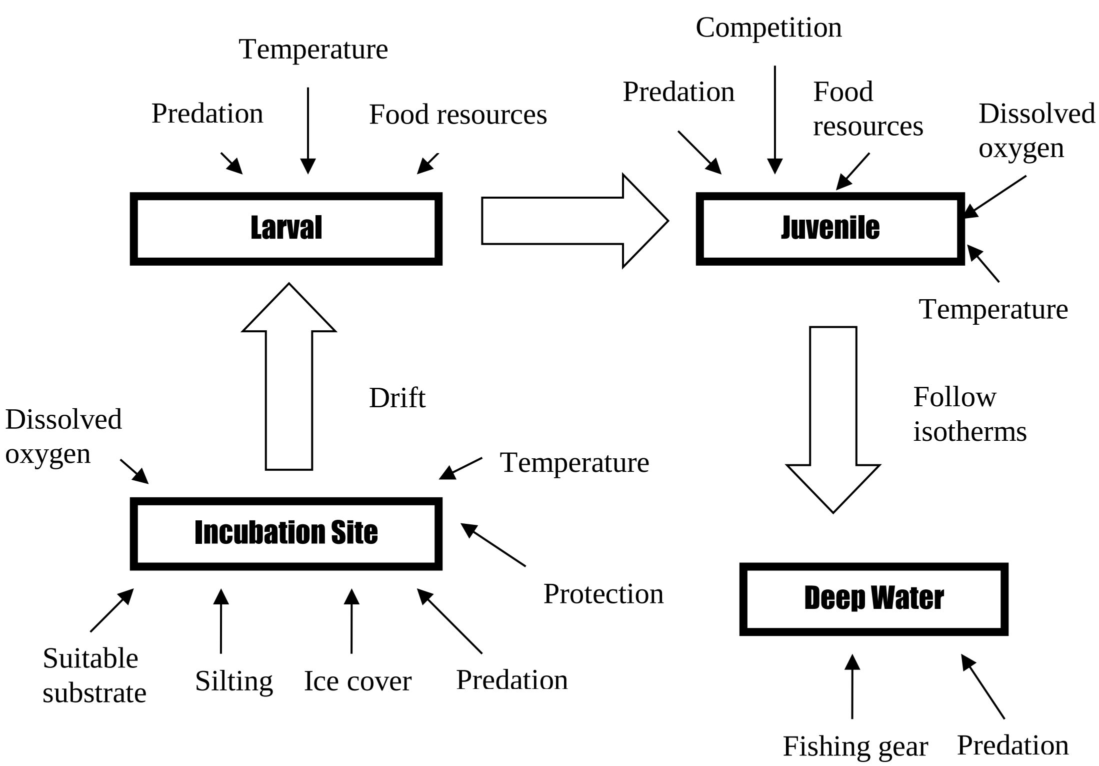


Figure 5. Habitat-specific factors and processes affecting Cisco reproductive success, recruitment success, and ecology (modified from Oldenburg et al. 2007).

APPENDIX 1: IMPEDIMENTS SURVEY AND RESPONSES

Q1: Please rate the severity of perceived impediments to Cisco rehabilitation that limit the ability to develop a management plan and create uncertainty about potential success for rehabilitation.

Summary Rankings (Top 3 scores and ties)

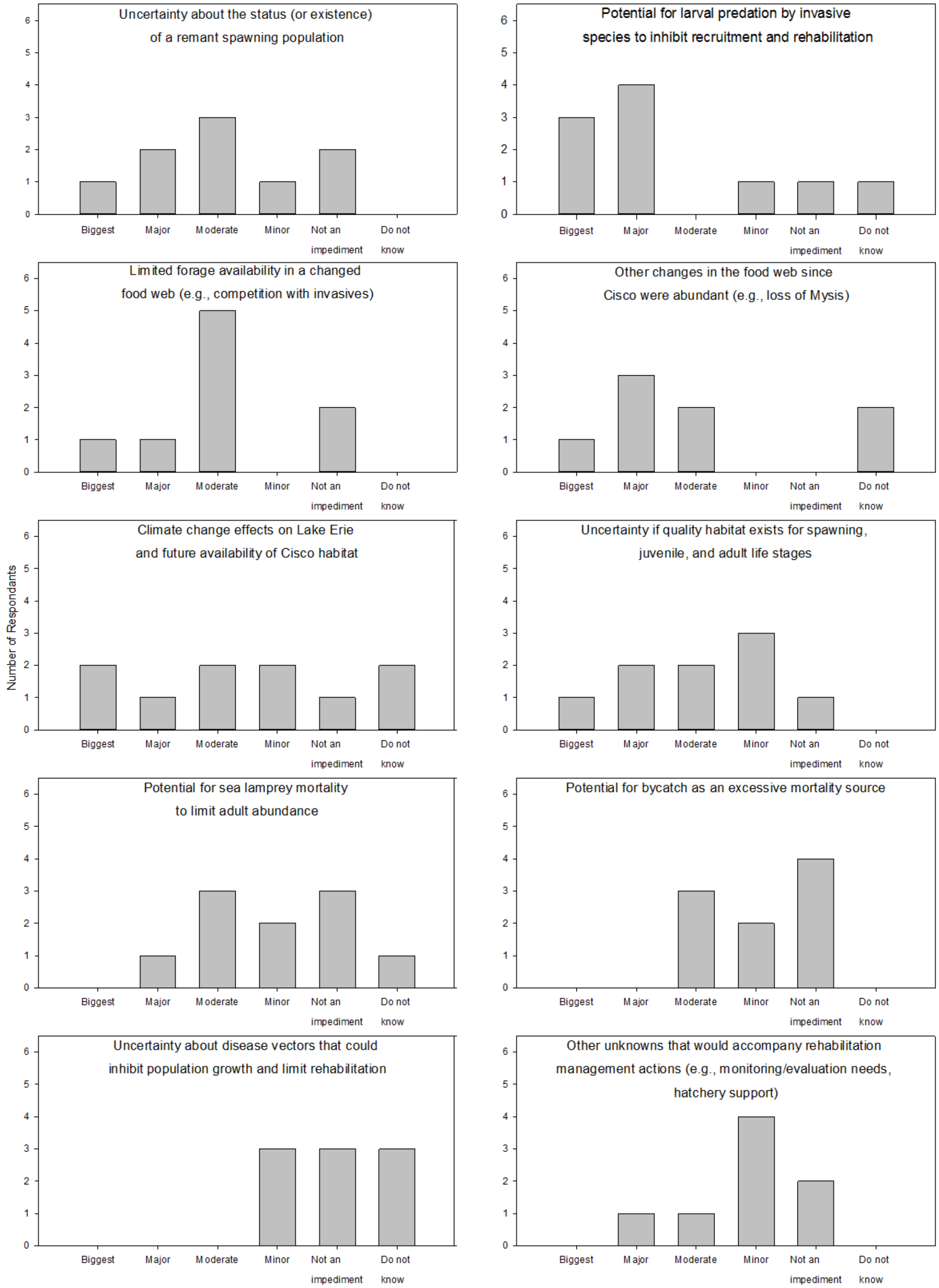
1) Potential for larval predation by invasive species to inhibit recruitment and rehabilitation
2) Potential for sea lamprey mortality to limit adult abundance
3)
    a. Uncertainty about the status (or existence) of a remnant spawning population
    b. Limited forage availability in a changed food web
    c. Climate change effects on Lake Erie and future availability of Cisco habitat
    d. Uncertainty if quality habitat exists for spawning, juvenile, and adult life stages

Q2: Rank the priority for informing knowledge gaps related to Cisco rehabilitation efforts
Summary Rankings (Top 3 scores and ties)

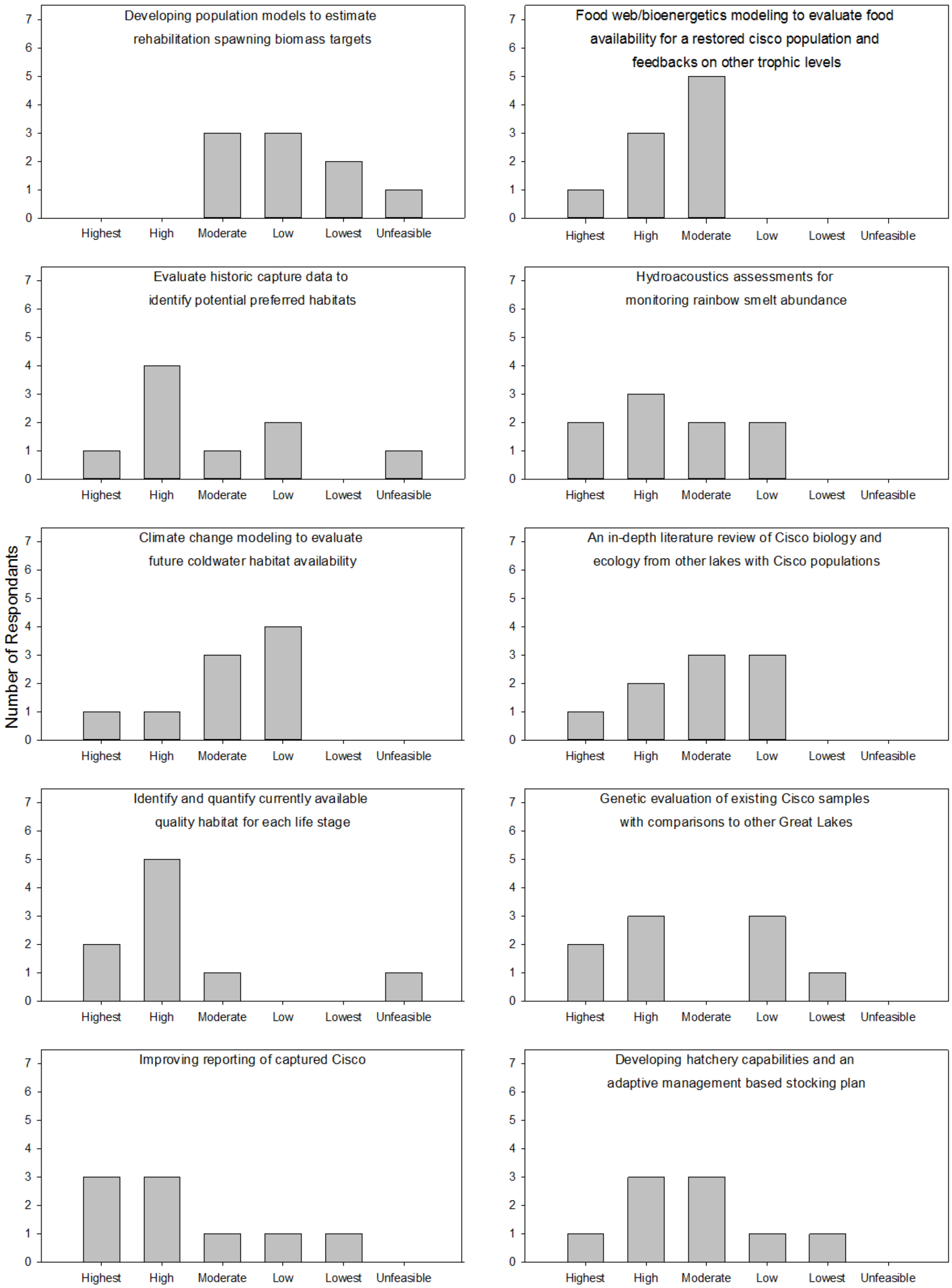
1)
    a. Improving reporting of captured Cisco
    b. Identify best brood stock source in case stocking is chosen as a priority management action
2)
    a. Food web/bioenergetics modeling to evaluate food availability for a restored Cisco population and feedbacks on other trophic levels
    b. Hydroacoustic assessments for monitoring rainbow smelt abundance
    c. Identify and quantify current available quality habitat for each life stage
3) Identify potential stocking locations

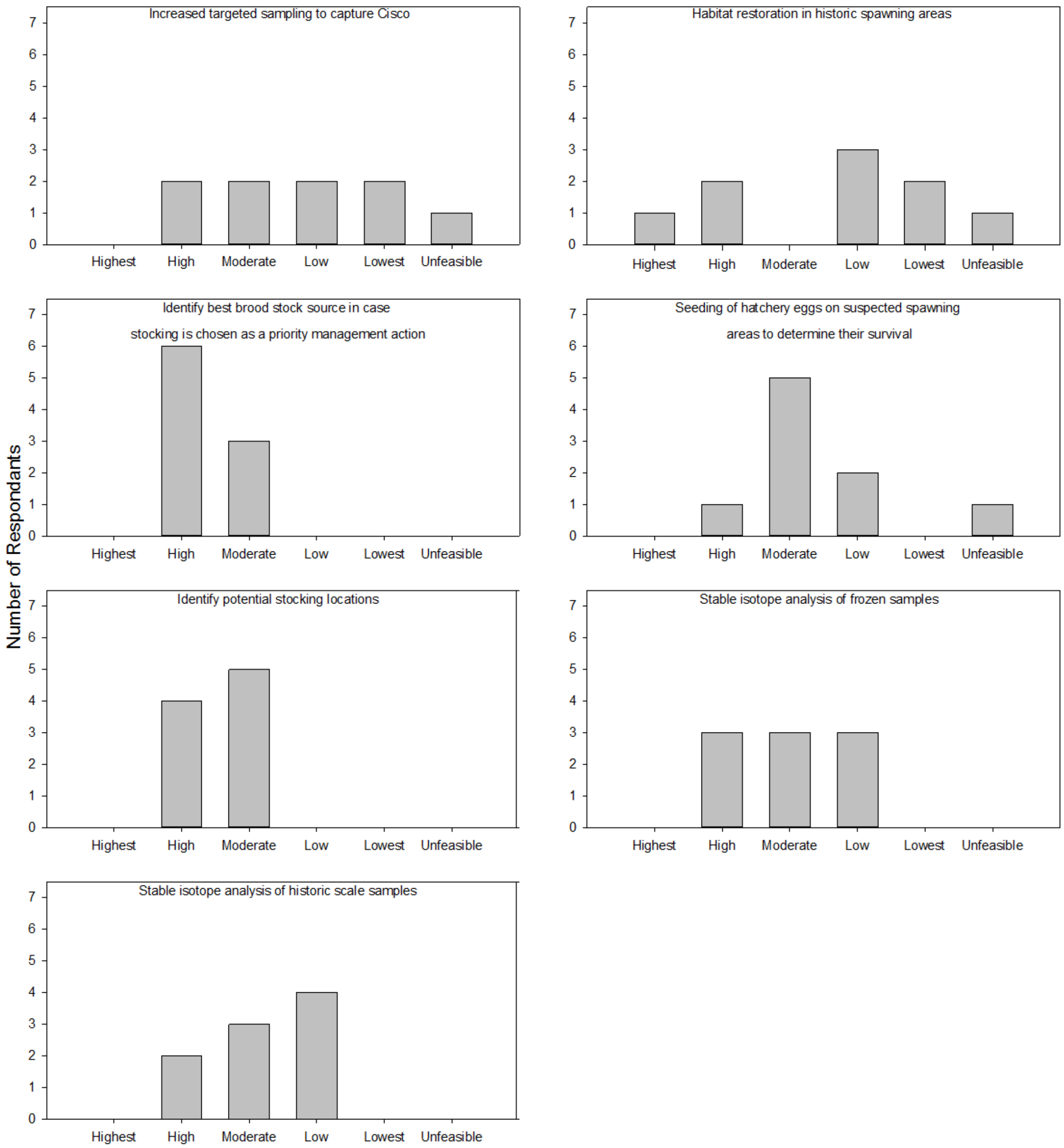
Q3: Optional – see results below
Q4: Optional – see results below

Q1: Please rate the severity of perceived impediments to Cisco rehabilitation that limit the ability to develop a management plan and create uncertainty about potential success for rehabilitation.

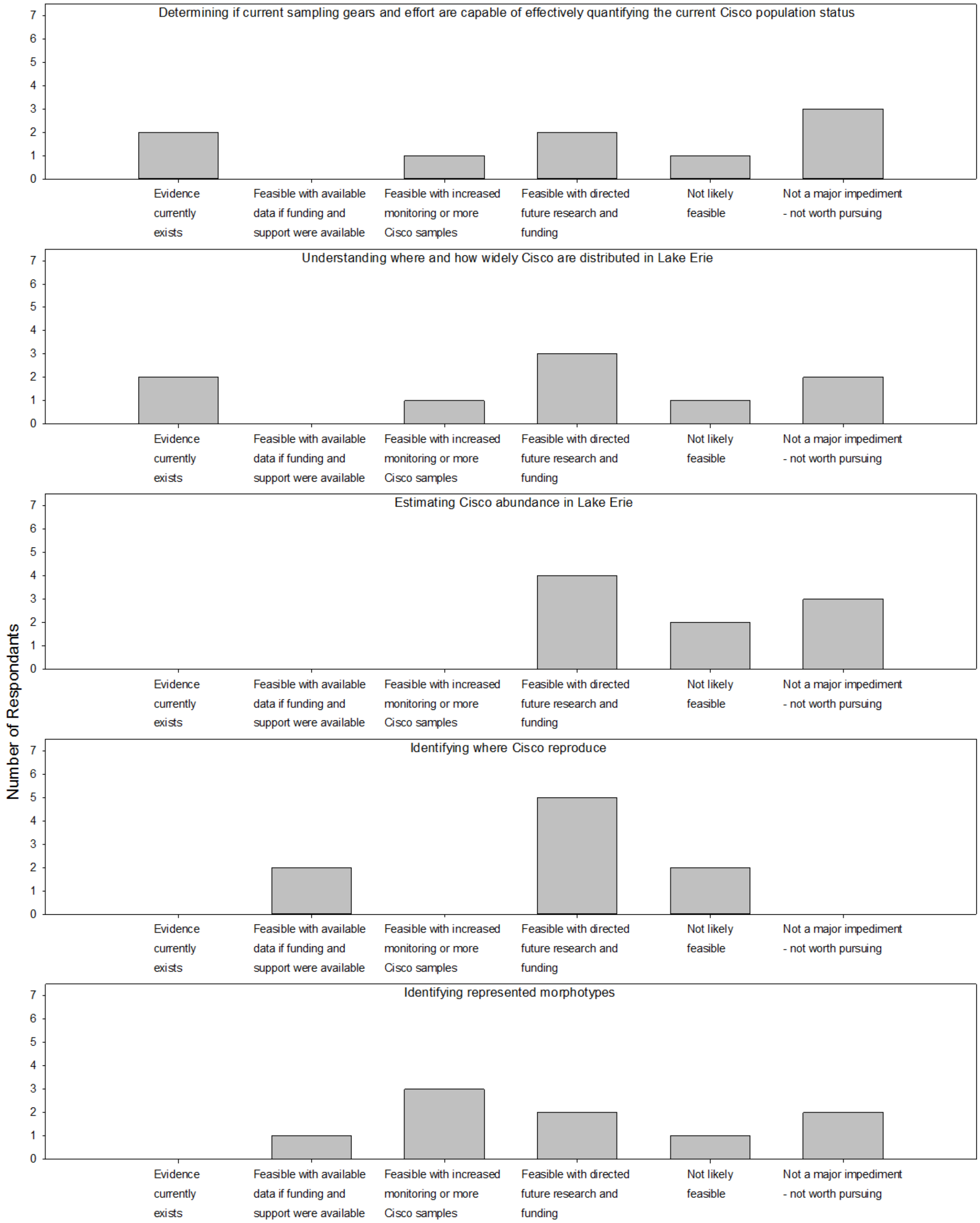


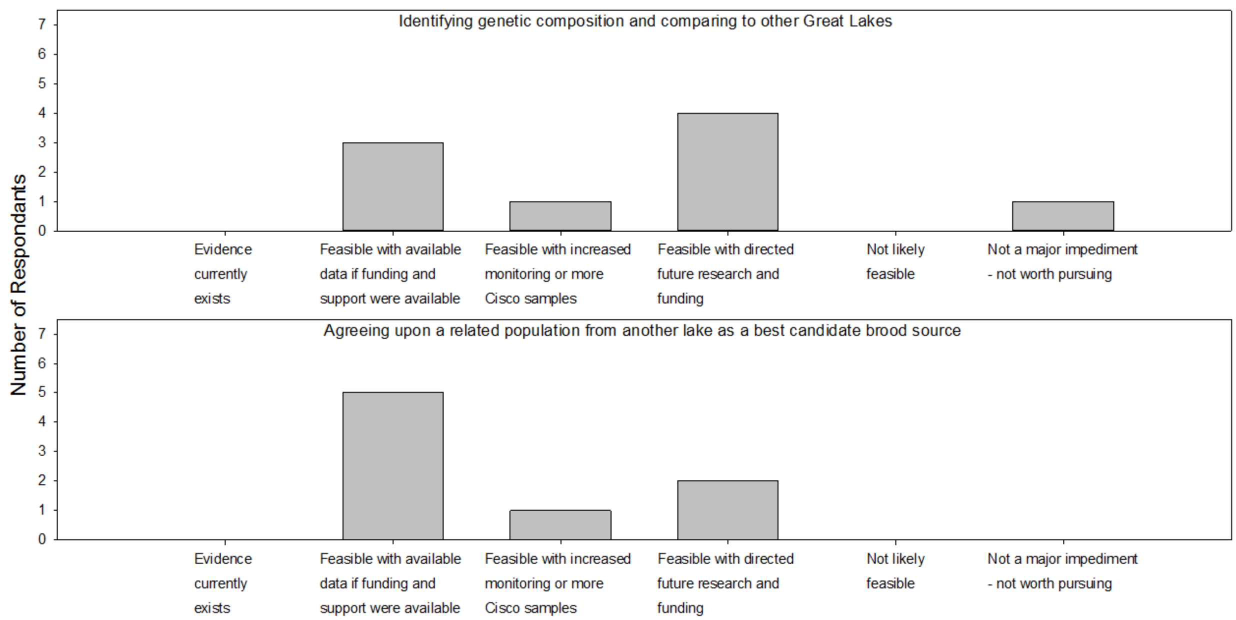
Q2: Rank the priority for informing knowledge gaps related to Cisco rehabilitation efforts



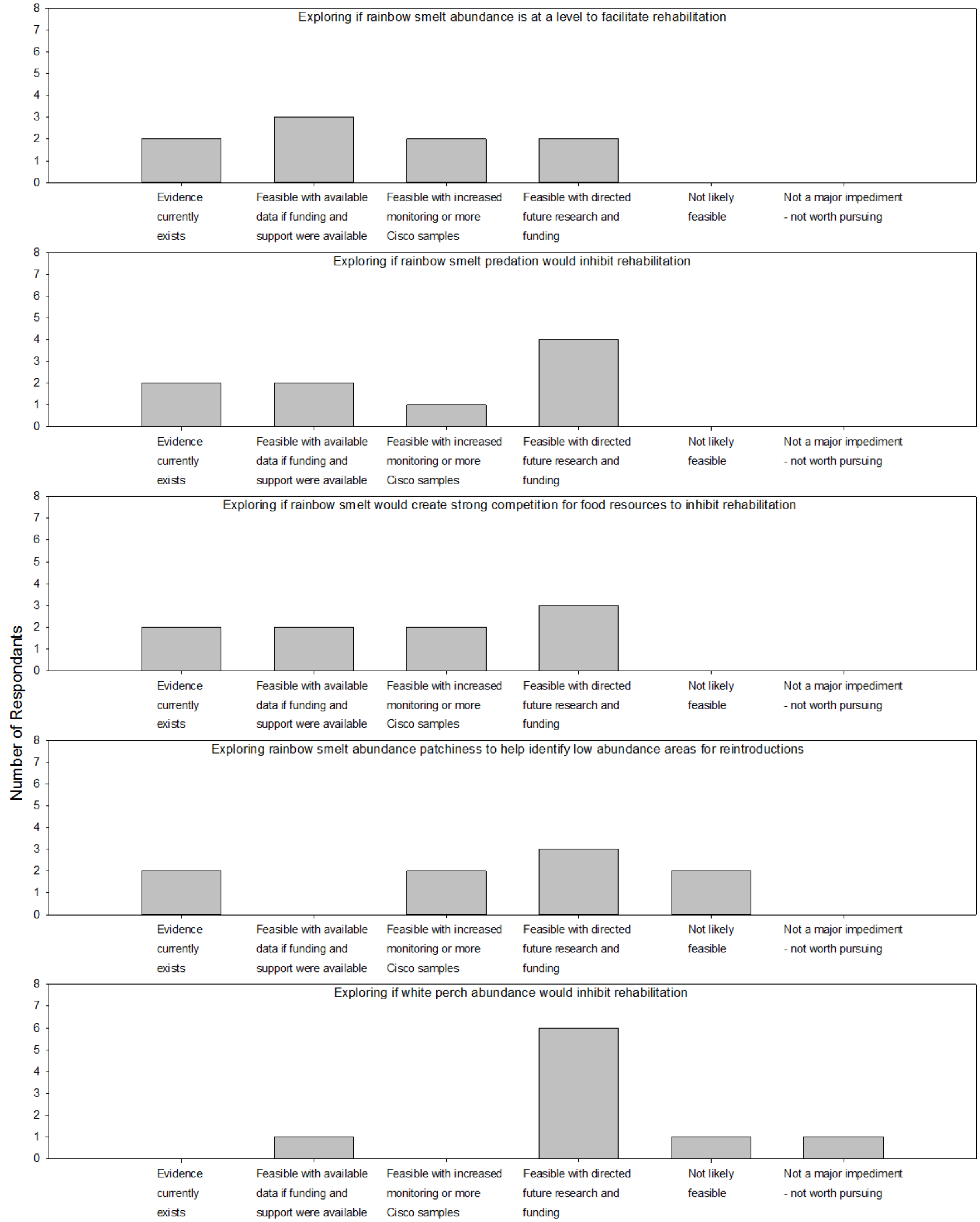

Number of Respondants
Increased targeted sampling to capture Cisco
Habitat restoration in historic spawning areas
Identify best brood stock source in case
stocking is chosen as a priority management action
Seeding of hatchery eggs on suspected spawning
areas to determine their survival
Identify potential stocking locations
Stable isotope analysis of frozen samples
Stable isotope analysis of historic scale samples
Highest
High
Moderate
Low
Lowest
Unfeasible
0
1
2
3
4
5
6
7

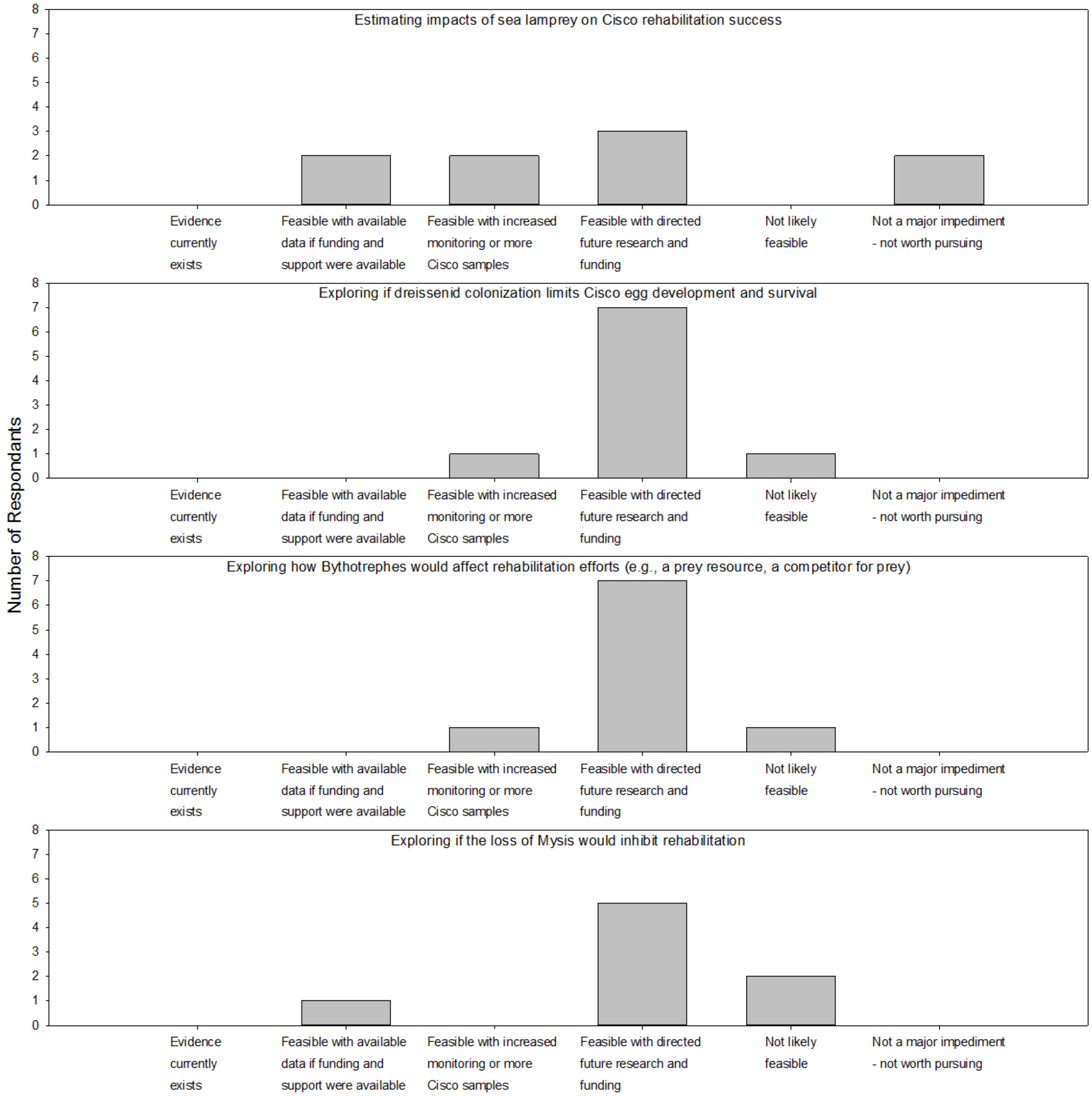
Q3 (optional): Rate the feasibility of quantifying the current population status and determining if a remnant Lake Erie spawning stock exists




Number of Respondants
Identifying genetic composition and comparing to other Great Lakes
Agreeing upon a related population from another lake as a best candidate brood source
0
1
2
3
4
5
6
7
Evidence currently exists
Feasible with available data if funding and support were available
Feasible with increased monitoring or more Cisco samples
Feasible with directed future research and funding
Not likely feasible
Not a major impediment - not worth pursuing

Q4 (optional): Understanding interactions between Cisco and a changed community (rank the feasibility of addressing)




Number of Respondants
Estimating impacts of sea lamprey on Cisco rehabilitation success
Exploring if dreissenid colonization limits Cisco egg development and survival
Exploring how Bythotrephes would affect rehabilitation efforts (e.g., a prey resource, a competitor for prey)
Exploring if the loss of Mysis would inhibit rehabilitation
Evidence currently exists
Feasible with available data if funding and support were available
Feasible with increased monitoring or more Cisco samples
Feasible with directed future research and funding
Not likely feasible
Not a major impediment - not worth pursuing
0
1
2
3
4
5
6
7
8

Appendix 2: Survey Comments

1. I could see "the unknowns" as an impediment to converging on agreement of an optimal management action and actually moving forward with rehab; that's a different type of impediment.

2. Could stocking a planktivorous species such as Cisco place any additional stress on existing native cold water species (Whitefish and possibly Burbot) that have experienced poor recruitment in recent years

3. I would think that enough time has passed for us to understand that cisco in Erie are not coming back on their own. It is curious that fish are still occasionally caught. But I wouldn't worry about losing diversity by moving fish in from another lake. I think smelt densities at present will be prohibitive. Black Bay of Superior used to support an amazing cisco fishery, but it now supports very high densities of smelt, similar to Erie. A few cisco still spawn at the mouth of Black Bay but the fishery is much reduced and we feel smelt predation on larvae is the major limiting factor (See Myers et al. 2014; Ecological modeling 294:71-83). Smelt obtain most of their nutrition through the pelagic pathway as do cisco so you'll also likely have a problem with competition for zooplankton. In Superior, Mysis account for 39% of the diet of cisco (Sierszen et al. 2014; FWB 59:2122-2136) so that being unavailable in Erie would be a problem. We're trying to secure money to build on the work of Ellen George at Cornell to study what are the habitat attributes that lead to successful egg hatching in Superior and Michigan so maybe in a few years we'll have a better idea if habitat is limiting in Erie. Hope you find these comments helpful.

4. I think in order to get cisco to take in Erie, you're going to need to find a donor that will occupy a vacant niche in the food web. Schmidt (2011) thought about the probability of extinction by considering overlap in stable isotope plots; I think when thinking about donors you have to use the same logic. That is matching holes in the plots to forms from other lakes that could fill those holes. I think seeding some historic spawning sites to see if you can get eggs to hatch would be important. I would be inclined to survey smelt with acoustic methods in spring to determine which bays that used to support cisco have, at present, the lowest smelt densities. Looking for spwaning fish is an interesting idea. It is amazing what one can find when one starts to look. Bottlenecks to survival seem to occur during the larval stage in Superior. They need nauplii at the right time and having high densities of smelt will be a deal breaker. I would think those factors would also be most important on Erie. Fish reproduce in Erie so I would think that spawning habitat would not limit cisco, but that is just my opinion.

5. Also believe that a major impediment is the uncertainty about the size of any extant population. Not usually picked up in index surveys, however, due to observations from commercial fishers over the years, is this because of the survey design? Very little is known about the extant population.

6. Habitat restoration difficult (perhaps not in Detroit R?). Need to determine if current population is extant or vagrant, and determine genetically next closest stock for potential broodstock. Ecological plasticity i.e. abilty to quickly adapt to niches, may reduce the need for in depth bioenergetic studies.

7. Population status would require strong financial and logistic effort for determination, but believe is feasible. genetic work is feasible and may be competed soon. Sample gear study first, then multi -year enhanced monitoring for distribution and abundance

8. I'm thinking there has been enough work with pelagic fish with midwater trawling to know the status of cisco in Erie is rather bleak. I guess I assume that smelt fishers cooperate when they catch a cisco, and that we are not dealing with a shoot, shovel, and shut up situation. Estimating the abundance would seem to me to be a pipe dream because it is so low. I like the idea of visiting some historic spawning sites with gillnets. That is how a number of remnant stocks have been found in the last few decades in Michigan and Huron. There have really been low numbers of cisco caught which does limit morphometric and genetic analyses, although I understand an effort is underway to try and extract dna from museum specimens. still, if the current fish are found to be unique, that would not stop me from considering reintroduction. I would be inclined to try and think about a donor that seems to be persisting with smelt.

9. I would want to be thinking about measuring smelt densities in spring when larvae would be present. I'm really struck by the lack of information on the feeding ecology of remnant stocks in Huron, Ontario. I think you would be looking for a donor from these systems. We know Mysis are important to cisco in Superior, but we don't know, at least to my knowledge, if that is true in the other lakes. I suspect that the benthic pathway may be more important to the cisco in the lower lakes because they tend to have bigger heads and deeper bodies like deepwater cisco.

10. Loss of mysis would certainly impact rehabilitation.

11. My understanding is you have few to no cisco in Lake Erie, so I don't think many of these questions apply. If there are historical data on autumn harvests or any historical data on spawning areas, that would be helpful.

12. Literature exists. No need to review it other than the Lake Erie literature or if your biologists don't know cisco biology. Previous work on seeding spawning grounds with embryos for lake trout showed it was not feasible or contributed little to the population. I think you really need to understand if a niche is available for cisco in Lake Erie.