IS IT POSSIBLE TO IDENTIFY HABITAT FOR A RARE SPECIES: SHORTJAW
CISCO (*COREGONUS ZENITHICUS*) IN LAKE HURON AS A CASE STUDY

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ABSTRACT

IS IT POSSIBLE TO IDENTIFY HABITAT FOR A RARE SPECIES: SHORTJAW CISCO (*COREGONUS ZENITHICUS*) IN LAKE HURON AS A CASE STUDY

Benjamin T. Naumann
University of Guelph, 2008

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The Committee on the Status of Endangered Wildlife in Canada has recommended that Shortjaw cisco (*Coregonus zenithicus*) be listed under the Species at Risk Act; if listed the species will receive legal protection, including its 'critical habitat'. Shortjaw cisco provides a case study for the feasibility of habitat identification for threatened species. Competing habitat use models were developed from three available physical habitat variables (Water Depth, Slope and Distance to Cliff) and were evaluated using binary logistic regression and Akaike information criteria. Of the habitat factors examined, Water Depth was the most important variable explaining the distribution of shortjaw cisco in Lake Huron. However, water depth information alone cannot identify habitat for this taxonomically uncertain and rare species in Lake Huron. Therefore, it is recommended that future studies of shortjaw cisco habitat use study locations where shortjaw cisco are still abundant and include depth as a variable along with variables in future models.

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IS IT POSSIBLE TO IDENTIFY HABITAT FOR A RARE SPECIES: SHORTJAW CISCO (*COREGONUS ZENITHICUS*) IN LAKE HURON AS A CASE STUDY

INTRODUCTION

Management of species at risk requires an understanding of factors that influence the species' risk of extinction (Dulvy et al. 2004, Fox 2005, Ricklefs 1990). The Canadian Federal Government passed the Species at Risk Act (SARA 2003) with the following purpose:

“... prevent wildlife species from being extirpated or becoming extinct, to provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity and to manage species of special concern to prevent them from becoming endangered or threatened.”

For a species to receive legal protection under SARA, it must proceed through a standard listing process (SARA 2003).

The SARA listing process begins with a species assessment from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Mooers et al. 2007). In 1977, COSEWIC was created to assess the status of Canadian species that were possibly at risk of extinction. In 2003, SARA identified COSEWIC as an advisory body to assess species status using the “*best available information and Aboriginal Traditional Knowledge*” (COSEWIC 2006). If a species is determined to be at risk of extinction, COSEWIC makes a recommendation to the responsible Minister regarding legal listing of species under SARA (Mooers et al. 2007). Based on the recommendation from COSEWIC, the Minister has three choices to consider: (1) accept the COSEWIC recommendation to list the species; (2) decline the COSEWIC recommendation to list the

species; or (3) send the recommendation back to COSEWIC for re-evaluation (SARA 2003). If the Minister accepts the COSEWIC recommendation to list the species under SARA, the species is immediately granted legal protection, including protection of the species' critical habitat (SARA 2003).

When a species is listed under SARA as either 'Extirpated', 'Endangered' or 'Threatened', recovery strategies are prepared (Mooers et al. 2007). If the Minister determines that recovery for a species is feasible, the recovery strategy is implemented to address: (1) threats to the survival of the species identified by COSEWIC; (2) measures required to achieve population objectives for the species; (3) methods to monitor the recovery of the species over the long-term and short-term; and, (4) identification of the species' critical habitat and development of methods to preserve unprotected critical habitat of the species (SARA 2003). SARA defines critical habitat as "the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species" (SARA 2003).

Habitat in general has been defined as "the resources and conditions present in an area that produce occupancy including survival and reproduction by a given organism. Habitat is organism-specific; it relates the presence of a species, population, or individual (animal or plant) to an area's physical and biological characteristics" (Hall et al. 1997). To identify the amount and configuration of habitat that is critical for the persistence of a particular species, it is important that general habitat distribution and use be analyzed.

The shortjaw cisco (*Coregonus zenithicus*) is a member of the subfamily Coregoninae (including whitefish and deepwater ciscoes) and is one of the most widely

distributed and taxonomically perplexing groups of all Canadian freshwater fishes (Murray and Reist 2003, Todd and Smith 1980). Shortjaw cisco is part of a species complex including six closely-related species: shortnose cisco (*C. reighardi*), bloater (*C. hoyi*), kiyi (*C. kiyi*), lake herring (*C. artedi*), blackfin (*C. nigripinnis*), and deepwater cisco (*C. johannae*) (Webb and Todd 1995). Taxonomic uncertainty among these species is amplified by phenotypic plasticity across their geographic ranges and morphologically similarities between deepwater cisco and lake herring (Koelz 1929, Scott and Crossman 1973, Todd and Steinhilber 2002).

Historically, shortjaw cisco was found in western and central Canada, including the Laurentian Great Lakes with the exception of Lake Ontario where the species has never been described (Scott and Crossman 1973) (Figure 1). In the Great Lakes, shortjaw cisco and other deepwater ciscoes have been declining in abundance and distribution since the 1800s (Smith 1968). It has been hypothesized that these declines may be due to commercial fishing, parasitism by sea lamprey (*Petromyzon marinus*), competition for food and habitat with alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*), hybridization with other cisco species, and habitat degradation (Smith and Todd 1984, Smith 1968, Steinhilber 2002, Todd 1985).

Shortjaw cisco has been extirpated from Lakes Erie and Michigan (Scott and Crossman 1973, Scott and Smith 1962). Before 2003, the last shortjaw cisco caught in Lake Huron was in 1982, and the species was deemed extirpated from Lake Huron by Todd (1985). Routine sampling of deep water cisco species in 2003 reported 12 specimens as shortjaw cisco from waters surrounding the Saugeen (Bruce) Peninsula, Lake Huron. After shortjaw cisco was identified, targeted shortjaw cisco sampling took

place. The Chippewas of Nawash Unceded First Nation (Nawash) and Parks Canada requested the analysis of deep water cisco and targeted shortjaw cisco data in 2006. The purpose of the requested analysis was to address uncertainties in shortjaw cisco habitat in Lake Huron.

In 1988, the first COSEWIC status report was prepared for shortjaw cisco, and the species was designated by COSEWIC as 'Threatened' throughout the species' distribution (Houston 1988). In 2003, shortjaw cisco status was re-examined by COSEWIC and was recommended to the Minister for listing under SARA as 'Threatened' (COSEWIC 2003). After consideration, the Minister referred the recommendation back to COSEWIC for re-evaluation citing: (1) lack of incorporation of Aboriginal Traditional Knowledge and (2) taxonomic uncertainty concerning the species (Minister of Fisheries and Oceans 2004).

There are two major assumptions that are explicitly made in this research project concerning taxonomic and identification uncertainty of the shortjaw cisco. The first assumption is that shortjaw cisco is a valid species. Taxonomic uncertainty within the genus *Coregonus* may originate from hybridization, introgression and phenotypic plasticity, which may have caused a merging of morphological traits and reduced levels of genetic differences (Scott and Crossman 1973, Todd and Smith 1980, Turgeon and Bernatchez 2003). Taxonomic uncertainty has increased the complexity in classifying individuals to the species level (Douglas et al. 1999, Turgeon et al. 1999). Considerable research has been undertaken to reduce the taxonomic uncertainty associated with deepwater cisco; however this issue has not been resolved to date.

The second assumption is that if shortjaw cisco is a valid species, it can be reliably identified from the other deepwater cisco species. The major tool used to identify shortjaw cisco for this study was *Tom Todd's Sure-Fire Guide To Morphological Characteristics of Ciscoes (Coregonus sp.) of the Great lakes Region* (Todd 2001). The plasticity of some of the characters used in this study to identify *Coregonus* species (e.g. gillrakers, snout angle, and mouth shape) can lead to substantial uncertainty in the final species identification.

After the 2003 identification of shortjaw cisco in waters surrounding the Saugeen Peninsula, Fisheries and Oceans Canada, Parks Canada and Nawash collaboratively pursued research in support of conservation efforts for shortjaw cisco, including an improved understanding of habitat distribution and use. These parties share a joint interest in understanding the ecology of shortjaw cisco and the SARA listing process, including, if necessary, the eventual designation of that habitat which is deemed critical to species recovery. These management decisions will need to address both conservation issues and Aboriginal and Treaty Rights.

Thus, the determination of shortjaw cisco habitat has emerged as a proximate necessity for the responsible management of the species. This problem can be posed as a more general uncertainty: is it possible to identify habitat for taxonomically uncertain and rare species? To date, there have been no attempts to quantify the abiotic or biotic habitat factors that affect the distribution of shortjaw cisco in the Great Lakes generally or Lake Huron specifically. A review of the available literature on shortjaw cisco ecology revealed a set of physical habitat factors that have been hypothesized to be related to the species' distribution namely: water depth, slope, and distance to sharp discontinuities in

topographic relief of the lake bottom (here after, 'cliffs'). These three variables were selected for this research project for their potential ecological importance as well as the availability of data from the targeted shortjaw cisco sampling program.

Water Depth to the bottom may influence the distribution of shortjaw cisco in Lake Huron, and is the most commonly cited habitat factor in literature related to shortjaw cisco. While shortjaw cisco is typically considered a bottom deepwater species, often occupying locations below the thermocline (Koelz 1929, Scott and Smith 1962, Todd and Smith 1980), it is not limited to deepwater environments. For example, shortjaw cisco has been found at water depths of 2-16 m in Barrow Lake, Alberta, which has a maximum water depth of 24 m (Steinhilber et al. 2002). However, in the Great Lakes where deepwater is available, shortjaw cisco have been found from 18 to 183 m deep (Koelz 1929). Perhaps individual shortjaw cisco are attracted to physical and/or chemical characteristics of deep water (e.g. high pressure, low light, low dissolved oxygen, low temperature). Stomach contents of shortjaw cisco sampled from throughout the species' distribution revealed that two species dominated their diet (Anderson and Smith 1971, Bajkov 1932, Koelz 1929, Scott and Crossman 1973, Steinhilber 2002). The deepwater amphipod, *Diporeia* sp. is among the most abundant benthic macroinvertebrates in the Great Lakes, ranging in water depth from 5-100+ m (Sly and Christie 1992). The opossum shrimp (*Mysis relicta*) is also an abundant deepwater invertebrate found in the Great Lakes, where it exhibits diurnal vertical migrations through the water column (Beeton 1960, Beeton and Saylor 1995, Robertson et al. 1968). Thus, the depth hypothesis states that shortjaw cisco distribution in Lake Huron is determined by the availability of deep water. The water depth hypothesis predicts a

unimodal distribution of shortjaw cisco in waters between approximately 20 and 180 m in depth.

Sloping substrate is a bathymetric habitat factor that may influence the distribution of shortjaw cisco in Lake Huron. In Lake Superior, the shortjaw cisco has been almost exclusively found on sloping lake bathymetry (Tom Pratt pers. comm. 2007). However, there have been no physicochemical or biological reasons put forward in the literature to account for a proximate mechanism. In the Great Lakes, *Diporeia* sp. are often abundant on sloping lake bottoms (Evans et al. 1990) and benthic *M. relicta* and *Diporeia* sp. are often in similar habitats (Parker 1980). The hypothesis that the distribution of shortjaw cisco in the Great Lakes is determined the availability of sloping substrate, predicts a direct relationship between slope and abundance of shortjaw cisco.

Distance to Cliffs is another bathymetric habitat factor that may influence the distribution of shortjaw cisco in Lake Huron. In Lake Superior, shortjaw cisco have often been found in proximity to underwater cliffs (Koelz 1929). In Lake Huron, commercial fishermen have historically targeted deepwater cisco species in locations near underwater cliffs (Jobes 1949). Underwater cliffs can force upwelling of deep, nutrient-rich water into shallower water depths, leading to high levels of primary production (Smith 1995). Reports of aggregations of *M. relicta* at such locations have been made from Lake Michigan and Lake Ontario (Johannsson 1992, Shea and Makarewicz 1989). The hypothesis that the distribution of shortjaw cisco in the Great Lakes is determined by underwater cliffs predicts an inverse relationship between distance to cliff and shortjaw cisco abundance.

The goal of this thesis is to determine if habitat could be effectively identified for a taxonomically uncertain and rare species. To achieve this goal, it was necessary to undertake the following specific objectives:

- (1) Compile and describe the distribution of targeted shortjaw cisco samples (effort and catch) from Lake Huron.
- (2) Develop a set of habitat use models (Water Depth, Slope, and Distance to Cliff) that represent alternative ecological hypotheses about the influence of physical habitat variables on shortjaw cisco distribution in Lake Huron.
- (3) Evaluate the degree to which distribution of sampled shortjaw cisco can be explained by the selected physical habitat variables.

MATERIALS AND METHODS

Study location

The study area consisted of waters surrounding the Saugeen Peninsula, Lake Huron, Canada (Figure 2). Waters within the study location can be characterized as oligotrophic and were representative of the Main Basin of Lake Huron with major water influences from Lake Superior and Lake Michigan (Sly and Munawar 1988).

Sample effort and catch

In 2003, Nawash, Fisheries and Oceans Canada, Parks Canada and Ontario Ministry of Natural Resources conducted targeted sampling for deepwater cisco in locations around the Saugeen Peninsula, Lake Huron where cisco species were historically found by Koelz (1929) and by commercial fishermen. Between 2004 and 2007, targeted shortjaw cisco sampling was continued by Nawash, Fisheries and Oceans

Canada, and Parks Canada (Table 2). Sampling was conducted using bottom-set gillnets (1100 m length) with mesh sizes ranging from 6.4 - 6.7 cm (2.5-2.6 in), with mesh panels 91.4 – 127 cm (36 and 50 in) in height, for durations ranging from 24-72 hours, but most commonly for 48 hours. Start and finish GPS coordinates of each sample event were recorded using an on-board GPS.

All individuals of deepwater cisco were retained for species identification. *Tom Todd's Sure-Fire Guide To Morphological Characteristics Of Ciscoes (Coregonus sp.) of the Great Lakes Region* (Todd 2001) was used for preliminary identification of *Coregonus* sp. by Nawash biologists; suspect shortjaw cisco and specimens with uncertain identities were sent to Fisheries and Oceans Canada (Burlington, Ontario). Final identifications were made by experts Nick Mandrak (Fisheries and Oceans Canada, Burlington, Ontario), Tom Pratt (Fisheries and Oceans Canada, Sault Ste. Marie, Ontario), and Tom Todd (United States Geological Survey, Ann Arbor, Michigan). Following expert identifications, shortjaw cisco were scored as present or absent for each sample.

Habitat use models

Three habitat variables predicted to influence the distribution of shortjaw cisco (Water Depth, Slope, Distance to Cliff) were combined to form a set of seven habitat use models representing different biological hypotheses about factors affecting shortjaw cisco distribution (Table 1). Water Depth, Slope, and Distance to Cliff for each sample were quantified using a digital elevation map (DEM) of Lake Huron of pixel size of 10 x 10 m imported to ArcGIS 9.1 (version 9.1, Environmental Systems Research Institute, Redlands, California, USA). The DEM was generated by Parks Canada using contour

data collected by the National Oceanic and Atmospheric Administration (NOAA) and Canadian Hydrographic Service (CHS). The start and finish GPS coordinates for each sample were converted from degrees, minutes, and seconds to decimal degrees; midpoints for each sample were determined and plotted on the DEM.

Circular buffers with a radius of 1100 m were created around each sample in ArcGIS. Typically, the size of buffers used to characterize habitat features is based on ecologically relevant distances (i.e. home range size); In the absence of detailed knowledge about the ecology of shortjaw cisco, a radius was arbitrarily established as the length of each gillnet, to create a circular buffer region surrounding each sample location. Water Depth was calculated by determining the average water depth for all of the pixels within the buffer.

Slope at each sample was calculated as follows: (1) a contour map layer was created from the DEM; (2) within each buffer, the steepest slope was determined by creating a line through the greatest change in elevation through the mid-point of the buffer; (3) Hawth spatial ecological GIS tools (Hawthorne 2007) were used to convert the line into points with a spacing equal to the resolution of the DEM, and the slope of the line of the regression of Water Depth over distance as the average slope of the sample event was calculated (SPSS 2006).

Underwater cliffs were defined as any submerged feature with a slope of 10° or greater. With the Spatial Analyst Extension in ArcGIS, the raster calculator was used to filter the slope layer to remove any water depth changes less than 10° degrees, and the Extraction Values to Points function was used to determine the Euclidean distance from each sample to the nearest defined cliff.

Statistical analysis

To reduce redundancy in the analysis, Pearson's correlation test was used to evaluate the correlations among habitat variables. Habitat use was modeled using binary logistic regression due to the fact that shortjaw cisco occurrence was measured as presence/absence (1/0). Binary logistic regression (SPSS 2006) was used to determine the -2 log maximum likelihood estimate, a measure of the information explained by each model from the empirical data.

Akaike's Information Criterion (*AIC*) was used to determine the relative strength of each model for predicting shortjaw cisco presence/absence (Burnham and Anderson 2002). Model selection criteria evaluate the weight of evidence in the data for each model and assesses the trade-offs between model fit and complexity to identify the most parsimonious model that accounts for the greatest variation with the smallest number of variables (Boyce et al. 2002, Burnham and Anderson 2002, Johnson and Omland 2004). Akaike's Information Criterion corrected for small sizes (*AIC_c*) was used to determine the rank order of fits for the set of competing models. The *AIC_c* equation is expressed as:

$$AIC_c = -2 \log \left(\mathcal{L}(\hat{\theta}) \right) + 2K + \frac{2K(K+1)}{n-K-1}$$

Where $-2 \log \left(\mathcal{L}(\hat{\theta}) \right)$ is the likelihood estimate, K is the number of variables for each model, and n is the sample size. The model with the lowest *AIC_c* score was considered the best approximating model (Burnham and Anderson 2002). Competing models were ranked by their *AIC_c* differences (ΔAIC_c) and Akaike weights. Models with ΔAIC_c scores less than 2.0 can be considered strongly supported by the data, while models with

differences in ΔAIC_c scores greater than 7.0 can be considered to have weak support (Burnham and Anderson 2002).

Akaike weights (totaling a value of one) determine the strength of the evidence in favor of a particular model being the ‘best model’ relative to other models in the set. Estimates of the relative importance of each variable were determined by summing the Akaike weights across all models in which the variable occurred (Burnham and Anderson 2002).

RESULTS

Seventy-three targeted deepwater cisco samples were distributed across six years of sampling from 2003 to 2007, inclusive (Table 2). Twenty-five specimens of shortjaw cisco were identified in the catches at 14 different sample locations (Table 2, Figure 2); abundance ranged from 1-6 specimens per sample (Appendix I). The majority of samples with identified shortjaw cisco contained single specimens, however two samples contained a total of 10 shortjaw cisco, accounting for 40% of the total number of individuals in the study. Samples with shortjaw cisco were obtained from throughout the study area, around the Saugeen Peninsula, Lake Huron (Figure 2).

Water depth for samples ranged from 24 to 155 m, while water depths associated with presence of shortjaw cisco ranged from 61 to 138 m (Figure 3). These absolute water depth distributions of effort and catch were generally similar. Slope of the substrate for the 73 samples ranged from very flat (<0.002) to moderately inclined (>0.060), with the greatest frequency of targeted samples located over very flat bathymetry (Figure 4). Slope data for samples where shortjaw cisco were caught ranged across all conditions

sampled (0.003-0.580). There was no obvious relationship between substrate slope and shortjaw cisco occurrence. Distance to Cliff for the targeted samples exhibited a large range, although most of the samples were within 2.5 km of a submerged cliff (Figure 5). Shortjaw cisco were found across the range of values for the variable Distance to Cliff, from zero less than 40 km, however they were not found in close proximity to cliffs in the same relative frequency as targeted sampling effort.

The three habitat variables were found to be statistically independent of each other; Pearson's correlation coefficient: Water Depth x Slope ($r=0.039$); Water Depth x Distance to Cliff ($r=0.177$); and Distance to Cliff x Slope ($r=0.163$). Therefore the 7 competing habitat use models were analyzed as a single set.

The results of model selection analyses for the competing habitat use models are summarized in Table 3. The set of 7 models are presented in rank order associated with calculated values for: corrected Akaike Information Criteria AIC_c (increasing); differences in corrected Akaike Information Criteria ΔAIC_c (increasing); and Akaike weight w_i (decreasing). Within the set of competing models, the univariate and bivariate models with Water Depth performed better than the others, with absolute ΔAIC_c values less than 2.0, indicating the strongest model fit, of those analyzed (Burnham and Anderson 2002). The variable with the highest relative importance from the three variables was Water Depth (0.87) while the variable with the lowest predictive strength was Slope (0.25) (Table 3).

DISCUSSION

The goal of this thesis was to determine if habitat could be effectively identified for a taxonomically uncertain and rare species. While depth was identified as the most important variable in explaining the distribution of shortjaw cisco, the results also suggest that physical and bathymetric variables alone do not reliably predict the presence/absence of shortjaw cisco in Lake Huron. This study demonstrated the difficulty in quantifying habitat for a rare species, as the statistical challenges of dealing with very small sample sizes.

One approach to addressing the challenge of small sample sizes would be to extend studies on the distribution of shortjaw cisco to systems where they are relatively abundant. Within the Great Lakes system, Lake Nipigon is the only lake still having a reported abundance of shortjaw cisco (Todd and Smith 1992). To identify Great Lakes habitat for shortjaw cisco, it is recommended that Lake Nipigon be used as a study location for habitat identification. This recommendation will help to ensure that more than an adequate sample size can be attained for statistical purposes. Once shortjaw cisco habitat is described in Lake Nipigon, this can be used as a basis to identify shortjaw cisco habitat for Lake Huron.

If it is determined that shortjaw cisco is not a taxonomically valid species (SARA 2003), would this study still be important? Deepwater ciscoes have been declining in distribution and abundance since the 1800's and existing populations are currently still declining within the Great Lakes, with exception to bloater, which are still abundance in the upper Great Lakes (Fave and Turgeon 2007). Some of these existing populations of deepwater cisco general habitat information is poor and any habitat information would

aid in the protection of critical habitat if listed under SARA. Ultimately regardless of species status, protection is a reflection of social value about whether people want to protect biodiversity at the level of shortjaw cisco in lake Huron.

Of the habitat factors examined in this study, Water Depth was the most important variable explaining the distribution of shortjaw cisco in Lake Huron. The results of this study showed that Water Depth alone, or in combination with the other two variables, ranked 1-3 (of 7) in ΔAIC_c and Akaike weights (w_i). The bivariate models that included Water Depth (Water Depth+Distance to Cliff and Water Depth+Slope) have a one parameter difference from the best model (Water Depth), the bivariate models' maximum log-likelihood values are close only due to association with Water Depth (Burnham and Anderson 2002). The importance of Water Depth is further supported by the observation that its relative predictive importance was more than double the values for Distance to Cliff and Slope (Burnham and Anderson 2002).

Shortjaw cisco water depth distribution observed in this study is consistent with the literature for shortjaw cisco distribution in the upper Great Lakes (Lake Superior, Michigan, and Huron). Shortjaw cisco has been found in water depths ranging from 18-183 m (Bajkov 1932, Van Oosten 1936), but are generally found in 55-144 m of water (Todd 2002). In Lake Superior shortjaw cisco has been caught in water depths of 110-144 m in spring, 55-71 m in summer, and 73-90 m in winter (Dryer 1966, Koelz 1929). Shortjaw cisco were found across the range of values for the variable Distance to Cliff, however they were not found in close proximity to cliffs in the same relative frequency as for targeted sampling effort. Targeted sampling effort to catch shortjaw cisco was deployed at various locations, based on the practical experience of commercial fishermen

and on reports of their historic deepwater cisco occurrence. Therefore, the sampling effort reported in this study was non-random with respect to location and associated habitat. The reader must keep in mind that this kind of non-random, targeted sampling effort is required to obtain any specimens that are in low abundance. It is possible that analysis of non-random sampled habitats have resulted in differences of presence/absence and ultimately model selection results (Type I error). This source of error can be reduced with careful project planning, and with clear questions and hypotheses, established before sampling effort is deployed.

Water Depth information cannot necessarily be used to successfully predict the occurrence of shortjaw cisco in Lake Huron. However, based on the results of this study, it would be reasonable to include water depth as a candidate factor in future predictive studies. The water depth distribution of shortjaw cisco observed in this study is recommended for use in determining the prior probability distribution of a predictive model (see Appendix II for parameter estimates). It is also recommended that depth be considered further, to include depths within the water column (mid-water) as another potentially important physical habitat variable affecting shortjaw cisco distribution within Lake Huron.

For effective use of a set of models in shortjaw cisco habitat protection, future models will require: (a) a prospective analysis capable of predicting shortjaw cisco occurrence and (b) a method of testing the predictions of shortjaw cisco distribution. Based on the results of this study, it is recommended that other physical and biological habitat factors that may contribute significantly to our understanding of shortjaw cisco distribution and that they be included into future analysis.

First, water temperature may be important for explaining shortjaw cisco distribution and should be included in the next set of habitat models. Shortjaw cisco is commonly found below the thermocline, perhaps due to physiological temperature constraints (Steinhilber 2004). As noted above, *M. relicta* dominate shortjaw diets, and they are also found below the thermocline, exhibiting diurnal vertical migrations through the water column to the thermocline (Beeton 1960). Therefore, it is reasonable to hypothesize that the distribution of shortjaw cisco in Lake Huron is influenced by water temperature.

Second, substrate is another habitat factor that may be important to shortjaw cisco distribution. Substrate was the second most frequently cited habitat factor identified from the shortjaw cisco literature. Parks Canada possesses a large amount of substrate data for the study region, however these data are not yet available for analysis (Scott Parker, pers. comm. 2008). The limited literature concerning shortjaw cisco ecology indicates that this species is often found above soft mud substrates (Bajkov 1932, Murray and Reist 2003, Scott and Crossman 1973). Once again, important prey for shortjaw cisco (e.g. *Diporeia* sp.) have been found in abundance at locations with soft substrates having high silt and organic content (Marzolf 1965, Sly and Christie 1992). Therefore, it is reasonable to hypothesize that the distribution of shortjaw cisco in the Great Lakes is influenced by substrate type.

Finally, predation may also play a role in determining shortjaw cisco distribution. Shortjaw cisco in the Great Lakes have been reported as prey for both lake trout (*Salvelinus namaycush*) and burbot (*Lota lota*) (Houston 1988). Hoff and Todd (2002) suggested that in Lake Superior, lake trout predation reduced shortjaw cisco populations

on the shallow margins of their bathymetric distributions, causing a shift to deeper habitats by shortjaw cisco. Therefore, it is reasonable to hypothesize that the distribution of shortjaw cisco in the Great Lakes is influenced by predation risk.

This study is the first attempt to evaluate the influence of selected physical habitat factors affecting the distribution of shortjaw cisco anywhere in its geographic range. If shortjaw cisco is listed under SARA, the species will be legally protected, including protection of its ‘critical habitat’. If a recovery strategy is determined to be feasible, ‘critical habitat’ of the listed species will be protected based on the available information (SARA 2003). It is important to realize that shortjaw cisco habitat in Lake Huron cannot be effectively identified due to the rarity of individual specimens and the need to investigate other physical and biological factors. In order to effectively identify and protect critical habitat for shortjaw cisco, it will be necessary to fundamentally redesign our approach to testing predictive habitat models with data collected from rigorously designed sampling programs. Therefore, it is recommended that future studies of shortjaw cisco habitat ensure careful project planning, use Lake Nipigon as a study location, and include depth as a variable along with other potential important physical and biological habitat variables into further models to better understand habitat for the species, which is currently still unknown.

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Table 1. The set of competing habitat use models used to explain distribution of shortjaw cisco (*Coregonus zenithicus*) in Lake Huron.

Habitat variables	Model structure
Water Depth (D)	$\beta_0 + \beta_1(D)$
Slope (S)	$\beta_0 + \beta_1(S)$
Distance to Cliff (C)	$\beta_0 + \beta_1(C)$
Water Depth+Slope	$\beta_0 + \beta_1(D) + \beta_2(S)$
Water Depth+Distance to Cliff	$\beta_0 + \beta_1(D) + \beta_2(C)$
Slope+Distance to Cliff	$\beta_0 + \beta_1(S) + \beta_2(C)$
Water Depth+Slope+Distance to Cliff	$\beta_0 + \beta_1(D) + \beta_2(S) + \beta_3(C)$

Table 2. Summary of shortjaw cisco (SJC) sampling effort and catch from Lake Huron 2003-2007. A total of 25 identified shortjaw cisco (*Coregonus zenithicus*) were captured at 14 of 73 samples.

Sample Characteristics		2003	2004	2005	2006	2007	Total
Sample effort	Winter	2	1	0	8	0	11
	Spring	0	0	0	9	13	22
	Summer	0	0	11	0	0	11
	Fall	10	0	9	0	0	19
	NA	10	0	0	0	0	10
	Subtotal	22	1	20	17	13	73
Sample event with SJC		9	0	2	3	0	14
Number of SJC		12	0	4	9	0	25

Table 3. Model fit and information criteria for the set of competing models to explain the distribution of shortjaw cisco (*Coregonus zenithicus*) in Lake Huron, based on targeted sampling (2003-2007). AIC_c refers to Akaike information criteria corrected for small sample sizes; ΔAIC_c refers the AIC_c differences, which rank models relative to the best approximating model; and Akaike weights (w_i) used to rank the set of competing models in descending order. Relative variable importance for each variable, showing the sum of Akaike weights for all models that include a particular variable (Water Depth, Distance to Cliff, Slope) from the set of competing models.

Model	AIC_c	ΔAIC_c	Akaike Weight (w_i)	Water Depth	Distance to Cliff	Slope
Water Depth	71.83	0.00	0.41	0.41	-	-
Water Depth+Distance to Cliff	72.59	0.77	0.28	0.28	0.28	-
Water Depth+Slope	73.84	2.01	0.15	0.15	-	0.15
Distance to Cliff	75.43	3.60	0.07	-	0.07	-
Slope	76.69	4.86	0.04	-	-	0.04
Slope+Distance to Cliff	76.89	5.06	0.03	-	0.03	0.03
Water Depth+Slope+Distance to Cliff	77.12	5.30	0.03	0.03	0.03	0.03
Total			1.00	0.87	0.41	0.25

Figure 1. Historic distribution of shortjaw cisco (*Coregonus zenithicus*) in North America. Dots represent presence of the species in different lakes (adapted from COSEWIC 2003).

Figure 2. Location of 73 targeted deepwater cisco samples around the Saugeen (Bruce) Peninsula in Lake Huron from 2003-2007. Dots represent locations of samples. Clear boxes represent samples where shortjaw cisco (*Coregonus zenithicus*) was found. (A) represents study area as a whole. (B) represents portion of study area in Bruce Archipelago with high density of samples.

Figure 3. Distribution of Water Depth (m) of targeted deepwater cisco samples, and Water Depth (m) of samples with shortjaw cisco (*Coregonus zenithicus*) in Lake Huron (2003-2007).

Figure 4. Distribution of sloping substrate targeted shortjaw cisco (*Coregonus zenithicus*) samples, and samples with shortjaw cisco in Lake Huron.

Figure 5. Distribution of Distances to Cliffs (m) of targeted shortjaw cisco (*Coregonus zenithicus*) samples, and Distance to Cliff of samples with shortjaw cisco in Lake Huron

Appendix I. Sample effort, catch information, and quantified habitat variables for shortjaw cisco (SJC) from Lake Huron 2003-2007.

Effort Code	Date	Season	Longitude	Latitude	Mean Water Depth (m)	Slope	Distance to Cliff (m)	SJC abundance
2003-SJC-001	12/2/2003	Fall	462468.0396	4959893.0530	45.83	0.004	28659	0
2003-SJC-002	12/2/2003	Fall	459582.9573	4959299.5510	61.78	0.004	31167	1
2003-SJC-003	12/2/2003	Fall	449622.9041	4948269.2570	135.64	0.008	36415	0
2003-SJC-004	12/2/2003	Fall	453637.4817	4942093.3230	84.96	0.005	43362	0
2003-SJC-005	12/2/2003	Fall	452301.4425	5014527.1300	86.41	0.013	1273	1
2003-SJC-006	12/2/2003	Fall	455052.0613	5012638.6780	119.45	0.012	1271	1
2003-SJC-007	12/2/2003	Fall	459613.4361	5011506.2080	155.93	0.042	434	0
2003-SJC-008	12/2/2003	Fall	451014.7153	5013625.0260	73.14	0.035	309	0
2003-SJC-009	12/2/2003	Fall	452148.8745	5014576.4260	87.56	0.010	1124	0
2003-SJC-010	12/2/2003	Fall	457472.1412	5013870.8710	102.73	0.058	224	4
2003-SJC-011	12/2/2003	Winter	451369.9326	5013659.3180	83.85	0.016	577	1
2003-SJC-012	12/2/2003	Winter	458031.6106	5012285.8470	151.85	0.013	746	0
2004-SJC-001	1/19/2004	Winter	480360.9274	4986093.8560	103.10	0.031	391	0
2005-SJC-001	5/30/2005	Summer	482878.8977	4990387.6010	126.93	0.004	1726	0
2005-SJC-003	5/30/2005	Summer	510786.6569	4968055.4270	93.36	0.006	1811	0
2005-SJC-005	6/1/2005	Summer	452267.5231	5013843.2010	89.81	0.010	1460	0
2005-SJC-006	6/1/2005	Summer	448482.7576	5014643.1900	30.13	0.001	993	0
2005-SJC-007	6/1/2005	Summer	455293.8635	5012624.9290	122.67	0.012	1202	0
2005-SJC-008	6/7/2005	Summer	439193.8391	5030498.8240	31.72	0.006	1087	0
2005-SJC-009	6/7/2005	Summer	443658.4827	5030566.5130	63.04	0.023	861	0
2005-SJC-010	6/7/2005	Summer	451710.7812	5019424.6290	31.69	0.026	612	0
2005-SJC-011	6/7/2005	Summer	453812.5393	5019977.3650	51.34	0.004	1894	0
2005-SJC-012	6/20/2005	Summer	432347.7958	5009518.6740	57.56	0.003	7217	0

Appendix I. Continued...

2005-SJC-013	6/20/2005	Summer	423711.3813	5000437.5140	136.96	0.006	4657	0
2005-SJC-014	6/24/2005	Fall	451462.7822	5019617.2540	24.31	0.021	552	0
2005-SJC-015	6/24/2005	Fall	453682.0460	5018657.1610	43.12	0.002	1158	0
2005-SJC-016	6/24/2005	Fall	453093.1883	5013238.0160	94.23	0.016	1556	0
2005-SJC-017	6/24/2005	Fall	449270.6169	5014759.9570	28.62	0.005	474	0
2005-SJC-018	6/24/2005	Fall	456002.8078	5013505.9650	103.73	0.061	255	0
2005-SJC-019	6/24/2005	Fall	431481.7152	5009159.4860	59.17	0.004	7778	0
2005-SJC-020	6/24/2005	Fall	426480.6966	5000048.3940	136.17	0.013	7448	2
2005-SJC-021	6/28/2005	Fall	482206.5293	4989707.1680	126.68	0.007	1540	0
2005-SJC-026	10/4/2005	Fall	451150.0723	4950315.4240	112.87	0.022	35824	2
2006-SJC-002	1/6/2006	Winter	454033.4115	5019908.1660	50.38	0.003	1820	0
2006-SJC-003	1/6/2006	Winter	454150.1494	5012230.3820	108.06	0.015	880	0
2006-SJC-004	1/6/2006	Winter	451181.2706	5015046.7360	55.24	0.036	89	0
2006-SJC-005	1/7/2006	Winter	439207.1791	5030394.9960	31.08	0.008	1000	0
2006-SJC-007	1/7/2006	Winter	455251.2647	5012610.4170	122.20	0.011	1218	0
2006-SJC-008	1/8/2006	Winter	434067.3277	5005341.5640	54.53	0.004	4302	0
2006-SJC-010	1/9/2006	Winter	482927.6784	4990230.0930	127.26	0.003	1652	0
2006-SJC-011	1/9/2006	Winter	491361.4587	4985583.4680	79.55	0.007	2471	2
2006-SJC-016	3/24/2006	Spring	431436.4933	5009091.4600	59.43	0.004	7795	0
2006-SJC-017	3/24/2006	Spring	427237.8959	4999633.2170	138.21	0.007	8238	6
2006-SJC-018	3/30/2006	Spring	439864.8660	5030582.1850	26.11	0.006	700	0
2006-SJC-019	3/30/2006	Spring	443848.5245	5030529.6310	63.31	0.024	670	0
2006-SJC-020	3/30/2006	Spring	448156.8406	5014112.5730	31.08	0.004	1210	0
2006-SJC-023	4/10/2006	Spring	513679.4375	4966778.8350	102.39	0.003	4262	1
2006-SJC-024	4/10/2006	Spring	514875.1982	4965074.4900	107.29	0.003	4996	0
2006-SJC-025	4/13/2006	Spring	452062.3262	5019448.7990	37.17	0.026	620	0

Appendix I. Continued...

2006-SJC-026	4/13/2006	Spring	453981.7899	5020530.7010	49.21	0.003	2100	0
2007-SJC-001	4/17/2006	Spring	438952.4249	5030345.6130	32.16	0.004	1134	0
2007-SJC-002	4/17/2006	Spring	443485.2113	5030365.3020	59.77	0.022	856	0
2007-SJC-003	4/9/2006	Spring	451820.3080	5019656.1760	29.26	0.024	370	0
2007-SJC-004	4/9/2006	Spring	454267.7029	5019707.4110	48.49	0.007	1520	0
2007-SJC-005	4/14/2006	Spring	453172.5916	5013102.2570	96.26	0.013	1440	0
2007-SJC-006	4/9/2006	Spring	449270.5657	5014753.4760	28.65	0.001	474	0
2007-SJC-007	4/14/2006	Spring	455831.1962	5013175.7190	118.38	0.032	621	0
2007-SJC-008	4/14/2006	Spring	447525.4427	5014352.0170	29.55	0.002	1746	0
2007-SJC-009	4/9/2006	Spring	452173.1983	5018221.2310	55.24	0.003	639	0
2007-SJC-010	4/14/2006	Spring	457643.5604	5012137.5240	143.58	0.025	571	0
2007-SJC-011	4/17/2006	Spring	441525.0738	5029211.9800	61.09	0.002	559	0
2007-SJC-012	4/17/2006	Spring	444514.7687	5032222.6910	77.84	0.029	1710	0
2007-SJC-013	4/17/2006	Spring	440013.4609	5031602.0130	27.67	0.000	250	0
18MNR		NA	463677.5892	5027147.2310	89.83	0.018	1830	1
20MNR		NA	452882.2490	5014881.0700	75.03	0.027	1499	0
22MNR		NA	451876.4730	5013186.6060	90.11	0.012	918	0
26MNR		NA	459853.9215	5016796.0530	63.15	0.007	1139	0
29MNR		NA	501354.1370	4997344.2930	96.45	0.003	7075	1
32MNR		NA	481737.7066	4986831.2850	92.43	0.036	0	1
35MNR		NA	490510.5410	4984482.6840	76.34	0.007	1955	0
37MNR		NA	448296.3185	4934309.9790	97.94	0.034	38571	0
38MNR		NA	448436.7502	4935789.6370	99.08	0.038	38726	1
39MNR		NA	448735.3286	4937298.0410	97.36	0.038	39099	0

Appendix II. Parameter estimates for each variable of each model, from the set of competing models to explain the distribution of shortjaw cisco (*Coregonus zenithicus*) in Lake Huron.

Model	Parameters	Parameter estimate
Water Depth	D	0.021
Slope	S	20.873
Cliff	C	<.001
Water Depth+Slope	D	0.020
	S	10.379
Water Depth+Distance to Cliff	D	0.020
	C	<.001
Slope+Distance to Cliff	S	18.639
	C	<.001
Water Depth+Slope+Distance to Cliff	D	0.019
	S	8.641
	C	<.001