SPAWNING CISCO INVESTIGATIONS IN CANADA WATERS OF LAKE SUPERIOR DURING 2007

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Introduction

Cisco *Coregonus artedi* form pre-spawning aggregations in Lake Superior during November with the bulk of spawning occurring during late November through early December (Dryer and Beil 1964). Eggs are broadcast into open water (Smith 1956) with fertilized eggs settling to the lakebed (Dryer and Beil 1964). Peak hatching occurs the following May (United States Geological Survey – Great Lakes Science Center, GLSC, unpublished data). Interannual variability in year class strength is high, but tends to be synchronous across different regions of Lake Superior (Bronte et al. 2003). November 2005 sampling of Thunder Bay showed 14 year-classes were present with the oldest fish being from the 1984 year-class (Yule et al. 2008). The ciscoes sampled were predominantly from five year classes that hatched during 1988, 1989, 1990, 1998, and 2003. These same strong year-classes were found in the western arm of Lake Superior during November 2006 (GLSC, unpublished data). Growth is rapid in the first few years of life with minimal growth after age-8 (Yule et al. 2008). Ciscoes exceeding 250 mm total length (TL) are typically sexually mature (Yule et al. 2006b, 2008). Thunder Bay ciscoes have high annual survival with rates for females and males averaging 0.80 and 0.75, respectively; females have higher rates of fishing-induced mortality compared to males but lower rates of natural mortality (Yule et al. 2008). Some Lake Superior stocks are currently commercially fished with the bulk of harvest occurring during November when fishers target females for their roe. The bulk of fish are harvested from Thunder Bay using suspended gillnets with mesh sizes ranging from 79-89 mm stretch measure.

Ciscoes younger then age-5 make up a very small proportion (<0.1%) of the harvest (Yule et al. 2008).

Pre-spawning cisco numbers in Thunder Bay were assessed with acoustic and midwater trawl methods during 13-18 November 2005 (Yule et al. 2006a). Average density of spawning-size (≥ 250 mm TL) cisco in Thunder Bay was estimated at 78.4/ha resulting in a standing stock estimate of 5.2 million fish (95% confidence interval, 95% CI = 4.3 – 6.2 million). A strong 2003 year-class was noted and most of these fish were smaller than 200 mm TL (Yule et al. 2006a; 2008). Subsamples of ciscoes caught by midwater trawling and commercial gill nets were aged and age-length keys were used to apportion the standing stock and harvest estimates to year classes. Using these estimates, the exploitation rate of market-size ciscoes (combined 1984-1999 year classes) was estimated at 8.5% for females and 2.5% for males (Yule et al. 2008). Catch-per-effort (CPE) data compiled over November 2005 showed the fishery-independent survey likely occurred after the bulk of large ciscoes had returned to Thunder Bay for spawning. A similar survey of Black Bay ciscoes in 2005 (18 November) likely occurred too early with commercial gillnet CPE increasing rapidly after 25 November that year (Yule et al. 2006a).

The purpose of this report was to summarize results of year one of a three-year study of spawning ciscoes in Canada waters of Lake Superior. This study was a joint effort between the GLSC and the Ontario Ministry of Natural Resources – Upper Great Lakes Management Unit (UGLMU). The primary goal of this ongoing study is to develop standard operating procedures for assessing pre-spawning ciscoes that can be carried forward by the UGLMU. The objectives specific to the November 2007 sampling included: 1) assess repeatability of survey results by conducting two surveys in Thunder Bay separated by one week; 2) map spatial distributions of spawning-size female and male ciscoes, rainbow smelt *Osmerus mordax* and kiyi *Coregonus kiyi*; 3) combine fishery-independent survey results and commercial harvest information to estimate exploitation rates; and 4) use results of the 2005 and 2007 surveys to explore the sustainability of the present total allowable catch (TAC) quota of 180,502 kg for management zones 1, 2 and 3 of Thunder Bay (Figure 1).

Methods

Fishery-independent surveys

To meet objective 1, we conducted two acoustic surveys of Thunder Bay during 2007 with the first survey spanning the nights of 14-18 November and the second 24-27 November. We used a systematic design with parallel transects separated by roughly 4 km (Figure 1). A transect was conducted south of Pie Island during survey 1 to determine if ciscoes were found outside the Bay, but not during survey 2 (Figure 1). Results of the sampling south of Pie Island were summarized in this report, but were not included in the calculation of fish densities for the bay. Acoustic data collection and processing methods have been described in detail previously (Yule et al. 2006b; 2008; *In review*) and therefore were only briefly described here. Sampling started 30 minutes after sunset and ended each night several hours before sunrise. We used a BioSonics DT-X echosounder (Seattle, Washington, USA) equipped with a 5.3^{o} (half-power width) 70 kHz circular split-beam transducer deployed to a depth of 0.5 m using a 2-m-long tow body. The echosounder was field-calibrated using a tungsten carbide sphere test on 25 November that showed the acoustic system provided high quality information. Vessel position was measured with a differentially corrected global positioning system (accurate to 1 m), and positional data was stored in the acoustic data files.

Acoustic data was processed with Echoview Software version 4.0.82.6547 (Sonar Data, Tasmania, Australia). A line to exclude surface noise was set at 2-4 m depth (depending on sea state) and a line to exclude the bottom was set at 0.5 m above the bottom signal. All segments of echograms containing electrical or other noise (i.e., all echoes obviously not from fish) were excluded before estimating fish densities. Total fish density (fish/ha) estimates were calculated in 10-m high by 1-km-long segments of travel (hereafter cells) using echo integration methods. We calculated the number of single targets that were less than and greater than -35.6 decibels (dB) in each cell and apportioned the total density in each cell to large and small fish accordingly. Yule et al. (*In Review*) showed this approach provided estimates of expected and observed trawl catches of small (< 250 mm TL) and large (≥ 250 mm) fish that approached unity over a wide range of densities. Estimates of small and large fish in each cell were summed from 2-4 m below the surface to the bottom exclusion line of each 1-km-long interval.

Midwater trawl samples were collected periodically, targeting 3-5 tows per night. A total of 19 and 15 midwater trawl samples were collected during survey 1 and 2, respectively (Figure 1). The midwater trawl had an effective fishing height and width of 10 m by 10 m with cod-end mesh of 13 mm stretch measure. The fishing depth and trawl stations were determined *a priori* before leaving port. The trawl was fished in discreet depths targeting surface waters (5-10 m head rope depth), intermediate depths (10-25 m), and deeper (> 25 m) tows each night where bathymetry allowed. Trawl duration was typically 20 minutes. The trawl fishing depth was monitored in real-time with NetMind

(Northstar Technical, Inc., St. John's, Newfoundland and Labrador, Canada) sensors with trawl fishing depth and trawl width stored at roughly 10-second intervals to computer files.

Catches were sorted to species on the vessel and placed in labeled plastic bags for processing at the UGLMU Thunder Bay laboratory the next morning. Catches of each species in each trawl sample were weighed in aggregate to the nearest gram. All cisco were measured to the nearest millimeter TL, weighed to the nearest gram, and assessed for sex and state of maturity (immature and mature). Small (< 200 individuals) catches of non-cisco were measured for individual TL. For large non-cisco catches, a sub-sample of 200 fish was measured and the remaining fish were counted. We assigned captured fish into the small- and large-fish groupings, and further divided these groupings into species categories (i.e., small fish = rainbow smelt, kiyi, bloater *Coregonus hoyi*, cisco and other species < 250 mm; and large fish = female cisco, male cisco, kiyi, bloater and other species ≥ 250 mm).

We used the methods of Yule et al. (*In Review*) linking acoustic intervals to nearest midwater trawl catches to (1) calculate density and biomass estimates of each size/species category along each 1-km interval, (2) calculate average densities of each size/species category using the 1-km intervals as sample units, and (3) a bootstrap approach of resampling acoustic densities and trawl catches with replacement to generate 95% confidence intervals for density and biomass. Density and biomass estimates were multiplied by the area of Thunder Bay surveyed (73,914 ha; i.e., the combined areas of zones 1, 2, 3 and 4 as shown in Figure 1) to estimate total abundance and total biomass (metric tons) of each size/species category.

Our null hypothesis was that density estimates of large male ciscoes, large female ciscoes and total large ciscoes (males + females) were not affected by survey timing. From the bootstraps for each survey we developed 1,000 estimates of the density of large males and large females. To determine if density estimates varied significantly across surveys, we calculated the difference for each of the 1,000 pairs and determined if the 95% CIs of the distribution of differences encompassed zero (i.e., the null hypothesis was rejected when zero was encompassed by the 95% CIs).

To map spatial distributions of ciscoes (female and male), smelt and kiyi (Objective 2), we imported acoustic density estimates measured along 1-km intervals into a geographical information system (ArcMap 9.2, ESRI Corportation, Redlands, California). Densities at unsampled locations were predicted using ordinary kriging with a geostatistical analyst extension. The optimal theoretical semivariogram model (i.e., nugget, sill, range) was developed from the experimental variogram by the GIS extension. Nearest neighbors were found using a circular search area comprised of four 90^{o}-wide sectors. A maximum of five and a minimum of two neighbors in each sector were used along with the theoretical variogram to predict densities at unsampled locations.

We collected a sub-sample of otoliths of cisco caught by midwater trawling for ageing to develop age-length keys for both males and females that we used to apportion abundance estimates of each sex to year-classes. During lab processing, we targeted the collection of 40 otolith pairs from both males and females from seven 50-mm length bins (100-450 mm total length).

Age-length keys were developed using 10-mm length bins to be consistent with methods for developing keys for commercially-harvested fish (see Yule et al. 2008). We opted to pool age structures gathered over the two surveys to develop a single age-length key for each sex. We estimated the abundance of each year-class by first applying age-length keys to length-frequency distributions of trawl-caught males and females from each survey. We assumed the trawl catches were representative of all at-large ciscoes and expanded the age-length distributions to the standing stock estimates gathered during each survey. Using this approach we developed abundance estimates of males and females belonging to each year-class for each survey.

Ages were estimated using the otolith crack-and-burn method (Schreiner and Schram 2001) by J. Tost (North Shore Environmental Services, Thunder Bay, Ontario). Length and age estimates were used to develop von Bertalanffy (VB) growth equations for both sexes. The VB growth equation ($l_t = L_\infty(1\text{-}e^{(-K*t)})$, where l_t is the average length in millimeters at age t, L_∞ is the asymptotic length in mm and K is the growth coefficient, was fitted to females and males in STATISTICA version 6.1 (Statsoft, Tulsa, Oklahoma, USA) using nonlinear least-squares curve estimation under the Levenberg-Marquardt algorithm.

Commercial catch data

Methods of obtaining and processing commercial catch data of ciscoes from Thunder Bay were previously described in detail by Yule et al. (2008). Briefly, we summarized the gillnet lift data to estimate total biomass of ciscoes harvested by management zone and apportioned these estimates to males and females based on records in the “net run” database (i.e., samples of 10 ciscoes per lift collected throughout the roe fishery). Each net run fish was measured to the nearest mm, weighed to the nearest gram and sexed. Total numbers harvested of each sex from each zone were calculated by dividing estimated harvested biomass by the average weight of harvested individuals. Total numbers were summed where fishing occurred during 2007 (zones 1, 2; Figure 1) to estimate total harvest from Thunder Bay. Otoliths of net run fish were removed, but at the time of report writing only the trawl-caught ciscoes had been aged.

We visually compared acoustic estimates of spawner densities measured during the two surveys to trends in CPE in suspended commercial gill nets during the 2007 roe fishery. We determined if average CPE during nights of survey 1 (14-18 November) varied significantly from survey 2 (24-27 November) using an unpaired t-test with α set at 0.05.

Estimation of rate of exploitation

Because age estimates of harvested fish were not available, we opted to calculate exploitation rate estimates for different size-classes (Objective 3). Using the net run database we developed length-frequency distributions of harvested males and females for management zones 1 and 2 using 50-mm length bins. The estimated total harvest of males and females from each zone were apportioned to length bins based on the length-frequency distributions. Numbers harvested in each length bin were summed across management zones. Length-frequency distributions of trawl-caught fish developed for each survey were used to apportion the acoustically-derived standing stock estimates of large ciscoes to 50-mm length bins. We calculated the rate of exploitation (u, Ricker 1975) for each length bin by dividing the estimated number harvested by the estimated number at large. Separate calculations of u for each survey were used to explore how survey timing affected estimates of exploitation. Results from the November 2005 survey (Yule et al. 2006a; Yule et al. 2008) were combined with results of the present study to explore the sustainability of the total allowable commercial catch quota for Thunder Bay (180,502 kg presently) into the foreseeable future (Objective 4).

Results and Discussion

A total of 5,288 fish were caught by midwater trawling (Table 1). By number, rainbow smelt were predominant during both the first (60.67%) and second survey (63.87%). More ciscoes were caught during survey 1 (1,183) compared to the survey 2 (677), but their percentage of the total catch across surveys was similar (survey 1 = 36.23%, survey 2 = 33.47%). Catches of kiyi and bloater were low with these species only representing 1.08% and 0.78% of the total catch, respectively. Other species including threespine stickleback *Gasterosteus aculeatus*, deepwater sculpin *Myoxocephalus thompsonii*, shortjaw cisco *Coregonus zenithicus*, alewife *Alosa pseudoharengus*,

siscowet *Salvelinus namaycush* and spoonhead sculpin *Cottus ricei* were rarer still, combining for only 0.30% and 0.31% of the catch during surveys 1 and 2, respectively. Rainbow smelt represented 93.81% of 3,489 small fish captured, while cisco represented 99.17% of 1,799 large fish caught.

During the previous sampling of Thunder Bay in November 2005, the length-frequency distribution of cisco captured by midwater trawling was bimodal with modes at 238 mm and 338 mm (Figure 2). The smaller mode largely represented cisco that hatched during the spring of 2003 while the larger mode represented a mixture of several older year-classes (1988, 1989, 1990, 1998; Yule et al. 2008). In comparison, the distributions collected during both November 2007 surveys were weakly bimodal and similar in shape. The strong 2003 year class could no longer be discerned from older fish based on size. Length bins smaller than 350 mm had slightly more males than females, but females predominated in the largest length bins (Figure 2). The occurrence of more females in larger length bins is consistent with the 2005 sampling results, and was due to males having higher rates of natural mortality (Yule et al. 2008) and lower L_∞ compared to females (see below).

A total of 193 males (Appendix A) and 250 females (Appendix B) were aged. Trawl-captured females we aged were predominantly age-4 (2003 year-class; 37%), age-5 (2002 year-class; 14%), age-9 (1998 year-class; 18%), and age-19 (1988 year-class; 10%). Trawl-captured males we aged were predominantly age-2 (2005 year-class; 9%), age-4 (54%), and age-9 (27%). The VB growth equation for females (Figure 3) equaled:

$$l_t = 381.117(1-e^{(-0.386894*t)}), N = 250, R^2 = 0.58.$$

The male VB growth equation equaled:

$$l_t = 355.05(1-e^{(-0.44937*t)}), N = 193, R^2 = 0.53.$$

Total fish densities in Thunder Bay were higher during both 2007 surveys compared to the 2005 survey. For example, total fish abundance (small and large fish) was estimated at 121.1 million (107.8-132.4 million) and 103.1 million (95% CI = 92 – 113.1 million) during survey 1 and survey 2 of 2007, respectively, while total fish abundance was estimated at 59.1 million (95% CI = 52.9-65.4 million) during November 2005 (Yule et al. 2008). A two-fold increase in rainbow smelt densities from 610/ha during November 2005 (Yule et al. 2006a) to November 2007 (survey 1 = 1,321/ha; survey 2 = 1,171/ha; Table 2) represented the bulk of the overall change in pelagic fish numbers. This increase is consistent with results of the GLSC annual spring fish community survey showing rainbow smelt densities in western Ontario waters of Lake Superior have increased from 2004 to 2007 (Gorman et al. 2008).

Densities of spawning-size ciscoes did not vary significantly ($P > 0.05$) across the two November 2007 surveys, averaging 142.0/ha (95% CI = 119.8 – 164.5/ha; Table 2) during survey 1 and 134.2/ha (95% CI = 117.3-151.9/ha) during survey 2. The estimated standing stock of spawning-size ciscoes for survey 1 was 10.5 million (95% CI = 8.8 – 12.1 million; Table 2), and for survey 2 the estimate was 9.9 million (95% CI = 8.6 – 11.2 million). Some high densities (100-500/ha) of large fish were tracked due east and west of Pie Island during survey 1, but over the 45 km of sampling collected outside Thunder Bay (i.e., south of Pie Island) large fish densities only average 30 fish/ha (SD = standard deviation = 24 fish/ha).

Both 2007 estimates exceeded the estimate generated from the November 2005 survey (5.2 million, 95% CI = 4.3 – 6.2 million; Yule et al. 2008). The increase in spawner abundance is consistent with the 2003 year-class growing in size and joining the adult stock. Standing stock biomass of spawning-size cisco was estimated at 2,765 metric tons during survey 1 (95% CI = 2,304 – 3,224 metric tons; Table 3) and 2,789 metric tons during survey 2 (95% CI = 2,424-3,146 metric tons).

During the November 14-18 survey, the ratio of spawning-size females to males was close to 1:1 (females = 52%; males = 48%), while females outnumbered males during the 24-27 November survey (females = 68%, males = 32%). Average female densities increased significantly from survey 1 (74.3/ha, 95% CI = 62.5 - 85.8) to survey 2 (91.3/ha, 95% CI = 81.5 - 102.1/ha), while average male densities decreased significantly over this interval (survey 1 = 67.7/ha, 95% CI = 57.7 – 78.7/ha; survey 2 = 42.9/ha, 95% CI = 35.8 - 49.8/ha). Finding a higher proportion of females during the latter survey is consistent with patterns observed around Lake Superior with females typically representing a greater proportion of commercial catches in suspended gillnets during late November (GLSC, unpublished data).

After applying length-age keys for females and males, the same strong year-classes found during 2005 were present during 2007 (Figure 4). The abundance estimates of the 2003 year-class (age-4) varied during the two 2007 surveys with an estimate of 10.9 million (males and females) during survey 1 and 6.2 million during survey 2. This difference was driven by the catches of small ciscoes during the two surveys. During survey 1 we caught 62 ciscoes ranging in length from 220 to 249 mm that were mostly age-4, compared to only 12 ciscoes of this size range during survey 2. The number of market-size females (all females older than age-12) was estimated at 2.39 million during survey 1 and 3.35 million during survey 2. This difference was the result of large female densities increasing from survey 1 to 2 (Table 2). The total abundance of females for these same year-classes was estimated at 3.18 million during the November 2005 survey.

Both spawning-size female (Figure 5) and male (Figure 6) ciscoes were broadly distributed over Thunder Bay during survey 1, with generally homogonous densities throughout the bay. During the late-November survey, densities of females were highest along the northwest coastline, and northeast of Pie Island (Figure 5). Densities of large males were highest along the northwest coastline, and were generally lower in the southern portion of Thunder Bay (Figure 6). The distributions of rainbow smelt measured during the two surveys were similar in that the highest densities were measured along the northwest coastline, especially at the far end of the bay (Figure 7). During both surveys, rainbow smelt densities were generally low over the east and southeast portion of Thunder Bay where the greatest bathymetric depths exist. Kiyi were found in moderate densities (101-250/ha) in localized areas during each survey, but their densities were less than 50/ha over most the sampled area (Figure 7).

Both the fishery-independent surveys and commercial lift records indicated that densities of large ciscoes in Thunder Bay varied without trend over the duration of the 2007 roe fishery (Figure 8). Average gill net CPE increased slightly from 0.48 kg/m of net fished (Standard error = SE = 0.05; N = number of lifts = 15) during the timeframe of survey 1 to 0.60 kg/m (SE = 0.05; N = 13) during survey 2 (Figure 8), but these differences were not statistically significant (unpaired t test = 1.66, df = 26, P = 0.11). There appears to have been an increase in CPE after survey 2 was completed (after 27 November), but CPE in these late-season lifts tended to be more variable compared to earlier lifts, with average CPE influenced by one lift with a very high catch rate (> 3 kg/m; Figure 8). An increase in densities of spawning-size females from survey 1 to survey 2 (Table 2) may have been offset by a concurrent decrease in male densities with the net effect being relatively stable CPE throughout the roe fishery.

Based on gillnet lift records, estimated harvest of ciscoes during the 2007 roe fishery of Thunder Bay equaled 156,139 kg (Table 4) less than the 2007 TAC (180,502 kg). Based on the net run fish database, females and males represented 76% and 24% of the harvest, respectively. The total estimated number of individuals harvested was 254,775 females and 87,105 males (Table 3). Most harvested ciscoes were larger than 350 mm TL, with 91% of harvested females and 90% of harvested males exceeding this length. The bulk of cisco harvested (75% of the females and 71% of the females) were 350- to 399-mm TL with 16% and 18% of the females and males harvested exceeding 400 mm TL, respectively. We estimated exploitation rates by dividing harvested numbers by at-large numbers generated from the two fishery-independent surveys. The exploitation rates of ciscoes smaller than 350 mm TL was less than 1.17% for both males and females for both surveys. The exploitation rates of female cisco increased with size with the rate for 350-399 mm females averaging 8.38% for the two surveys (range = 6.73%-10.03%; Figure 9), and *u* for females > 400 mm averaging 16.78% (range = 13.09%-20.47%). Exploitation rates for males > 350 mm TL was estimated at 10.01% during survey 1 and 13.98% during survey 2, and averaged 11.99% for the two surveys. It is important to note that our estimates of cisco abundance were developed as the population was being actively fished so at-large estimates are likely conservative for those fish that recruited to the fishery. The net effect is that exploitation rates might be slightly under-estimated.

Management considerations

Total densities of large ciscoes did not vary significantly over the two 2007 surveys, but densities of spawning-size females increased significantly from survey 1 to survey 2, while densities of spawning-size males declined significantly over this same interval. When the two survey results were compared to the same commercial harvest information, the exploitation rate of the largest of females (350-399 mm and > 400 mm length bins) was estimated to be higher during survey 1 compared to survey 2 (Figure 9), with the opposite pattern noted for the largest males (> 350 mm). At present, the Lake Superior Technical Committee (LSTC) is recommending that exploitation rate of adult female ciscoes from commercial fishing be held below 10-15% (M.P. Ebener, LSTC Chairperson, personal communication). The estimated exploitation rates of the 350-399 mm size-class (the size-class supporting the bulk of the 2007 harvest) averaged 11.99% for males and 8.38% for females, generally lower than the safe-harvest level recommended by the LSTC. Exploitation of the largest of females (> 400 mm) exceeded the safe-harvest level when we used the survey 1 standing stock estimate (Figure 9), but not the results of survey 2. When stock size estimates were apportioned to year-classes using age-length keys, we found fewer market-size females (age-12 and older; 1987-1999 year-classes) during survey 1 (2.39 million) compared to survey 2 (3.35 million). However, this range of estimates encompassed the estimate of market-size females obtained during November 2005 (3.18 million). Given that (1) a strong 2003 year-class is about to enter the fishery, (2) the 350-399 mm TL size-class supporting the bulk of the 2007 fishery had acceptably low exploitation rates, and (3) we noted no change in densities of market size fish from 2005 to 2007; we conclude that the present TAC (180,502 kg annually) does not need adjustment at this time. However, our survey results suggest that the year-classes that followed the 2003 cohort have been comparatively weak. If recruitment continues to be low over the next few years as the 1988, 1989 and 1990 year-classes are lost to senescence, we may encounter a situation whereby the fishery is only being supported by two strong year classes that recruited in 1998 and 2003. If such a scenario transpires, it will be prudent to reduce the TAC to protect spawners from harvest until another strong year-class is realized.

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Table 1. Midwater trawl catches during the two surveys of Thunder Bay conducted during November 2007. The total number (#) caught and the percentage each species represented of the total catch during each survey is presented.

	Survey 1 (14-18 November)		Survey 2 (24-27 November)		Survey 1 & 2	
Midwater trawl samples	19[1]		15			
Species	# caught	Percentage	# caught	Percentage	# caught	Percentage
Rainbow smelt	1,981	60.67%	1,292	63.87%	3,273	61.89%
Cisco	1,183	36.23%	677	33.47%	1,860	35.17%
Kiyi	35	1.07%	22	1.09%	57	1.08%
Bloater	28	0.86%	13	0.64%	41	0.78%
Threespine stickleback	4	0.12%	9	0.44%	13	0.25%
Deepwater sculpin	3	0.09%	0	0.00%	3	0.06%
Shortjaw cisco	1	0.03%	1	0.05%	2	0.04%
Alewife	0	0.00%	1	0.05%	1	0.02%
Siscowet	1	0.03%	0	0.00%	1	0.02%
Spoonhead sculpin	1	0.03%	0	0.00%	1	0.02%
Total	3,265	100.00%	2,023	100.00%	5,288	100.00%

[1] = includes the 4 midwater trawl samples collected south of Pie Island.

Table 2. Densities (number/ha) and total abundances (millions) of small (< 250 mm total length) and large fish during two surveys of Thunder Bay gathered during November 2007 using acoustic and midwater trawl samples. Lower and Upper 95% confidence intervals (95% CI) for each size/species category are also presented.

	Survey 1 (14-18 November)			Survey 2 (24-27 November)		

Density (number/ha)

	Observed	Lower 95% CI	Upper 95% CI	Observed	Lower 95% CI	Upper 95% CI
Small fish (< 250 mm)						
Cisco (both sexes)	97.2	71.6	119.2	23.5	15.5	29.8
Bloater	33.4	23.8	41.1	12.4	8.1	17.2
Other	17.8	12.0	22.7	21.5	15.8	26.3
Rainbow smelt	1,321.4	1,212.5	1,414.2	1,170.9	1,067.6	1,261.5
Kiyi	25.4	19.4	31.2	30.6	19.8	40.2
Large fish (≥ 250 mm)						
Cisco (males)	67.7	57.3	78.7	42.9	35.8	49.8
Cisco (females)	74.3	62.5	85.8	91.3	81.5	102.1
Bloater	0.3	0.1	0.7	0.7	0.4	1.0
Other	0.1	0.1	0.4	0.1	0.0	0.1
Kiyi	0.0	0.0	0.0	1.7	1.2	2.5

Total abundance (millions)

	Observed	Lower 95% CI	Upper 95% CI	Observed	Lower 95% CI	Upper 95% CI
Small fish (< 250 mm)						
Cisco (both sexes)	7.2	5.3	8.8	1.7	1.1	2.2
Bloater	2.5	1.8	3.0	0.9	0.6	1.3
Other	1.3	0.9	1.7	1.6	1.2	1.9
Rainbow smelt	97.7	89.6	104.5	86.5	78.9	93.2
Kiyi	1.9	1.4	2.3	2.3	1.5	3.0
Large fish (≥ 250 mm)						
Cisco (males)	5.0	4.2	5.8	3.2	2.6	3.7
Cisco (females)	5.5	4.6	6.3	6.7	6.0	7.5
Bloater	0.0	0.0	0.0	0.1	0.0	0.1
Other	0.0	0.0	0.0	0.0	0.0	0.0
Kiyi	0.0	0.0	0.0	0.1	0.1	0.2

Table 3. Biomass (kg/ha) and total biomass (metric tons) of small (< 250 mm total length) and large fish during two surveys of Thunder Bay gathered during November 2007 using acoustic and midwater trawl samples. Lower and Upper 95% confidence intervals (95% CI) for each size/species category are also presented.

	Survey 1 (14-18 November)			Survey 2 (24-27 November)		
Biomass (kg/ha)						
	Observed	Lower 95% CI	Upper 95% CI	Observed	Lower 95% CI	Upper 95% CI
Small fish (< 250 mm)						
Cisco (both sexes)	9.1	6.7	11.2	2.2	1.4	2.8
Bloater	1.9	1.3	2.3	0.8	0.5	1.0
Other	0.1	0.0	0.1	0.0	0.0	0.0
Rainbow smelt	8.0	7.3	8.6	6.4	5.7	7.0
Kiyi	0.8	0.6	1.0	1.6	0.9	2.3
Large fish (≥ 250 mm)						
Cisco (males)	15.0	12.8	17.4	10.3	8.6	12.0
Cisco (females)	22.4	18.4	26.2	27.5	24.2	30.6
Bloater	0.1	0.0	0.1	0.1	0.1	0.1
Other	0.1	0.0	0.1	0.0	0.0	0.0
Kiyi	0.0	0.0	0.0	0.2	0.1	0.3
Total biomass (metric tons)						
	Observed	Lower 95% CI	Upper 95% CI	Observed	Lower 95% CI	Upper 95% CI
Small fish (< 250 mm)						
Cisco (both sexes)	668.9	492.5	825.1	161.9	106.2	207.8
Bloater	140.4	99.6	171.1	56.2	35.8	76.6
Other	6.7	2.9	9.5	2.2	1.0	2.4
Rainbow smelt	588.4	537.1	632.0	471.6	419.8	517.9
Kiyi	60.6	46.1	73.0	119.0	63.4	173.1
Large fish (≥ 250 mm)						
Cisco (males)	1,108.7	942.8	1,285.0	759.1	632.6	883.9
Cisco (females)	1,656.4	1,361.3	1,939.4	2,029.7	1,791.5	2,262.5
Bloater	3.7	0.9	6.1	5.9	4.2	10.3
Other	5.2	0.4	8.5	1.5	0.2	2.2
Kiyi	0.0	0.0	0.0	17.0	10.3	22.2

Table 4. Total biomass harvested (kg), average mass of harvested males and females (kg), and numbers of males and females harvested from two management zones of Thunder Bay during the 2007 roe fishery spanning 1 November to 7 December.

Management zone	Biomass harvested (kg)	Average mass of harvested males (kg)	Average mass of harvested females (kg)	Number of males harvested	Number of females harvested
1	81,438	0.470	0.480	40,250	130,102
2	74,701	0.409	0.445	46,855	124,673
Total	153,853	-	-	87,105	254,775

Survey 1 (November 14-18) Survey 2 (November 24-27)

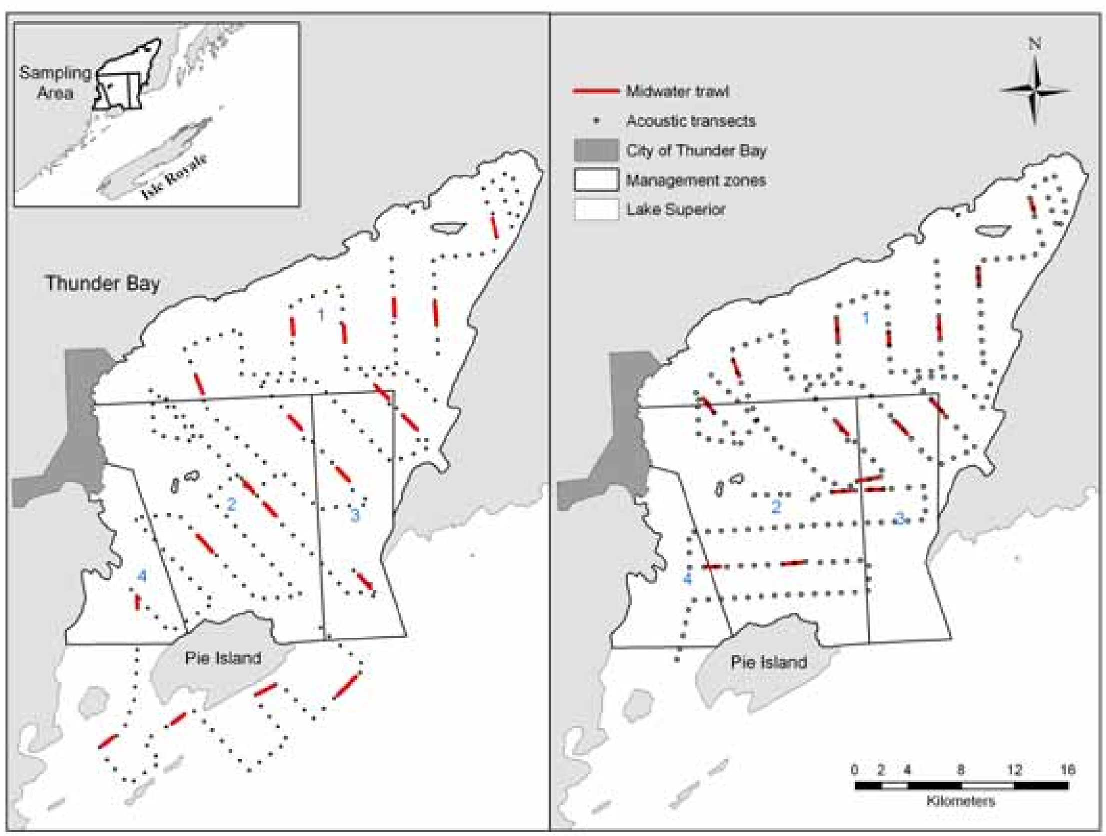

Figure 1. Maps showing acoustic transects and midwater trawl stations sampled during two fishery-independent surveys of Thunder Bay conducted during November 2007. Boundaries of four management units are also shown.

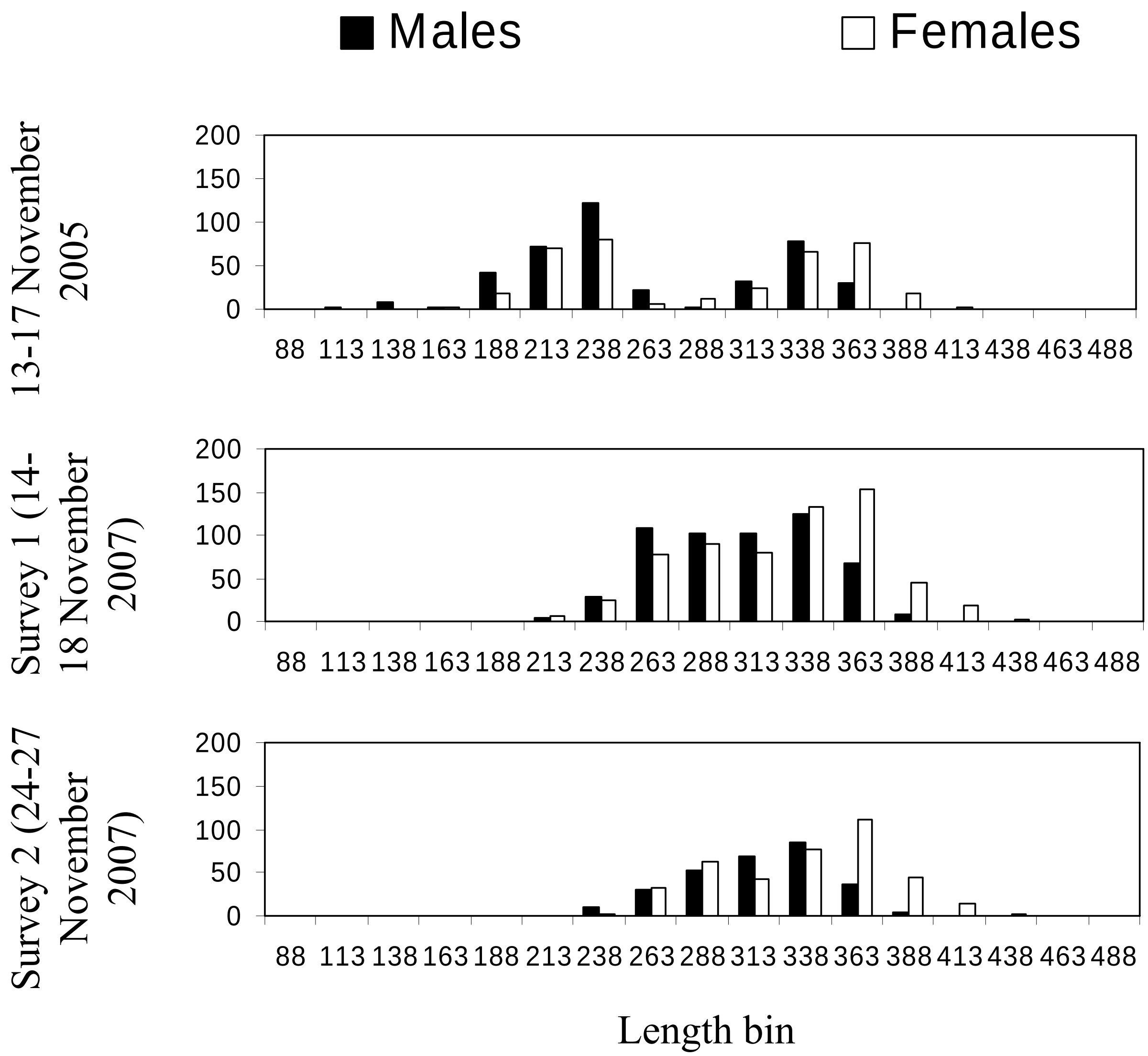

Figure 2. Length-frequency distributions of ciscoes captured from Thunder Bay in midwater trawl samples during November 2005, and during the two surveys of November 2007.

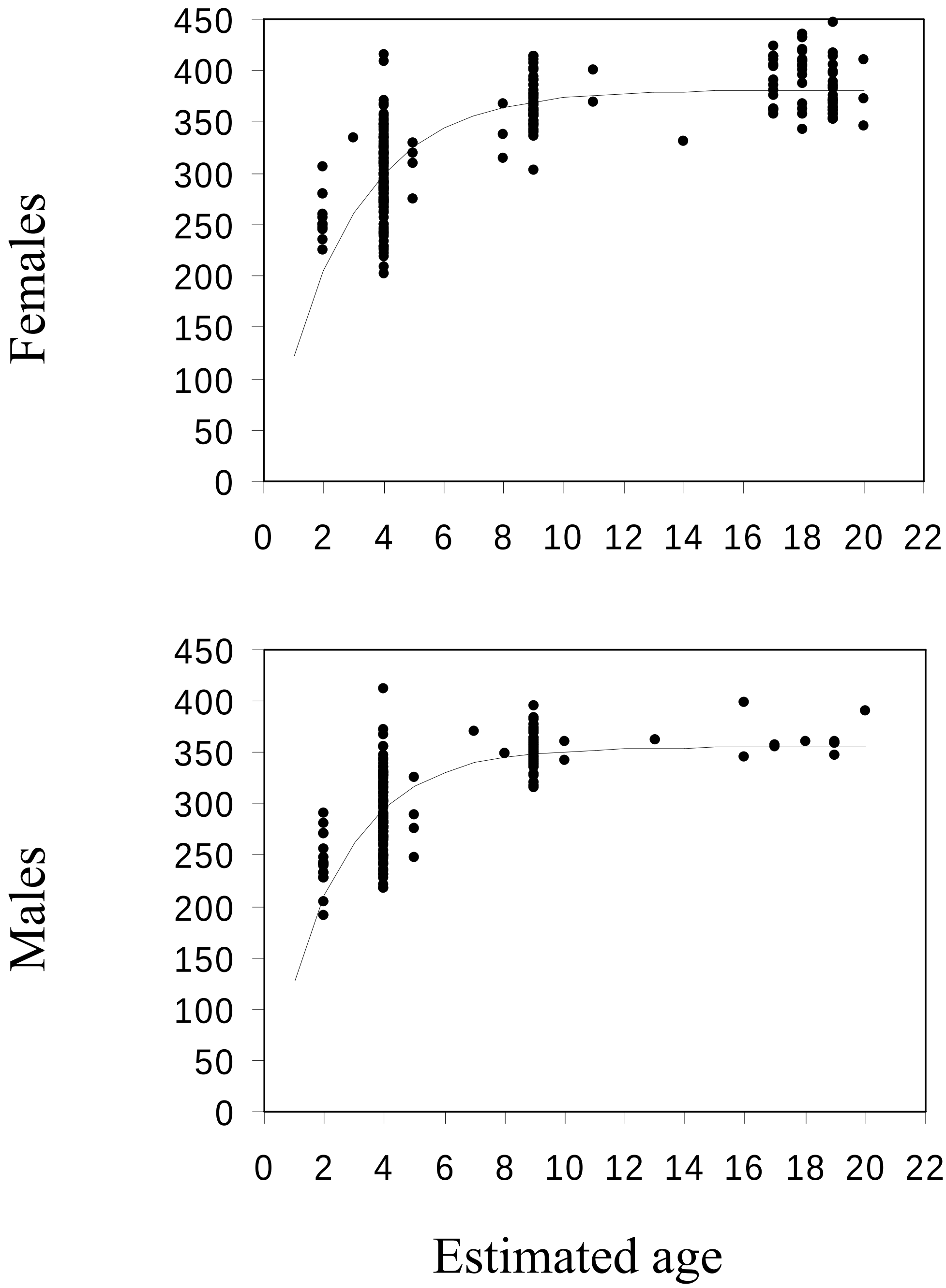

Figure 3. Von Bertalanffy (VB) growth equations for female and male cisco based on age estimates of midwater-trawl caught fish. The VB growth equation for females equaled $l_t = 381.117(1-e^{(-0.386894*t)})$, N = 250, $R^2 = 0.58$; and the male VB growth equation equaled $l_t = 355.05(1-e^{(-0.44937*t)})$, N = 193, $R^2 = 0.53$.

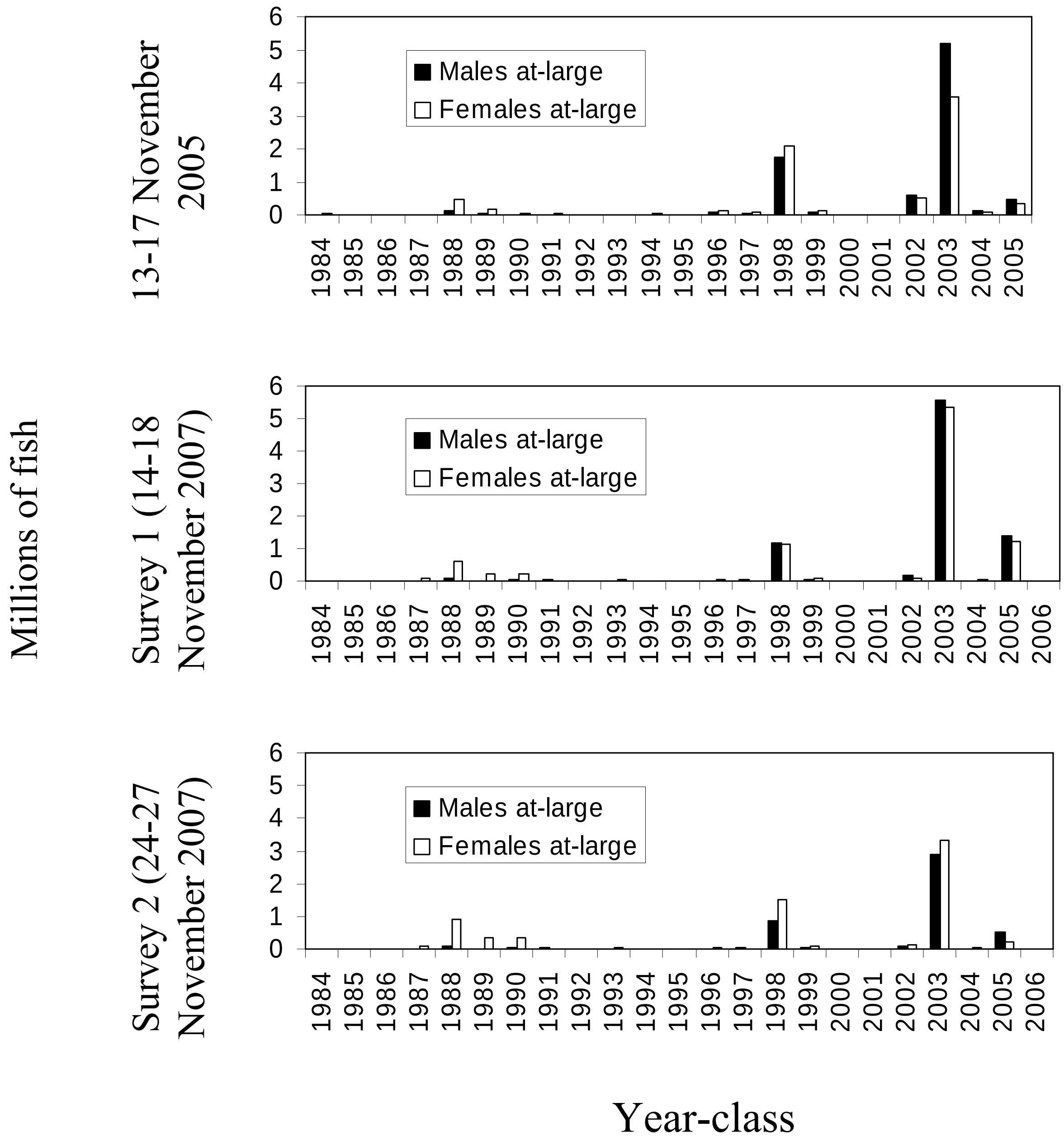

Figure 4. Estimated number (millions of fish) of male and female ciscoes of different year-classes at large during the November 2005 survey (top panel), and the two surveys of November 2007.

Survey 1 (November 14-18) Survey 2 (November 24-27)

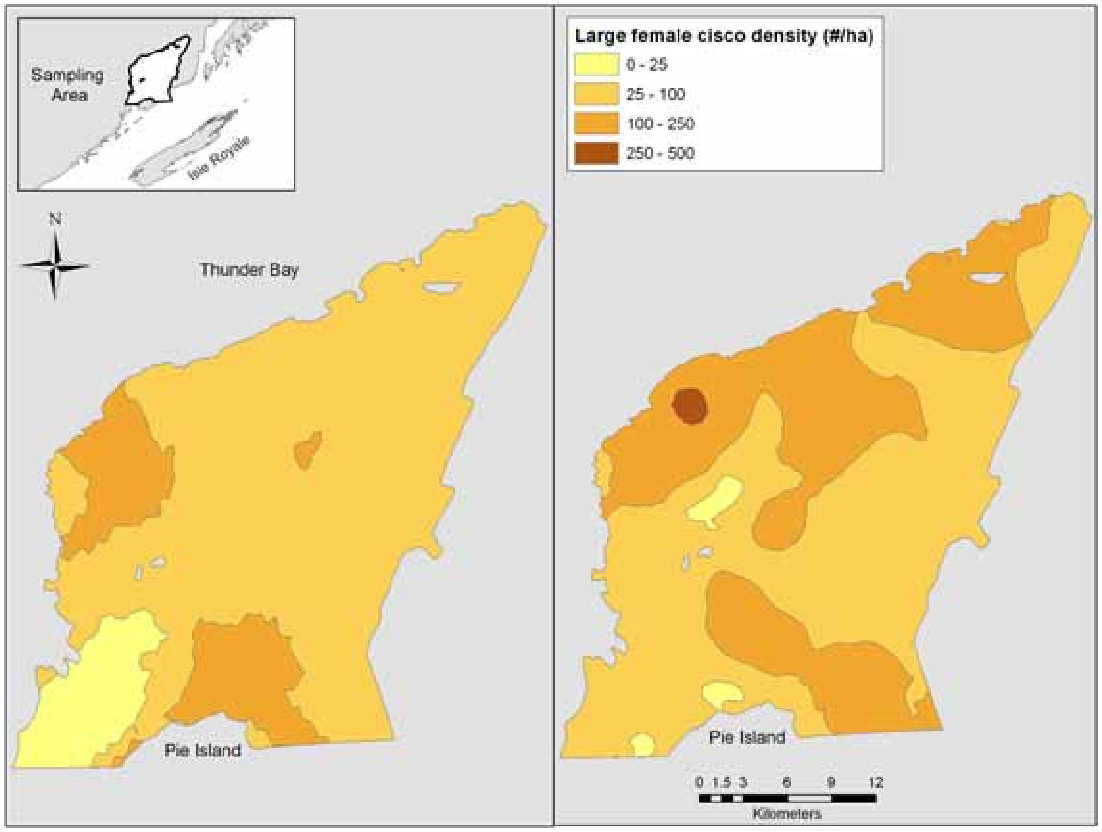

Figure 5. Maps showing densities of spawning-size females gathered during the two November 2007 surveys of Thunder Bay. The interpolated surfaces were created using ordinary kriging.

Survey 1 (November 14-18) Survey 2 (November 24-27)

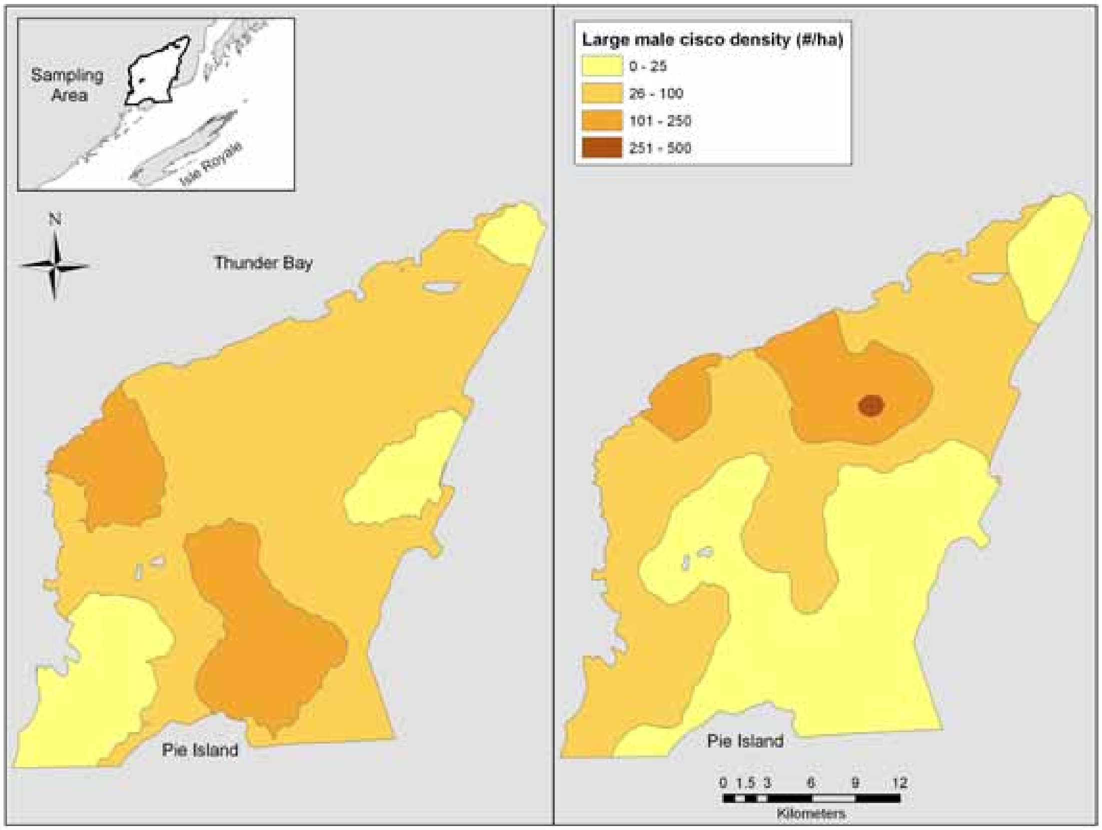

Figure 6. Maps showing densities of spawning-size males gathered during the two November 2007 surveys of Thunder Bay. The interpolated surfaces were created using ordinary kriging.

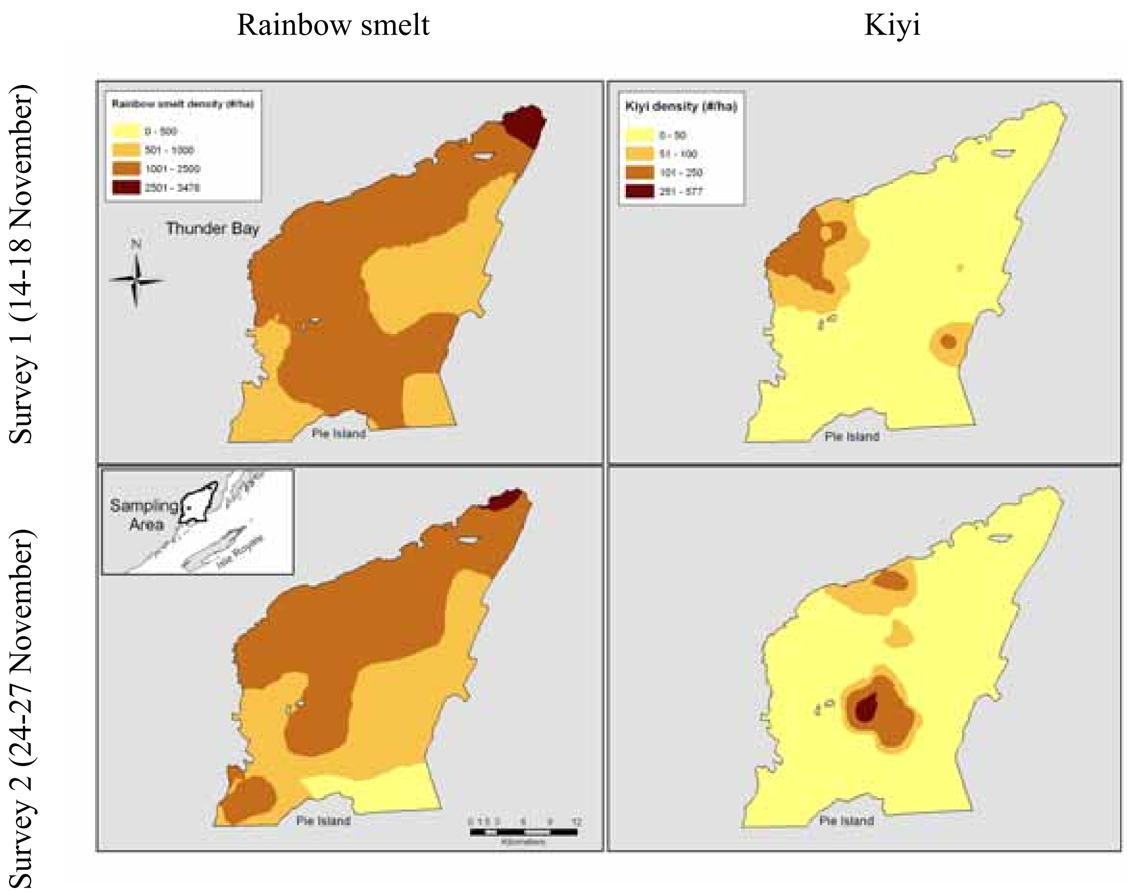

Figure 7. Maps showing densities of rainbow smelt and kiyi gathered during the two November 2007 surveys of Thunder Bay. The interpolated surfaces were created using ordinary kriging.

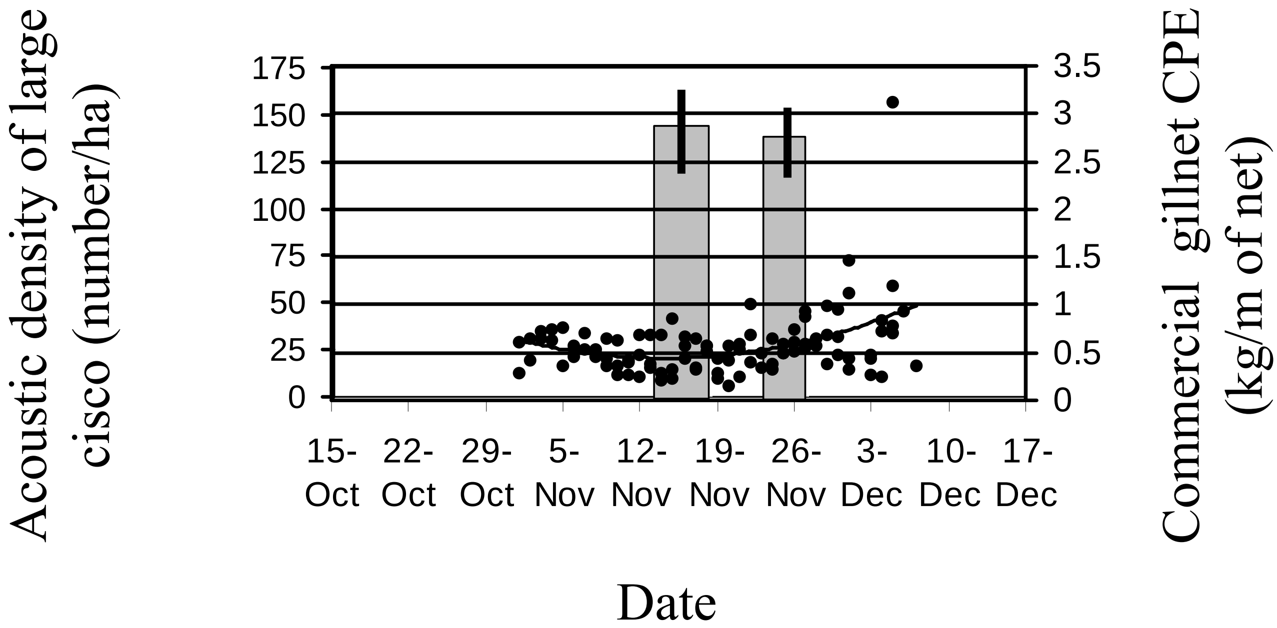

Figure 8. Acoustic density of large cisco (number/ha) measured during two fishery-independent surveys (gray bars) of Thunder Bay, and commercial floating gillnet catch-per-effort (CPE; kg/m) plotted against landing date (solid circles). Error bars for the acoustic density estimates are 95% confidence intervals. A 2nd order polynomial was fit to the CPE data (black line) to characterize the temporal trend.

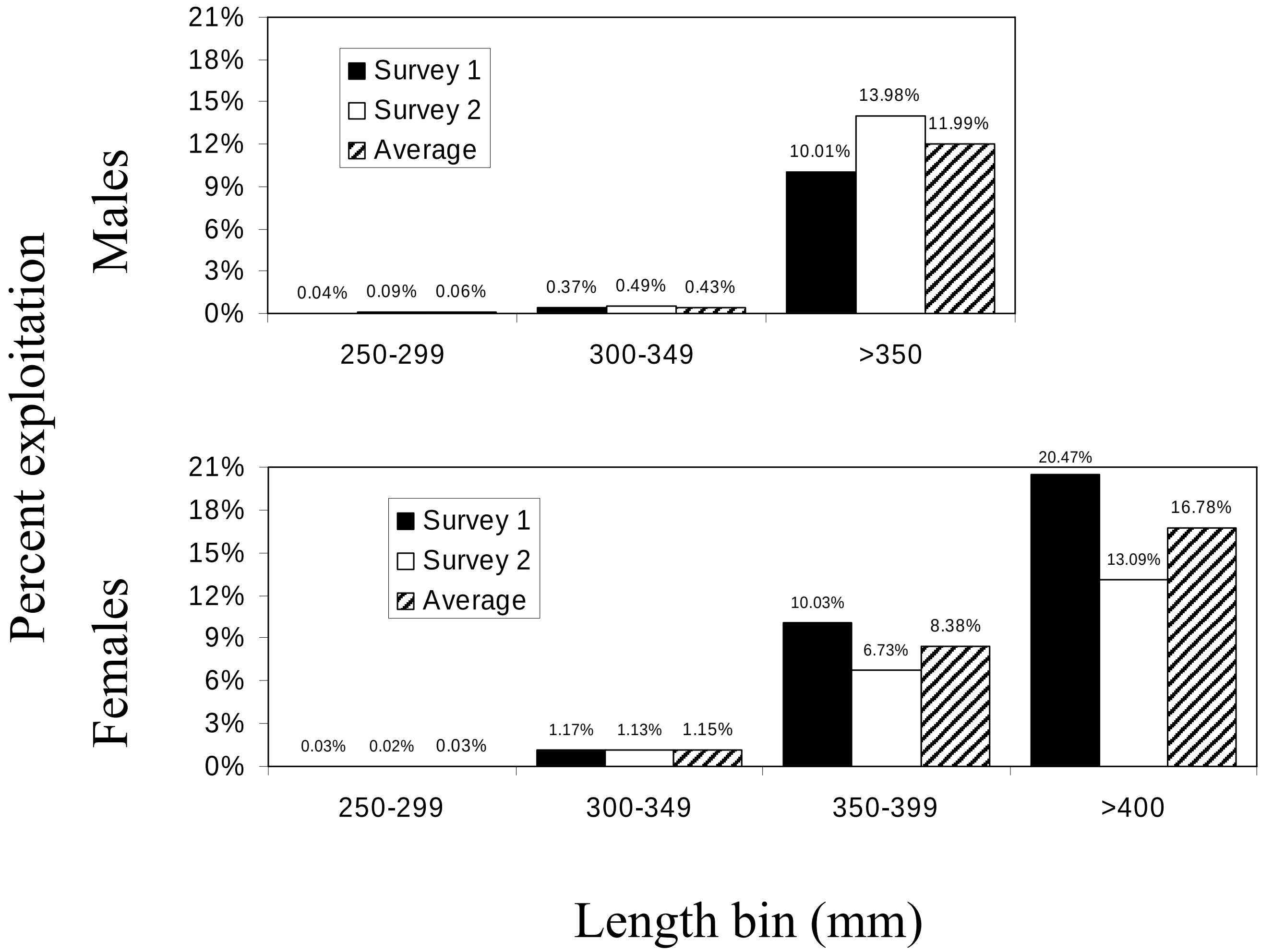

Figure 9. Estimates of percent exploitation of Thunder Bay ciscoes from the 2007 roe fishery by 50-mm length bins.

Appendix A. Length-age distribution of males caught by midwater trawling from Thunder Bay during November 2007.

					Males (Year-class)											
Length (mm)	05	04	03	02	00	99	98	97	96	94	93	91	90	89	88	87
Age	2	3	4	5	7	8	9	10	11	13	14	16	17	18	19	20
190-199	1															
200-209	1															
210-219			2													
220-229	2		2													
230-239	3		4													
240-249	5		8	1												
250-259	1		3													
260-269			11													
270-279	2		14	1												
280-289	1		15	1												
290-299	1		5													
300-309			6													
310-319			9				2									
320-329			10	1			3									
330-339			7				6									
340-349			3			2	8	1				1			1	
350-359			2				16						2		2	
360-369			1				10	1		1				1	1	
370-379			1		1		4									
380-389							2									
390-399							1					1				1
410-419			1													
Totals	17		104	4	1	2	52	2		1		2	2	1	4	1

Appendix B. Length-age distribution of females caught by midwater trawling from Thunder Bay during November 2007

					Females (Year-class)											
Length (mm)	05	04	03	02	00	99	98	97	96	94	93	91	90	89	88	87
Age	2	3	4	5	7	8	9	10	11	13	14	16	17	18	19	20
200-209			2													
210-219			1													
220-229	1		5													
230-239	1		2													
240-249	5		8													
250-259	2		1													
260-269			7													
270-279	2		16	1												
280-289				17												
290-299				13												
300-309	1		6	1			1									
310-319			12			1										
320-329			9	1												
330-339		1	7	1		1	2				1					
340-349			7				6									
350-359			4				9						1	1	5	
360-369			2			1	9		1				3	2	7	
370-379			1				5						1		4	1
380-389							3						2	1	4	
390-399							3						1	1	2	
400-409			1				3		1				2	5	1	
410-419			1				3						3	3	2	1
420-429													1	1		
430-439														3		
440-449															1	
Totals	12	1	92	34		3	44		2		1		14	17	26	2