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Evaluating the current status of deepwater ciscoes (*Coregonus* spp.) in the Canadian waters of Lake Huron, 2002-2012, with emphasis on Shortjaw Cisco (*C. zenithicus*)

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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TABLE OF CONTENTS

ABSTRACT

Historically, all six species of deepwater ciscoes (*Coregonus* spp.) and Cisco (*C. artedi*) present in the Great Lakes were found in Lake Huron. The last records of Deepwater Cisco (*C. johannae*) and Shortnose Cisco (*C. reighardi*) in Lake Huron were 1952 and 1985, respectively. Both species are now considered extinct. Of the species still present in other Great Lakes, the last record in Lake Huron of Blackfin Cisco (*C. nigripinnis*) was 1960, Shortjaw Cisco (*C. zenithicus*) was 1982, and the Kiyi (*C. kiyi*) was 1985. The purpose of this study was to evaluate the status of deepwater cisco species in the Canadian portion of Lake Huron. Between 2002 and 2006, cisco samples were collected by the Chippewas of Nawash First Nation, in collaboration with Fisheries and Oceans Canada (DFO), Ontario Ministry of Natural Resources (OMNR), and Parks Canada. Gillnets were bottom set at 71 locations in depths of 30-200 m. Across all years, a total of 2552 ciscoes were collected in Lake Huron. Of these 2552 ciscoes, 1538 were Bloater (*C. hoyi*), 72 were Cisco, 20 were Shortjaw Cisco, and 320 could not be identified to species. In 2007, a total of 20 bottom-set gillnets were set by DFO in the North Channel and northern main basin of Lake Huron. A total of 433 ciscoes were collected. Bloater dominated the catch followed by a lesser number of Cisco; only two fish were identified as Shortjaw Cisco, caught in the same net set in the North Channel. In 2012, cisco samples were collected by the OMNR from locations near Lion's Head and Tobermory. Gillnets were bottom set at 15 locations in depths of 49-92 m. A total of 203 ciscoes were collected. Of these, 110 were Bloater, 75 were Cisco, 17 were Shortjaw Cisco, and one specimen could not be identified to species. Shortjaw Cisco were collected from five sites near Lion's Head, in depths of 77-92 m. The Shortjaw Cisco specimens were the first collected in Lake Huron since 1982.

Évaluation de l'état actuel des ciscos de profondeur (*Coregonus* sp.) dans les eaux canadiennes du lac Huron, de 2002 à 2012, et notamment du cisco à mâchoires égales (*C. zenithicus*)

RÉSUMÉ

Par le passé, les six espèces de ciscos de profondeur (*Coregonus* sp.) et le cisco de lac (*C. artedi*) présentes dans les Grands Lacs l'étaient aussi dans le lac Huron. Les dernières observations de cisco de profondeur (*C. johannae*) et de cisco à museau court (*C. reighardi*) dans le lac Huron remontent à 1952 et à 1985, respectivement. Les deux espèces sont maintenant considérées comme étant disparues. Parmi les espèces toujours présentes dans les autres Grands Lacs, le dernier signalement de cisco à nageoires noires (*C. nigripinnis*) dans le lac Huron date de 1960, la dernière fois que l'on y a vu un cisco à mâchoires égales (*C. zenithicus*) était en 1982, et cela remonte à 1985 pour le cisco kiyi (*C. kiyi*). Cette étude vise à évaluer l'état des espèces de ciscos de profondeur dans la portion canadienne du lac Huron. Entre 2002 et 2006, des échantillons de cisco ont été prélevés par la Première Nation de Chippewas of Nawash en collaboration avec Pêches et Océans Canada (MPO), le ministère des Richesses naturelles de l'Ontario (MRNO) et Parcs Canada. Des filets maillants à poisson de fond ont été installés à 71 emplacements, à des profondeurs variant entre 30 et 200 m. Durant cette période, un total de 2 552 ciscos ont été prélevés dans le lac Huron. Parmi ces 2 552 ciscos, 1 538 étaient des ciscos de fumage (*C. hoyi*), 72 étaient des ciscos de lac, 20 étaient des ciscos à mâchoires égales, et 320 n'ont pas pu être identifiés. En 2007, un total de 20 filets maillants à poisson de fond ont été installés par le MPO dans le chenal nord et dans le bassin principal du lac Huron. Au total, 433 ciscos ont été prélevés. Le cisco de fumage dominait les prises, suivi de près par le cisco de lac; seuls deux poissons ont été identifiés comme étant des ciscos à mâchoires égales dans le même filet du chenal nord. En 2012, des échantillons de cisco ont été recueillis par le MRNO à des sites près de Lion's Head et de Tobermory. Des filets maillants ont été installés au fond à 15 emplacements à des profondeurs entre 49 et 92 m. Au total, 203 ciscos ont été prélevés. Parmi ceux-ci, on dénombrait 110 ciscos de fumage, 75 ciscos de lac, 17 ciscos à mâchoires égales, et 1 spécimen non identifié. Des ciscos à mâchoires égales ont été collectés à cinq sites près de Lion's Head, à des profondeurs entre 77 et 92 m. Ces spécimens de ciscos à mâchoires égales étaient les premiers individus prélevés dans le lac Huron depuis 1982.

INTRODUCTION

The deepwater coregonine assemblage endemic to the Great Lakes originally contained six species. Although Koelz (1929) described more species, several were later synonymised and, although the deepwater cisco fishery (commonly known as the “chub fishery”) was very important in the Great Lakes, the catches were rarely identified to species (Lawrie and Rahrer 1973). Two species, Deepwater Cisco (*Coregonus johannae*) and Shortnose Cisco (*C. reighardi*), are now considered extinct and the remaining four species have been extirpated from at least one Great Lakes basin (Table 1). All of these species declined in the Great Lakes as a result of a combination of extensive commercial fishing, habitat degradation, and the invasion of exotic species.

Historically, lakes Huron and Michigan were the only lakes with all six deepwater cisco species and the Cisco (*C. artedi*). The Deepwater Cisco was the first endemic species to go extinct - it was last recorded in Lake Huron in 1952 (Parker 1988). The Shortnose Cisco was last recorded in Lake Huron in 1985, and is also likely now extinct (Webb and Todd 1995). The Kiyi (*C. kiyi*) was last recorded in Lake Huron in 1985, and is likely extirpated (COSEWIC 2005). The most recent record for Blackfin Cisco (*C. nigripinnis*) from Lake Huron is two specimens collected in the Canadian waters off Southampton, Ontario in 1960 (COSEWIC 2007). In Lake Huron, Shortjaw Cisco (*C. zenithicus*, including the synonymised *C. alpenae*; Todd and Smith 1980; Todd et al. 1981) comprised approximately 25% of the deepwater cisco community in the Koelz (1929) survey, but were relatively uncommon in Georgian Bay waters. Similarly, collections in American waters of Lake Huron in 1956 revealed that Shortjaw Cisco comprised 19% of the total deepwater cisco catch (United States Geological Survey, Great Lakes Science Center (USGS-GLSC), unpubl. data). Only individual specimens were taken in the 1970s, and a lone individual was taken in Lake Huron in 1982 off Ausable Point, Michigan (Todd 1985). In Lake Huron, the Bloater (*C, hoyi*) harvest peaked in the early 1960s, then plummeted by the late 1960s and did not increase again to the 1980s, the result of increased recruitment that began in the 1970s (Mohr and Ebener 2005). By the late 1980s, Bloater was the most abundant fish in the deepwater community.

Between 2002 and 2006, cisco samples were collected by the Chippewas of Nawash First Nation, in collaboration with Fisheries and Oceans Canada (DFO), Ontario Ministry of Natural Resources (OMNR), and Parks Canada. In 2007, DFO and OMNR sampled the North Channel and northern areas of the main basin. In 2012, OMNR (Upper Great Lakes Management Unit) sampled locations in the vicinity of Lion’s Head and Tobermory. The main objective of this research was to survey the deepwater cisco community of Lake Huron, paying particular attention for the presence of species believed to be extirpated from the lake. Where possible, the biological and habitat characteristics of captured ciscoes were also noted.

METHODS

2002-2006 SAMPLING

Cisco samples were collected by the Chippewas of Nawash First Nation, in collaboration with Fisheries and Oceans Canada, Ontario Ministry of Natural Resources, and Parks Canada. Between 2002 and 2006, 71 gillnet sets were made in depths of 30-200 m, the depths frequented by deepwater ciscoes in large lakes (Scott and Crossman 1973), surrounding the Bruce Peninsula where Bloater or Shortjaw Cisco had been historically collected in Lake Huron (Koelz, 1929; Figure 1; Appendix; see Harford et al. 2012 for further sampling details). The nets were 1100 m bottom-set monofilament gillnets, with 6.4-6.7 cm stretched mesh sizes, and 91.4–127.0 cm mesh panels. Gillnets were deployed for 24-72 h depending on weather conditions, but were most commonly deployed for a period of 48 h (Naumann and Crawford 2009). Six net sets were made in April 2002, 12 sets December 2, 2003-January 21,

2004, 25 sets May 30-June 22, 2005 and September 28-October 1, 2005, and 26 sets January 6-12, 2006 and March 24-April 15, 2006 (Table 2). Ciscoes were transported to DFO Burlington for an examination of morphological characters that would assist in species identification.

For each specimen, morphological character measurements were taken based on Koelz (1929). The morphological characters examined included: lower jaw position (LJ); angled snout (AS); number of gill rakers (GR); length of gill rakers (GRL); paired fin length (PFL); and, eye diameter (ED) (Figure 2). Gill raker characteristics were examined by extracting the first gill arch. Gill raker length was measured and standardized by dividing GRL by total length of the fish. Standardized gill raker length (SGRL) was then categorized as short, medium, or long. The lowest 25% of SGRL in the Lake Huron specimens (n=1943) were considered short (< 0.0312), the highest 25% of SGRL were considered long (> 0.0365), and the remaining SGLR (between 0.0312 and 0.0365) were considered medium. These SGRL values were used only as a guideline and no definitive species identifications were made using only these ranges. Species identifications were made by using the morphological character guide developed by Tom Todd (USGS, unpubl. report[1]) (Table 2). A subset of the specimens, including most putatively identified as Shortjaw Cisco, were further examined by Tom Todd (USGS-GLSC), a noted cisco expert.

2007 SAMPLING

A total of 20 bottom-set gillnets were set in the Canadian waters of Lake Huron, June 19-24, 2007, over depths ranging 28-108 m. Eleven nets were set in the North Channel, and nine in the northern main basin between Duck, Cockburn, and Manitoulin islands. Two types of nets were used in the sampling; a traditional net and an experimental net. The traditional net was composed of four 92 m nylon mesh panels, alternating 64 mm and 70 mm stretch mesh (for a total gang length of 366 m); mesh size and material for the traditional nets were chosen to closely replicate the nets used in the historic Koelz (1929) surveys, although Koelz (1929) used cotton or linen nets instead of nylon. The experimental net consisted of eight randomly assigned 46 m monofilament panels, with stretched mesh sizes of 38, 45, 51, 57, 64, 70, 76, and 89 mm. The experimental nets were designed to capture a wider size and age range of fishes. Minimum and maximum depth data were collected from every net set, and an Ekman dredge was used to collect a sediment sample from the immediate area where each net was set.

Captured ciscoes were tentatively identified to species based on external morphological characteristics (primarily mouth and fin position, gill raker characteristics, and colour), with the aid of a variety of unpublished keys. All ciscoes were frozen and returned to the laboratory, and 104 ciscoes were selected for additional morphometric and biological analyses. In the laboratory, frozen fish were thawed, photographed (full body, head, and gill rakers), weighed, and total length recorded. Fishes were identified by three biologists, and any potential changes in classification from the original field classification were noted. A number of specimens had characteristics from more than one species; these fish were classified as intermediate forms with the species for which they most closely fit the criteria listed first (e.g., a Shortjaw Cisco / Bloater would have more Shortjaw Cisco characteristics than Bloater characteristics). Gill rakers and a tissue sample for future genetic analysis were removed and stored in 70% ethanol. Aging structures (scales and otoliths) were also collected, and individuals were examined for sex determination and state of maturity.

[1] Todd, T.N. no date. Tom Todd's sure-fire guide to morphological characteristics of ciscoes (*Coregonus* spp.) of the Great Lakes region. United States Geological Survey. Ann Arbor, MI. Unpublished report.

2012 SAMPLING

Fifteen overnight benthic gillnets were set in the Canadian waters of Lake Huron, August 15-23, 2012. Five nets were set near Lion's Head, and 10 nets set near Tobermory. The gillnets were 400 m long and 2 m deep. Each net was composed of four 25 m panels of 38 mm mesh (stretch measure), and two 50 m panels of 51, 64, and 76 mm mesh. All panels of like mesh were tied together before tying onto the next largest mesh size, resulting in four 100 m panels of one mesh size. Duration of effort ranged from 20 to 25 hours. Bottom depth of net sets ranged from 49.4 to 92.5 m.

Captured ciscoes were frozen and returned to the laboratory for morphometric and biological analyses. Species identifications were made by using the morphological character guide developed by Tom Todd (USGS, unpubl. Report[1]) (Table 2). Otoliths were collected, and individuals were examined for sex determination and state of maturity.

RESULTS

2002-2006 SAMPLING

Across all years, a total of 1950 ciscoes were collected in Lake Huron. Of these 1950 ciscoes, 1538 were Bloater, 72 were Cisco, 20 were Shortjaw Cisco, and 320 had a combination of characters that prevented them from being identified to species (Table 3). No Shortnose Cisco were identified, as none of the specimens had dark pigmentation on the tip of the snout, a key characteristic of the species (Webb and Todd 1995). No Blackfin Cisco were identified, as none of the specimens had a high gill raker count (>50; Table 2), a key characteristic of the species (Scott and Crossman 1973).

Of the 1943 ciscoes collected in 2002-2006 and measured, 53 fish had an included jaw, 661 fish had a terminal jaw, and 1229 fish had an extended jaw (Figure 2). The majority of fish had gill rakers that were medium in length (between 0.0312 and 0.0365) and had counts between 40 and 45 (Figure 3, Figure 4). Very few fish had gill raker counts less than 40 and gill rakers classified as short or long (Figure 4).

2007 SAMPLING

A total of 433 ciscoes were collected in 2007; 228 from the North Channel, and 205 from the northern main basin (Table 4). Approximately 90% of the ciscoes were captured in experimental nets. Bloater dominated the catch, followed by a lesser number of Cisco; only two fish were identified as Shortjaw Cisco (Table 4). The relative abundance of Cisco was relatively similar between locations and net types, while Bloater were captured in similar densities between locations, but in higher abundance in experimental nets (Table 5). The relative abundance of Shortjaw Cisco was very low, only 0.3 fish/net km in experimental nets from the North Channel (Table 5).

The mean depth of net set was deeper in the northern main basin, at 90.0 m (SE ± 2.5 m), than in the North Channel, at 59.8 m (SE ± 5.3 m). The substrate for all sets was silt, clay, or a combination of silt and clay. The two Shortjaw Cisco were captured in the same net, at 59 m depth over primarily silt substrate, in the North Channel.

Similar gill raker patterns were observed in the fishes captured in 2007, with most of the ciscoes having 40-46 rakers, and very few fish having < 40 rakers (Figure 3). Both ciscoes identified as Shortjaw Cisco had an included jaw and relatively short gill rakers, although the gill raker counts (43) were higher than most Shortjaw Cisco historically possessed.

2012 SAMPLING

A total of 204 ciscoes were collected. Of these, 110 were Bloater, 75 were Cisco, and 17 were Shortjaw Cisco (Table 6). All fish identified as Shortjaw Cisco were collected from the Lion's Head area. Due to poor condition, two specimens could not be identified to species. Of the ciscoes collected in 2012, 17 fish had an included jaw, 71 fish had a terminal jaw, and 116 fish had an extended jaw. Sixteen of the Shortjaw Cisco captured were female and one was male. The otoliths of 14 Shortjaw Cisco were interpreted. Their mean age was 9.2 years and ranged 7-14 years.

Shortjaw Cisco were collected from five gillnets, set at bottom depths between 77 and 92.5 m (mean depth: 85.9 mm). Eighty-eight percent of individuals were captured in panels of 38 mm mesh and 12 percent in panels of 51 mm mesh.

DISCUSSION

Of the 2165 cisco specimens collected in Lake Huron in 2002-2012 and identified to species, most were Bloater (n=1902), followed by Cisco (n=224) and Shortjaw Cisco (n=39). The Shortjaw Cisco specimens represent the first collection in Canadian waters of Lake Huron since 1982. Shortjaw Cisco were caught in the vicinity of where they were reported by Koelz (1929) (Appendix), as well as new locations in the vicinity of Fathom Five National Park in Georgian Bay and west of Tobermory in Lake Huron.

The specimens identified as intermediate forms may be "true" hybrids created by the breeding of parents of different species, or simply individuals of one species that have characteristics that fit the description of, or are intermediate to, more than one species. As ciscoes in the Great Lakes exhibit little genetic diversity, but much phenotypic variation (Todd et al. 1981), it is difficult to distinguish the origin of the intermediate forms. Koelz (1929) recognized that intermediate forms occur in nature and stated that such forms were no more prevalent in whitefishes than in other species, and that most Great Lakes whitefish individuals should be identifiable to subspecies. However, it is generally thought that, in fact, Koelz removed intermediate forms from the samples that he used to describe subspecies. Scott and Crossman (1973) noted that ciscoes in the Great Lakes had changed dramatically since Koelz (1929) and hypothesized that introgressive hybridization has been occurring as a result of increasing rarity, due to overexploitation, of the parent species. The origin of the intermediate forms requires further examination.

A subset of the Shortjaw Cisco specimens collected in this study, 2003-2006, as well as specimens collected in 2007, was used to model habitat preferences for the species (Naumann and Crawford 2009). Of models based on all possible combinations of water depth, substrate slope, and cliff distance, the model determined that water depth alone was the best predictor of Shortjaw Cisco occurrence. Shortjaw Cisco were collected in depths of 61-160 m with half collected in depths of 141-160 m. Naumann and Crawford (2009) indicated a need for additional sampling to better understand what influences the occurrence of Shortjaw Cisco.

Of the 2165 ciscoes caught in Lake Huron, 2002-2012, less than 2% were Shortjaw Cisco. While the current proportion of Shortjaw Cisco in the deepwater cisco community is well below the ~25% Shortjaw Cisco observed in the benchmark Koelz (1929) survey, the identification of any Shortjaw Cisco after a 20+ year absence is a positive sign. Shortjaw Cisco have also recovered in Lake Superior over the same timeframe after a long period of slow decline (Gorman 2012, Pratt 2012), suggesting that similar factors may be playing a role in Shortjaw Cisco population dynamics between the two Great Lakes. Additional, extensive sampling is required to determine the spatial and temporal extent of Shortjaw Cisco distribution and abundance in Lake Huron and associated environmental drivers.

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*Table 1. Occurrence status of deepwater cisco species (*Coregonus *spp.) in Lake Huron (from Roth et al. 2013).*

Scientific Name	Common Name	Status
Coregonus hoyi	Bloater	Extant
Coregonus johannae	Deepwater Cisco	Extinct
Coregonus kiyi	Kiyi	Extirpated
Coregonus nigripinnis	Blackfin Cisco	Extirpated
Coregonus reighardi	Shortnose Cisco	Extinct
Coregonus zenithicus	Shortjaw Cisco	Extant

*Table 2. Morphological characteristics of ciscoes (*Coregonus *spp.). Modified from Todd (no date)*[1].

Species	Angled snout	Unique pigmen-tation	Lower jaw position			Gillraker Length			Gillraker Number				Paired Fin Length			Eye Diameter	
			Included	Terminal	Extended	Short	Medium	Long	35-40	40-45	45-50	51+	Short	Medium	Long	Moderate	Large
C. artedi	•		•	▲	•		•	▲		•	▲	•	▲	▲		▲	
C. hoyi	•			•	▲		▲	•	•	▲	•			▲		▲	
C. zenthicus	▲		▲	•		▲	•		▲				▲	▲		▲	
C. kiyi	•		•	•	▲		▲	•		▲					▲		▲
C. nigripinnis	•	▲ *(fins)*	•	•	▲		▲				•	▲		▲		•	▲
C. reighardi	▲	▲ *(snout)*	▲	•		▲	•		▲				▲			▲	
C. johannae				▲					▲ *(>37)*						▲	▲	

Table 3. Cisco species caught in Lake Huron, 2002-2006.

Year	No. of Net Sets	*Coregonus* Species					Total
		artedi	*hoyi*	*zenithicus*	*artedi/hoyi*	*hoyi/zenithicus*	
2002	6	6	140	0	18	5	169
2003	12	8	845	4	205	57	1119
2004	2	0	18	0	28	7	53
2005	25	39	343	10	0	0	392
2006	26	19	192	6	0	0	217
Total	71	72	1538	20	251	69	1950

Table 4. Ciscoes captured in the North Channel and northern main basin of Lake Huron, by net type, in 2007.

Location	Net type	*Coregonus* Species			Total
		artedi	*hoyi*	*zenithicus*	
North Channel	Traditional	10	29	0	39
	Experimental	30	157	2	189
Main basin	Traditional	2	5	0	7
	Experimental	35	163	0	198
Total		77	354	2	433

Table 5. The mean number of ciscoes captured per gill net kilometer from the North Channel and northern main basin of Lake Huron, by net type, in 2007.

Location	Net type	*Coregonus* Species		
		artedi	*hoyi*	*zenithicus*
North Channel	Traditional	6.2	4.7	0.0
	Experimental	6.4	24.6	0.3
Main basin	Traditional	3.8	1.3	0.0
	Experimental	5.7	28.7	0.0

Table 6. Ciscoes captured in Lake Huron in 2012.

Location	*Coregonus* Species			Total
	artedi	*hoyi*	*zenithicus*	
Lion's Head	60	105	17	182
Tobermory	15	5	0	20
Total	75	110	17	202

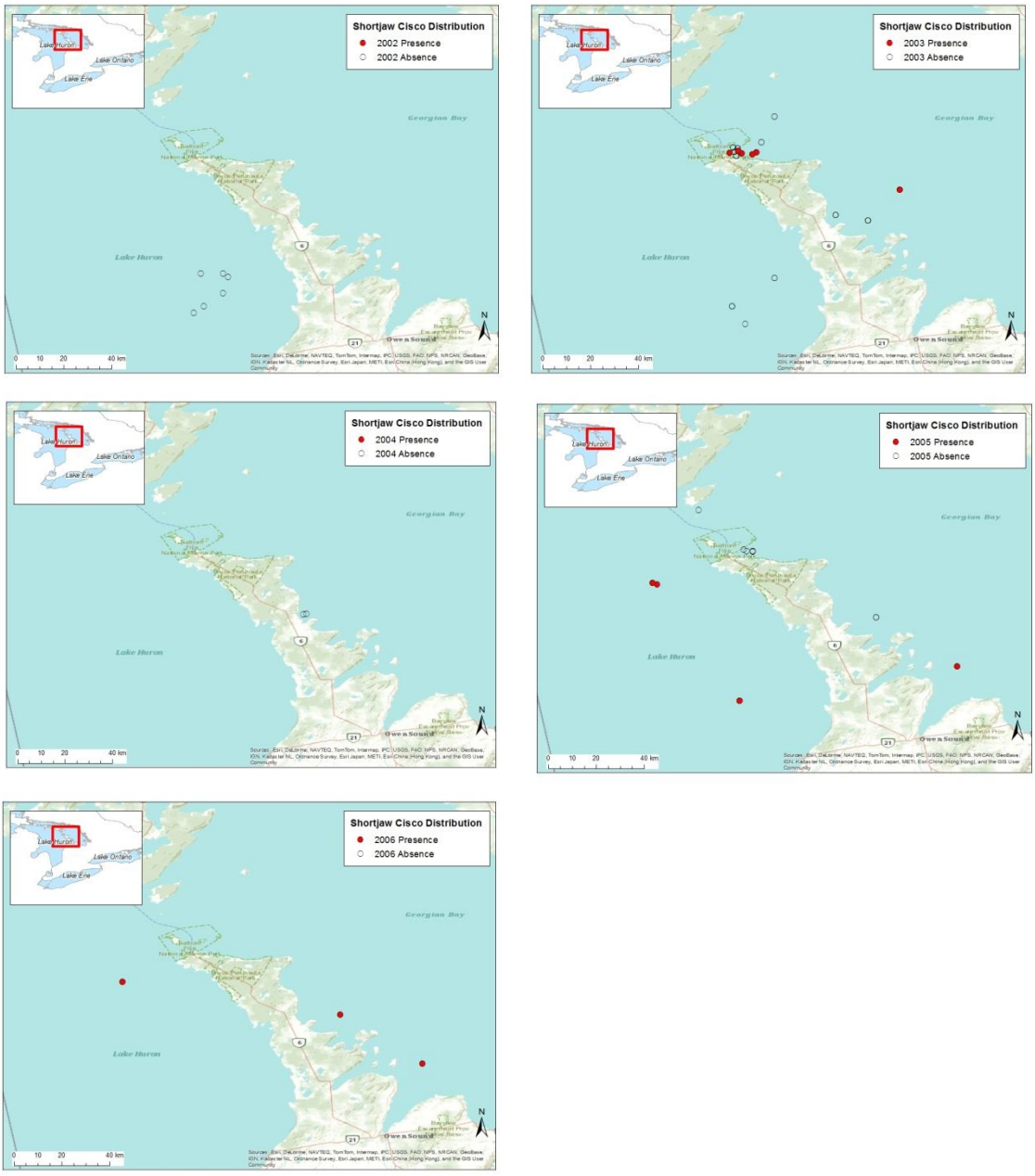


Figure 1. Locations of cisco sampling in the Canadian portion of Lake Huron, 2002-2006, with locations where Shortjaw Cisco were caught identified. Note that multiple net sets may have taken place at a single site.

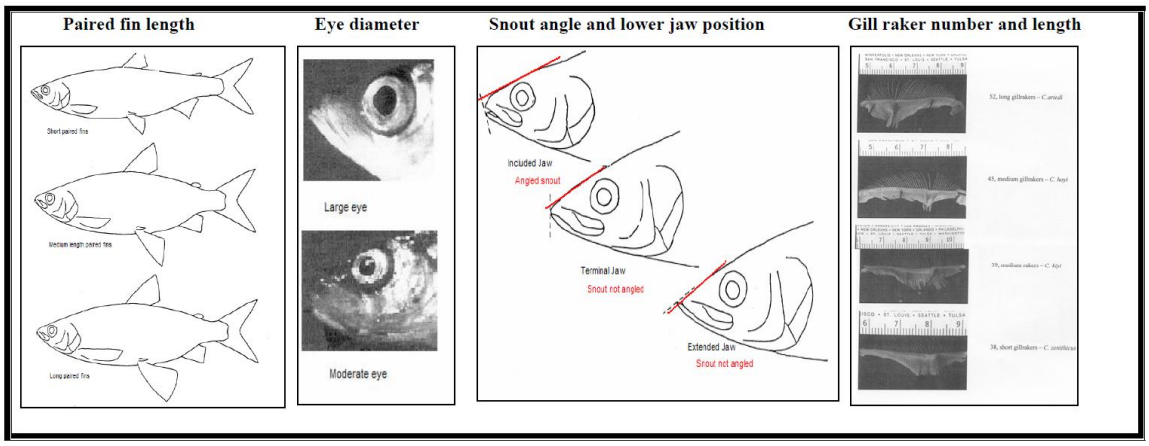


Figure 2. Morphological characteristics used to determine cisco species. Modified from Todd (no date).

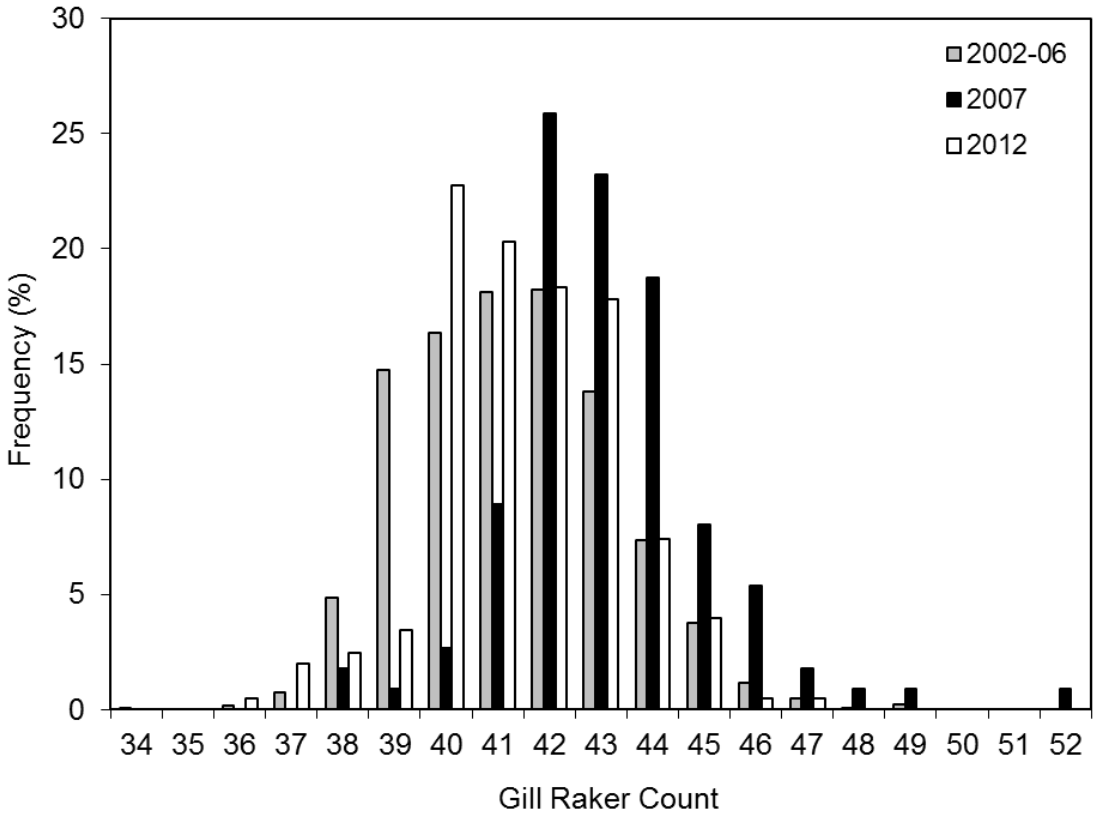


Figure 3. Frequency of number of gill rakers in ciscoes caught in around the Bruce Peninsula in 2002-2006 (n = 1943) and 2012 (n = 204), and the North Channel and northern main basin in 2007 (n = 104).

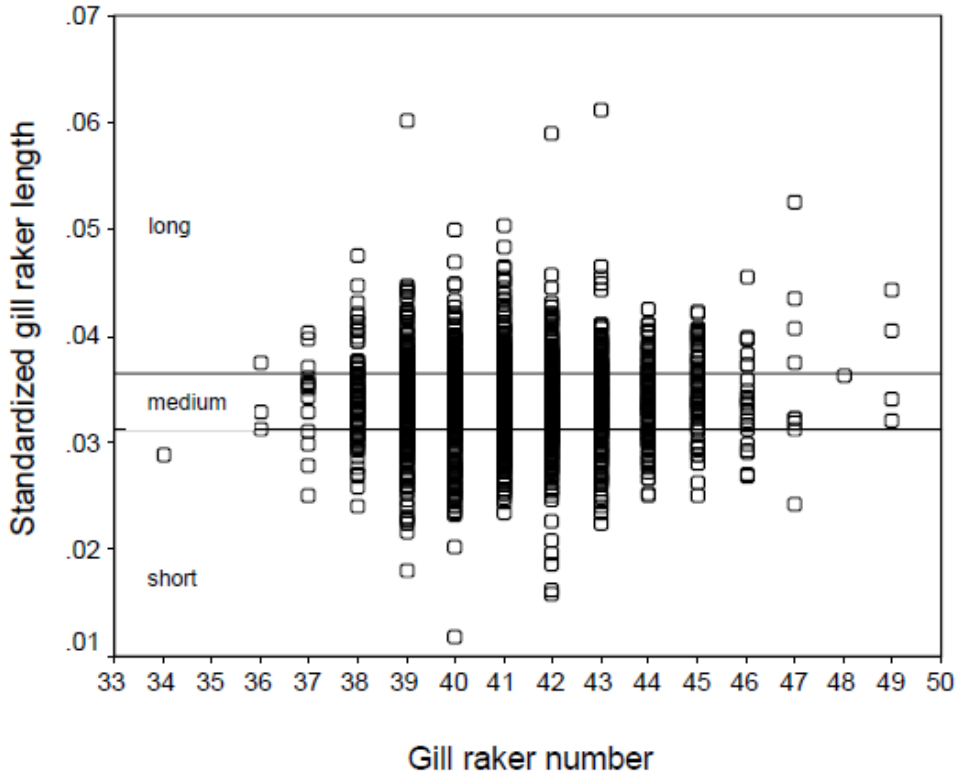
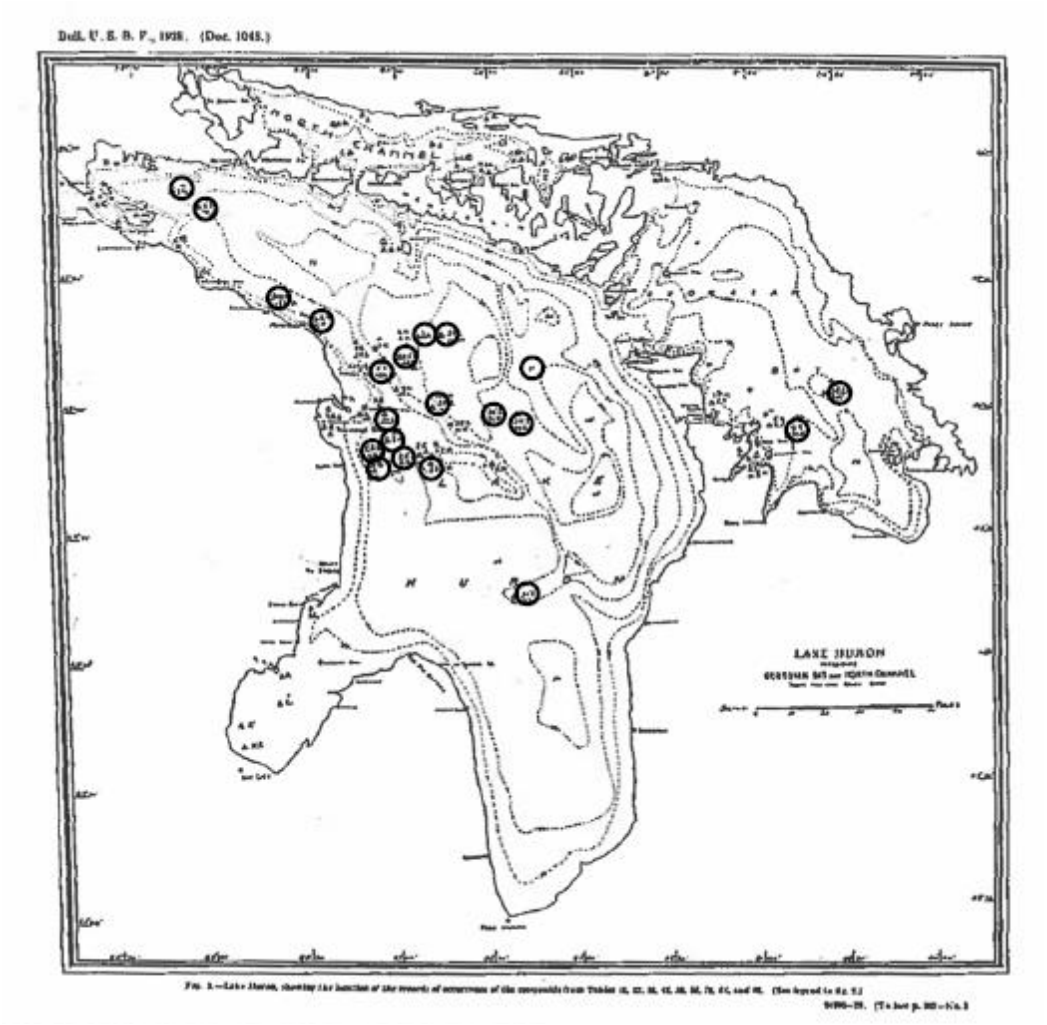


Figure 4. Correlation of gill raker length/fish total length (SGRL) with gill raker number in ciscoes (n=1943) caught in Lake Huron, 2002-2006. Horizontal lines denote boundaries of three classes of gill rakers length (short, medium and long).

APPENDIX



Appendix. Historic sampling locations in Lake Huron where C. zenithicus *(z) was found (modified from Koelz 1929).*