COMPARISON OF COMMERCIAL LANDINGS OF CISCO TO ACOUSTIC ESTIMATES OF ABUNDANCE IN THUNDER BAY AND BLACK BAY, ONTARIO

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Abstract

The two largest remaining cisco *Coregonus artedi* commercial fisheries on Lake Superior are supported by the Thunder and Black Bay, Ontario, stocks. The sustainability of these fisheries relies on controlling the harvest in relation to the size of the populations. During mid-November 2005 we conducted acoustic and midwater trawl surveys of both bays to assess abundances of various year-classes at-large which we compared to commercial catches to estimate exploitation levels. At present, the cisco population in Thunder Bay is dominated by the 2003, 1998, 1990, 1989 and 1988 year-classes. These five strong year-classes were caught previously during an annual USGS spring bottom trawl survey as age-1 fish, while the remaining year-classes were largely absent from trawl catches as yearlings. Using acoustic methods, we estimate the numbers of large (> 250 mm) ciscoes in Thunder and Black bays at 5.2 million (95% CI = 4.3 – 6.2 million) and 244,000 (95% CI = 32,000 – 456,000), respectively. We estimate that commercial fishers harvested 2.49% of males older than age-6 and 8.46% of age-6 and older females from Thunder Bay. Plots of catch-per-unit-effort (CPUE) of commercial nets versus landing date showed that our survey of Thunder Bay occurred when CPUE was high, indicating most spawners were present. The CPUE of ciscoes in Black Bay increased rapidly after our survey, suggesting our acoustic abundance estimate is conservative. Given the 1998 and 2003 year-classes are both strong and well established, we conclude that present commercial harvest quotas will not jeopardize the persistence of the Thunder Bay stock into the foreseeable future (i.e., next 5-10 years). Given that our abundance estimate from Black Bay is conservative and the estimate suffers from poor

precision, we can not comment on the sustainability of the current Black Bay harvest quota.

Introduction

During the peak harvest years of the1940s, Lake Superior cisco *Coregonus artedi* supported commercial fisheries with annual landings exceeding 6 million kg. Total yield dropped dramatically during the 1960s, especially in U.S. waters, and this decline has been attributed largely to overfishing (Lawrie and Rahrer 1972; Selgeby 1982). While U.S. landings declined, landings from Canadian waters remained stable, averaging around 1 million kg annually from 1930 to the late 1980s (Baldwin et al. 1979; Dextrase et al. 1986). During the 1970s, Black Bay supported annual commercial landings ranging from 400,000 to 800,000 kg (Dextrase et al.1986; Jacobson et al. 1987). Thunder Bay landings during this interval were lower (100,000 – 200,000 kg annually), but were generally stable (Jacobsen et al. 1987). From the 1970s to the present the bulk of harvest in Canada has occurred in Thunder Bay, Black Bay and the northern coast east of Thunder Bay to the Nipigon Strait (Ebener and Stockwell *In preparation*).

During most of the 20th century, ciscoes from Black and Thunder bays were harvested for their flesh. In the early part of the century, operators targeted ciscoes using bottom-set gillnets constructed of multifilament twine with stretch measures smaller than 73 mm. Around 1960 a bottom-trawl fishery for ciscoes developed in Black Bay and by 1971 roughly 80% of the Black Bay harvest was taken by bottom trawling (Dextrase et al 1986). Given the stability in commercial landings using these early gears (Jacobsen et al. 1987) an argument can be made that these cisco flesh fisheries in Canada were sustainable. Around 1975 there was a dramatic change in the market for ciscoes with processors demanding roe largely for overseas customers. Commercial fishers began targeting females earlier in the fall by suspending gill nets with mesh sizes larger than 83 mm stretch made from monofilament line (Dextrase et al. 1986). As operators moved towards suspended nets they moved to taller nets which had roughly 3 times the surface area of nets fished in the 1960s (Dextrase et al. 1986).

In the mid-1980s, Ontario Ministry of Natural Resources (OMNR) fisheries managers became concerned that harvest levels of cisco from Thunder and Black bays may not be sustainable. Population metrics were beginning to exhibit telltale signs of overfishing which had been previously observed in U.S. fisheries (Selgeby 1982). Dextrase et al. (1986) examined commercial catch data from Black Bay from 1965 to 1983 and reported that the mean lengths and ages of commercially-caught ciscoes increased gradually over this interval. Females were representing a larger portion of the catch in later years, and lengths-at-age of young fish were increasing suggesting faster growth and possibly lower densities. Commercial gill net catch-per-unit-effort (CPUE) statistics were within the range of historic levels (1960-1985) through 1986, but dropped dramatically during 1987 and 1988. The lack of a declining trend in commercial CPUE prior to 1987 may have been masked by increased efficiency of commercial gillnets owing to taller nets being fished and a switch from multifilament twine to monofilament (Dextrase et al. 1986).

MacCallum (1989) reported that the cisco fisheries of Black Bay and Thunder Bay in the late 1980s were almost entirely supported by a single cohort that recruited in 1984, and that catches should be reduced immediately as a means of protecting the stock. An independent analysis of the OMNR data (Spangler 1990) concurred with OMNR interpretations of aging data and catch statistics. The OMNR opted to close the Black Bay fishery in 1989 and to reduce quotas in Thunder Bay by 50%. The fishery in Black Bay was opened again in 1990, but at a much reduced level.

Based on a recommendation by Spangler (1990), beginning in 1992 the OMNR started a cooperative gill net program with the Western Lake Superior Commercial Fisherman's Association designed to assess pre-recruit cisco year-classes. Smaller mesh gill nets (38-, 51- and 64-mm stretch measure) have been attached to commercial gangs during the fall fishery to measure CPUE of young fish. Three strong year-classes of cisco recruited to Lake Superior during 1988-1990 and these fish along with the 1998 cohorts presently support the commercial fishery (Anonymous 2001). The annual age-1 cisco recruitment index for Thunder Bay (Figure 1) collected by the Great Lakes Science Center during their spring fish community survey (see Bronte et al. 2003 for details) also serves as valuable source of information for forecasting the future of cisco fisheries in Canadian waters (Anonymous 2001). At present, cisco catch quotas in Ontario are adjusted based on: 1) trends in CPUE based on mandatory catch reports, 2) trends in the spatial distribution of the fishery, 3) commercial fish sample age distributions, and 4) pre-recruit information based on small mesh gill nets and the age-1 bottom trawl recruitment index (Anonymous 2001). During the 2005 fishing season catch quotas for Thunder Bay and Black Bay equaled 170,000 kg and 60,000 kg, respectively.

Fishery management depends on controlling the quantity of fish harvested in relation to the size of the exploited population (Gulland 1983). Acoustic assessment techniques could provide managers with fishery-independent information on cisco abundance to judge the sustainability of harvest quotas. Yule et al. (2006) showed that densities of large (> 250 mm) cisco can be assessed on spawning grounds. In that study, large female ciscoes were the only large-bodied fish occupying open water, and efforts to estimate mature cisco densities by excluding acoustic backscatter of smaller fishes (rainbow smelt *Osmerus mordax* and juvenile cisco) were encouraging. In this present study, we repeated the methodology of Yule et al. (2006) to determine if methods to estimate mature cisco densities can be applied to Thunder Bay and Black Bay. Commercial catch data were compiled and catches sub-sampled to estimate the numbers of males and females harvested. Otoliths were collected to develop length-at-age keys for both commercially-caught ciscoes and also ciscoes caught by midwater trawling (i.e., at-large ciscoes). This information was used to estimate what proportion of at-large males and females of varying ages were harvested during the fall 2005 fishery. We also combined information on spawning female densities, size-structure and fecundity to estimate the numbers of eggs cast by females which we compare to an estimate of the number of eggs harvested. By compiling these data we examined the likelihood that present harvest quotas will promote the short-term (5-10 years out) sustainability of the Thunder Bay and Black Bay roe fisheries.

Methods

We sampled Thunder Bay over four nights between 13-17 November and Black Bay on one night (18-19 November 2006). Sampling occurred in three management zones (zones 1, 2 and 3) in Thunder Bay and part of zone 7 in Black Bay (Figure 2). We sampled in a systematic fashion conducting a series of parallel acoustic transects spaced at roughly 3 km intervals in both bays. A collected acoustic data along a total of 197 km and 49 km of transects in Thunder and Black bays, respectively. We limited sampling to the area of Black Bay where the vast majority of commercial fishing for cisco has historically occurred (OMNR, unpublished data).

Midwater trawling and bottom trawling

We assessed fish community composition by conducting a total of 12 midwater trawls and four bottom trawls in Thunder Bay and 3 midwater trawls in Black Bay (Figure 2). November 2004 acoustic data collected in Wisconsin waters suggested most large ciscoes occupied the top 20 m of the water column at night and that rainbow smelt tended to be deeper (Yule et al. 2006). We examined fish vertical distribution patterns in Thunder Bay by conducting horizontal tows in three depth strata (i.e., 4 tows with the headrope higher than 10 m depth, 6 tows with the headrope ranging from10-20 m depth, and 2 tows with the headrope below 20 m). We had planned to sample Black Bay over two nights, but because of an approaching storm we limited sampling to one night. The 3 midwater tows in Black Bay were conducted with the headrope above 10 m depth where catches of large ciscoes from Thunder Bay had been highest.

The midwater trawl (Gourock Trawls, Ferndale, WA) had 15.2 m head rope and foot rope lines, and 13.7 m breast lines. The nylon mesh graduated from 152 mm stretch measure at the mouth to 13 mm stretch measure at the cod end. The bottom trawl (3/4 Yankee trawl number 35) had 11.9 m head rope, 15.5 m foot rope and 2.2 m wing lines with 89 mm stretch measure at the mouth, 64 mm stretch measure at the trammel and 13 mm stretch measure at the cod end. A NetMind (NorthStar Technical, Inc, Saint Johns, NF) depth sensor was used to measure midwater trawl head rope depth in real time. Wingspread was measured using sensors that logged data at roughly 10 s intervals during deployment. The volume of water swept by the midwater trawl was calculated by multiplying the tow distance by the average wingspread times the average trawl mouth height measured using VEMCO miniature depth/temperature loggers placed on the headrope and footrope lines (depths were recorded by the VEMCO loggers every three seconds). The bottom area swept by the bottom trawl was calculated by multiplying the distance the trawl was on bottom by the average wingspread.

Fish were sorted to species in the field, placed in plastic bags, iced and processed the next day at the OMNR Thunder Bay laboratory. Species were weighed in aggregate to the nearest gram. For small (< 100 individuals) non-cisco catches all individuals were measured to the nearest millimeter. For larger catches, 50-100 individuals were measured and the remaining fish were counted. One catch of rainbow smelt *Osmerus mordax* from Black Bay was exceptionally large so the number caught was estimated by the total weight divided by the average weight of 100 rainbow smelt based on three sub-samples.

All cisco were measured to the nearest millimeter. The vast majority of cisco were weighed individually to the nearest gram, sexed, and their reproductive state was assessed (i.e., unknown, males and females = mature or immature). Individual lengths and weights of cisco greater than 250 mm (both sexes) were used to develop a length-weight regression. Otoliths were extracted from cisco for aging, targeting 20 individuals per seven 50 mm length bins (range = 100 – 450 mm) from each bay. Fish were aged using the “crack and burn” method as recommended by the Lake Superior Technical Committee (Schreiner and Schram 2000). Fifteen ovaries per 50-mm length bin were targeted to assess fecundity. Fecundity per female was estimated using techniques described by Yule et al. (2006).

Acoustic data collections and processing

Acoustic data from Thunder Bay and Black Bay were collected using a 6.8°, 120 kHz, split-beam transducer manufactured by BioSonics Inc. (Seattle, WA). Sampling occurred using a pulse frequency of 3-5 pings/s. Vessel position was measured using an Ashtech model BRG2 differentially corrected global position unit (accurate to 1 m) and this positional information was continually embedded in the acoustic data files. Total fish densities (number/ha) were calculated for 10 m vertical cells over 1,000 m horizontal intervals using echo integration techniques described by Yule et al. (2006). Horizontal travel distances were calculated with Echoview acoustic post-processing software (version 3.25.55.06, SonarData, Ltd., Tasmania, Australia). We first estimated total fish densities in each cell and then estimated the density of large cisco by multiplying total density by the proportion of single targets in each cell exceeding -35.6 decibels (dB) (see Yule et al. 2006 for details). We calculated total fish densities and densities of large ciscoes per 1,000 m interval by summing all vertical cells.

We used the trawls collected during the 2005 spawning season to test the efficacy of our acoustic technique for enumerating large ciscoes. We combined the 17 midwater trawls collected during November 2005 (14 from the present study and 3 from Wisconsin) with a data set of 16 trawls we had used to develop the -35.6 dB threshold for excluding small fish. We overlaid midwater trawl headropes and footropes on echograms using a parallelogram drawing tool available in Echoview software. We predicted the catch of large cisco in each midwater trawl using the following formula:

Predicted catch of large (> 250 mm) cisco = $(10^{Sv/10} / \sigma_{bs})$ * Proportion of single targets > -35.6 * Volume of water swept by the trawl (m^3), where total fish density in the trawl path (number / m^3) was calculated by ($10^{Sv/10}$ / σ_{bs}) with *Sv* equaling the average backscattering volume strength in dB in the trawl path, and σ_{bs} is the mean backscattering cross section of individual fish in the trawl path. The single-target detection parameters used to calculate mean target strength (TS) in dB are presented in Yule et al. (2006). By convention, $\sigma_{bs} = 10^{(TS/10)}$. We compared actual catches of large cisco to predicted catches using geometric mean regression (GMR). Central trend lines from GMR are preferred over linear regression when large measurement errors are suspected in both independent and dependent variables (Brown and Austen 1996). We examined two null hypotheses: 1) the slope of the central trend line did not significantly different from 1 and 2) the y-intercept did not vary significantly from zero.

We used a geostatistical approach (Pettitgas and Lafont 1997) to calculate estimation variance (σ_E^2) for total fish density and density of large cisco in Thunder Bay (see Yule et al. 2006 for details). Briefly, experimental variograms were constructed using nine 2,000 m lags using EVA2 software (Petitgas and Lafont 1997). Theoretical variogram models (with nuggets) were fit by eye to experimental variograms. These models were used to calculate σ_E^2 using the intrinsic 2-D method (scheme E) available in EVA2. We assumed errors were normally distributed, therefore, the 95% confidence intervals (95% CI) for total fish densities and densities of large cisco in Thunder Bay survey were calculated by the mean $\pm$ 1.96 σ_E.

Coverage in Black Bay was too limited to warrant using EVA2 to calculate σ_E^2. When calculating average fish densities in Black Bay, we opted to use the seven segments of the survey path where sampling occurred east to west (Figure 2) as sample units. We assumed these transect segments were independent samples. Because the mean estimates were based on only 7 samples, we used an algorithm by Brown and Austen (1996) to calculate 95% confidence intervals when sample sizes are small. Fish abundance estimates were calculated by multiplying the arithmetic mean density (and 95% confidence intervals) by the total area of three Thunder Bay management zones (66,579 ha) and Black Bay we sampled (12,619 ha). Bay areas were calculated using ArcMap 9.1 (ESRI, Redlands, CA).

We mapped total fish densities and densities of large cisco in Thunder Bay using ordinary kriging available in the ArcMap geostatistical analysis extension. Densities at unsampled locations were estimated based on theoretical variogram models. Maps showing fish density contours for Black Bay were created using the inverse distance squared weighted interpolation method. For both bays, interpolated density values were calculated using a minimum of 2 and a maximum of 5 neighboring density values.

Estimating abundance of male and female ciscoes

The acoustic abundance estimate of large ciscoes in Thunder Bay was apportioned to size groups based on midwater trawl catches. We first calculated for each trawl tow in Thunder Bay the relative proportions of males and females belonging to 6 groups (i.e., males: 250-299 mm, 300-349 mm, >350 mm; and females: 250-299 mm, 300-349 mm, > 350 mm) so that the proportions of all six groups in each trawl summed to one. We then calculated an average proportion for each group using all the trawls as samples. We felt justified in pooling all 12 midwater trawls in this fashion because a cursory analysis of the 6 sex-length proportions compiled using the 4 southernmost midwater trawls did not vary appreciably from proportions calculated using the 8 northernmost midwater trawls. We then multiplied these proportions by the total acoustic abundance estimate of large cisco to estimate abundance per group. We then apportioned the abundance of each group to cohorts based on aging keys for males and females compiled using the same sex-length groups.

Estimating the numbers of eggs cast

The numbers of eggs cast by females is subject to uncertainty because the estimate is based on other estimates (female abundance, female size-structure and fecundity versus female size relationships) which all suffer from imprecision (Yule et al. 2006). To estimate eggs cast by females (and 95% confidence intervals) we used a bootstrap technique that incorporated uncertainty in all three aforementioned components. First, we randomly selected 197 1-km interval density estimates from the 197 observed estimates with replacement and calculated a mean bootstrap density. Next, we randomly selected 12 midwater trawls with replacement and calculated the mean proportional contribution of our previously-defined sex-length groupings. We then apportioned the bootstrap mean density by the proportion of each group. We then randomly selected 64 pairs of fecundity observations (weight, number of eggs) with replacement, calculated the slope and intercept using linear regression, and applied this regression to estimate average fecundity of the three female length-groups based on the average weight of females in each group. Average weight for each length-group was based on the length-weight regression applied to the average observed length for each length-group. Female density by length-group was multiplied by average fecundity by length group to estimate average egg density (eggs/ha) cast by each length-group. These average densities were then multiplied by the total surface area of three Thunder Bay management zones to estimate total eggs eventually cast by each length-group. Summing across length-groups gave total eggs cast. This process was repeated 1,000 times to generate distributions of numbers of eggs cast. We used the bias-corrected percentile method (Manly 1997) to calculate 95% confidence intervals for total eggs cast. Yule et al. (2006) used a bootstrapping technique to evaluate where the greatest uncertainty in egg deposition estimates came from (female density estimates, size-structure estimates, or the estimated relationship between fecundity and fish weight). We used the same methodology to evaluate uncertainty in our egg deposition estimate for Thunder Bay.

To examine which year-classes were contributing most to potential reproductive output and to the roe harvest, we apportioned the numbers of eggs cast to grouped year-classes (2000-2005, 1993-1999, and 1984-1992). We first estimated proportion of each grouped year-class in each of the three length-groups (250-299, 300-349, and > 350 mm) for female fish based on the length-age key for female fish captured in the midwater trawl. Average egg density for each length-group was then multiplied by the proportion of each grouped year-class (2000-2005, 1993-1999, and 1984-1992) to estimate contribution of each grouped year-class to total egg density. These values were then multiplied by Thunder Bay surface area.

We had insufficient data on Black Bay cisco size-structure and fecundity to warrant predicting numbers of eggs cast.

Analysis of commercial catch data

Daily catch reports for each licensed operator were obtained from the Ontario Commercial Fisheries Association (OCFA, Blenheim, ON) Commercial Fish Harvest

Information System. Each fisher is required to report the total biomass of cisco harvested along with effort used (yards of net) each day (Anonymous 2001). Most commercial fishers, through a partnership arrangement with the commercial industry, provide the first ten ciscoes caught in each net on each day. These fish, called “net run” fish, were placed in plastic bags with labels that identified management zone, mesh size, landing date, etc. The net run fish were normally picked up daily by OMNR staff. Individual net-run fish were then given a unique serial number, sexed, measured to the nearest millimeter (fork length and total length), weighed to the nearest gram, otoliths were extracted, and a record of each fish was entered into a “net run” database. Because net run fish were collected continuously throughout the fishing season, the fish in the database provide a representative sample of the commercial catch over the fishing season.

To estimate the numbers of fish harvested per management zone we divided the total kg harvested by the average weight of ciscoes harvested from each zone (derived from the net run database). Monies for ageing of all the net run fish were not available, so a sub-sample was aged. Fish in the database were first sorted by sex, zone and length. Up to 10 fish per 10 mm length bin for each combination of sex and management zone were aged. When fewer than 10 fish were in a 10 mm length bin, all were aged. When more than 10 fish were in a 10 mm length bin, 10 were selected randomly from the total number in each bin. Aged fish were then used to develop age-length keys for each management zone that were then used to estimate the ages of all fish in the net run database. These management zone age keys were then used to apportion the total numbers caught from each zone to year-classes. Only 20 net run ciscoes were recovered from zone 3, so when apportioning the total catch in this zone to year-classes we used an age key developed using fish from zones 1 and 2. After apportioning harvested fish to age-classes by zone we summed the three zones for Thunder Bay to estimate total harvest for each age-class. We developed charts showing numbers at-large and numbers harvested by year-class. The numbers of eggs harvested by commercial operators was calculated by multiplying the numbers of each year-class harvested by the average number of eggs carried by females of that age (calculated from their mean weight from the net run database), summed over all year-classes. We calculated an estimate of egg exploitation by dividing the estimate of eggs harvested by the estimate of eggs cast by mature females at-large.

MacCallum and Cullis (1988) demonstrated that an understanding of the timing when ciscoes return to spawning grounds can be gathered by plotting commercial-net CPUE (i.e., kg/m) per night against landing date. We compiled plots for the 2005 fishing season for both bays by management zone (minus zone 3 where landings were low) to determine if our acoustic and trawl surveys were conducted when most adult ciscoes had returned to spawn. We limited the analysis to floating net lifts (81-89 mm stretch measure) fished for one night.

Results

Trawl catches

A total of 2,810 fish from 14 species were caught in the 12 midwater trawl tows collected in Thunder Bay. Rainbow smelt were predominant (64.95% by number), followed in decreasing order by cisco (28.19%), bloater *C. hoyi* (4.13%) and kiyi *C. kiyi* (2.42%). The remaining 10 species only accounted for 0.32% of the total midwater trawl catch. Ciscoes and rainbow smelt were caught in all trawls, while bloater and kiyi were caught in 9 and 8 trawls, respectively. Seven species (~5,835 fish) were caught in the three midwater trawls from Black Bay. Rainbow smelt represented 99.43% of the catch and cisco 0.24%. Only 14 ciscoes were caught from Black Bay which limited our ability to characterize the spawning stock.

There was minimal overlap in length distributions of rainbow smelt and cisco captured in midwater trawls from Thunder Bay. Most rainbow smelt were smaller than 150 mm (Figure 3A) and most ciscoes exceeded this length (Figure 3B). The length distribution of cisco was bimodal with modes at 225 mm and 325 mm. The deepwater chubs were generally smaller than the ciscoes captured with kiyi having a modal length of 125 mm and bloater a modal length of 225 mm (Figure 3C). Only 9.48% of the bloaters captured exceeded 250 mm total length.

Cisco were found throughout the water column in night midwater trawls in Thunder Bay (Figure 4), but densities were generally highest in tows where the average head rope depth was above 10 m. Rainbow smelt were rare in these surface tows and their densities generally increased with increasing trawl depth (Figure 4). Bloater and kiyi were found at a wide range of depths, but their densities were greatest in the two deepest tows (Figure 4).

A total of 730 captured ciscoes were dissected to determine their sex and state of maturity. Of this total we could identify the sex and maturity of 724 fish. Of the 207 males smaller than 250 mm we examined, 38.65% were mature (Figure 5A) compared to only 11.64% of 146 small females we examined (Figure 5B). Males and females represented 58.64% and 41.36% of the cisco smaller than 250 mm, respectively. The sex of all 371 cisco greater than 250 mm was determined. Of this total, 166 (44.74%) were males and 205 (55.26%) were females. Examination of gonads showed that 93.37% of the males larger than 250 mm (Figure 5A) were mature compared to 95.12% of the females (Figure 5B). All mature females carried eggs with no evidence that any spawning had occurred. A one-way ANOVA showed significant ($P < 0.0001$) differences in mean lengths of immature males, mature males, immature females and mature females. A post hoc Student's t test showed mean lengths of mature females (338 mm) were significantly ($P < 0.05$) larger than mature males (295 mm), but immature males (222 mm) did not vary significantly (228 mm) from immature females. Immature and mature male and female were found in similar proportions from all trawls regardless of depth (Figure 6).

A breakdown of the catch of large male and female ciscoes from Thunder Bay is presented in Figure 7. The proportion of males and females in the 250-300 mm and 300-350 mm size-classes were similar, while females > 350 mm were more common than males exceeding this length. The mean proportions were used to apportion the acoustic abundance estimate of ciscoes > 250 mm in Thunder Bay to the 6 sex-length groupings.

The length versus weight relationship for ciscoes > 250 mm equaled: ln [weight(g)] = 3.53 * ln [length(mm)] – 14.86, $R^2 = 0.92$, $N = 288$, range = 250-425 mm (Figure 8). We measured fecundity of 64 green females from Thunder Bay. The fecundity (total number of eggs) versus female weight relationship equaled: 44.48 * [female weight(g)] – 440.35, $R^2 = 0.84$, $N = 64$, range = 44 – 660 g (Figure 9).

A total of 1,473 fish from 16 species were caught in the four night bottom trawls from Thunder Bay. Ninespine stickleback *Pungitius pungitius* were predominant (59.27% by number), followed by rainbow smelt (15.21%), spoonhead sculpin *Cottus ricei* (9.10%), slimy sculpin *Cottus cognatus* (5.16%), lake whitefish *C. clupeaformis* (3.67%), deepwater sculpin *Myoxocephalus thompsoni* (3.26%),and bloater (2.04%). Most fish caught in night bottom trawls were small (< 200 mm). The average density of rainbow smelt was 34.3/ha, while the average density of all other small species combined (i.e., alewife *Alosa pseudoharengus*, deepwater sculpin, Eurasian ruffe *Gymnocephalus cernuus*, kiyi, ninespine stickleback, round whitefish *Prosopium cylindraceum*, slimy sculpin, spoonhead sculpin and trout-perch *Percopsis omiscomaycus*) was 237/ha (Figure 10A).

Lake whitefish were the most common species capable of growing to large sizes caught in night bottom trawls (Figure 10B). Of the fish greater than 250 mm (consistent in size with mature cisco), lake whitefish had the highest densities (7.90/ha), followed by demersal predators (burbot, lake trout and siscowet combined density = 2.38/ha), bloater (1.84/ha), and cisco (0.2/ha). These results suggest that the vast majority of ciscoes were sufficiently off the bottom at night to assess using acoustic techniques.

Acoustic survey results

The predicted capture of large cisco in midwater trawls based on acoustic data was correlated with actual catches (Figure 11). The slope of the central trend line (1.11) did not vary significantly from one (t = 0.97, df = 31, P = 0.34), and the y-intercept (4.02) did not vary significantly from zero (t = 1.66, df = 31, P = 0.11). This result indicates that the acoustic technique described by Yule et al. (2006) continues to provide reasonable estimates of large cisco densities.

Variogram construction showed that Thunder Bay fish density data exhibited sufficient spatial structuring to warrant using a geostatistical approach to estimate variance and to map distributions using ordinary kriging. For total fish densities, spatial structuring was moderate (Figure 12A) with the variogram model nugget (a measure of both white noise and micro-scale variation; Petitgas 1993) representing 27% of the total variance. Density data for large cisco showed a much higher degree of spatial structuring (Figure 12B). The ratio of the large cisco experimental variogram nugget to sill was low (0.10) and most of the variability in density (90%) was explained by spatial structuring. Mello and Rose (2005) computed variograms under different scenarios of random and aggregated fish density distributions, and our theoretical variogram for large cisco densities most closely approximates their scenario of moderately variable fish density samples within dense aggregations.

In Thunder Bay, the arithmetic means for total fish density and density of large cisco were 888 and 78.4 fish/ha, respectively. The estimation variances (σ_E^2) for total fish densities and densities of large cisco in Thunder Bay were 2,291 and 55, respectively. The 95% CI for the total fish density estimate equaled 794 to 982/ha, while the 95% CI for the large cisco density estimate was 63.9 to 92.9/ha. With a surface area of 66,579 ha we estimate total pelagic fish abundance in Thunder Bay at 59.1 million (95% CI = 52.9 to 65.4 million). The abundance estimate of cisco > 250 mm was 5.2 million (95% CI = 4.3 to 6.2 million). Of this total, we estimate 2.7 million large cisco were in zone 1 (80.6/ha), 1.8 million occupied zone 2 (79.2/ha) and 700,000 occupied zone 3 (67.3/ha).

In Black Bay the total fish density in the area sampled was 3,670/ha (95% CI = 930 to 6,400/ha), while the density of large cisco was 19.3/ha (95% CI = 2.6 to 36.1/ha). The area of Black Bay we sampled had a surface area of 12,619 ha so we estimate total fish numbers at 46.3 million (95% CI = 11.8 to 80.8 million) and numbers of large cisco at 244,000 (95% CI = 32,000 to 456,000). Density samples were highly variable, thus estimates have rather poor precision.

Total fish densities were generally higher in the western portion of Thunder Bay (Figure 13A) where bathymetric depths are generally shallower. Total fish densities in Black Bay showed a distinct trend with higher densities measured in the northern most portion of the bay we sampled (5,000 to 10,000 fish/ha, Figure 13A). Densities of large cisco in Thunder Bay were generally higher over bathymetric depths ranging from 30 to 50 m (Figure 13B). Some areas of Thunder Bay supported very high densities (> 400/ha) of large cisco (Figure 13B). The distribution map of large cisco in Thunder Bay is consistent with one large stock, not multiple isolated stocks. An area with moderately high densities of large ciscoes (50-100/ha) was present in the southwest portion of Black Bay (Figure 13B).

A plot of vertical distributions of all acoustic targets in Thunder Bay showed that densities were rather homogonous in the top 40 m of the water column (Figure 14). Densities of large (> -35.6 dB) acoustic targets, consistent with large cisco, were highest in the top 20 m of the water column (Figure 14).

The acoustic system failed to capture observed modes in length distributions of rainbow smelt and ciscoes captured by midwater trawling. To estimate abundances of rainbow smelt and small (<250 mm) ciscoes in Thunder Bay we scaled the acoustic density of fish smaller than 250 mm (i.e., total fish density – density of large ciscoes = 810/ha) by the percentage of the total midwater trawl catch of fish smaller than 250 mm that were rainbow smelt (75.31%) and ciscoes (17.33%). Using this approach, we estimate the density of rainbow smelt in Thunder Bay at 610/ha and small cisco at

140.3/ha. The estimate of small ciscoes was apportioned to small males and females assuming 58.64% were males and 41.36% were females. By using this approach we assume that all species were equally vulnerable to midwater trawl capture, and that we successfully characterized the composition of small fish in Thunder Bay based on our trawling effort.

Comparison of at-large ciscoes to commercial catches

A total of 196 cisco captured by midwater trawling from Thunder Bay were aged (Appendix A). Of this total, 85 were males, 106 were females, and the sex of 5 age-0 fish (all smaller than 129 mm) could not be determined. Captured males were predominantly age-2 (2003 year-class hatched during spring 2003) and age-7 (1998 year-class) with a few (N = 4) males age-17 (1988 year-class). Females were predominantly age-2, age-3, age-7, age-16 (1989 year-class) and age-17. The oldest cisco we caught was a female age-21 (1984 year-class). Density estimates of different male and female size groups were apportioned to year-classes based on the proportions calculated from the aging results (Figure 15A). Strong year-classes detected during the annual spring bottom trawl survey (2003, 1998, 1988-1990, Figure 15B) were present during the November 2005 midwater trawl survey (Figure 15A), validating both the age-1 index from bottom trawling as a tool for early year-class detection and the employed crack-and-burn aging technique. The age-1 data suggests that the 1989 and 1990 year-classes were both stronger than the 1988 year-class (Figure 15B), but we caught more fish from the 1988 year class during November 2005 (Figure 15A).

Plots of ciscoe CPUE in commercial nets versus landing date from Thunder Bay (Figure 16A) show that our survey occurred at a time when catch rates were high, indicating most spawners were present. Conversely, our survey of Black Bay (the night of 18-19 November) occurred when CPUE in commercial nets was still quite low (Figure 16B). The CPUE data suggest there was a large influx of fish in Black Bay after 24 November. These results suggest that our acoustic abundance estimate of large ciscoes (244,000, 95% CI = 32,000 to 456,000) in Black Bay is likely a conservative estimate of the numbers of fish that ultimately spawned in the bay.

The total numbers of "net run" fish saved by commercial fishers from management zones 1, 2 and 7 were 410, 235 and 433, respectively. Of this total, 162 from zone 1, 122 from zone 2 and 173 from zone 7 were aged. Aged fish were used to develop length-age keys for net run fish recovered from each zone (Zone 1 = Appendix B, Zone 2 = Appendix C, and Zone 7 = Appendix D). These keys were then used to apportion the total numbers of fish harvested from each zone (Table 1) to sexes and ages. We then summed the numbers harvested by year-class across the three management zones for Thunder Bay (Figure 17A). A break-down of the estimated numbers of each year-class at-large in Thunder Bay during mid-November is shown in Figure 17B. Age-2 ciscoes were the most abundant cohort at-large with the combined estimate of males and females equal to 7.89 million (Figure 17B). The next most abundant year-class at-large was age-7 fish (hatched in 1998) with an estimated 3.44 million at large (1.58 million males and 1.86 million females). Three rather distinct age grouping are evident in both Figure 17A and 17B with gaps between them coinciding with years of low or zero recruitment. We used these missing year-classes to define three broad age-groups (2005-2000, 1999-1993, and 1992-1984). We summed the total numbers of fish in each group harvested and at-large and used these data to calculate percent harvest by age group

(Figure 18). This approach was chosen because we recognized that calculation of percent exploitation by year-class was unjustified given the difficulty in aging fish (especially older individuals) accurately. Furthermore, we have far greater confidence in our ability to correctly assign aged fish to these age groups given gaps we observed in annual recruitment. We estimate percent exploitation of males and females belonging to the 1999-1993 age-grouping at 2.31% and 7.53%, respectively (Figure 18). The percent exploitation of males and females belonging to the oldest age-grouping (1992-1984) was estimated at 4.65% and 11.37% (Figure 18). The higher mortality of older fish can be attributed to a greater proportion of these older fish being vulnerable to the range of gill net mesh sizes used in the fishery (81 – 89 mm stretch measure). We combined data for the two oldest age groups (i.e., market size) from Thunder Bay and recalculated percent mortality of males at 2.49% and females at 8.45% (Figure 18).

Using length-at-age data and our estimates of fish at-large and numbers harvested, we developed frequency distributions of the total numbers of fish at-large and fish harvested using 25 mm length bins for both sexes (Figures 19). Data for the 1999-1993 (Figure 19A) and 1992-1984 (Figure 19B) age groupings show that the largest of ciscoes in each grouping were more susceptible to capture in commercial nets. The ratio of females to males at-large for the 1999-1993 age-grouping was essentially 1:1 (Figure 19A), while at-large females far outnumbered at-large males for the older age grouping (Figure 19B). Greater total harvest of the oldest females over the oldest males (Figure 19B) likely results from 1) females living longer, 2) their general larger size leading to higher probability of gill net capture, and 3) a shift in habitat occupied by males as the spawning season progresses making them less susceptible to surface gillnets. Using the net run fish database we compiled the numbers of males and females caught commercially by 5-day intervals from 1 November through 4 December (Table 2). Males represented 26% of the commercial catch by number from Thunder Bay during early November, but by late November they represented only 9% of the catch. A similar pattern can be observed in the catch data from Black Bay. These data suggest that males are likely behaving differently than females later in the fall, possibly occupying deeper water at night (Yule et al. 2006), which makes them less vulnerable to suspended gill net capture compared to females.

Based on data presented in Figures 19A and 19B we conclude that the vast majority of ciscoes older than age-6 had reached sufficient sizes to be fully vulnerable to commercial nets. This conclusion is further substantiated by the near identical age distributions of fish at-large and those harvested (Figure 20).

Egg cast and egg exploitation

Total number of eggs eventually cast in Thunder Bay was estimated at 69.7 billion eggs (95% CI = 59.9 and 82.0 billion; Figure 21A). Similar to the findings of Yule et al. (2006), most of the uncertainty in our egg deposition estimate can be attributed to estimates of mature female cisco densities (Figure 21A).

Based on the average number of female ciscoes by year-class harvested from Thunder Bay, their mean weight, and the relationship between fecundity and female weight we developed (Figure 9) we estimate total harvest of eggs from Thunder Bay at 5.2 billion (7.46%). The 1993-1999 year-classes contributed 44.6 billion eggs (64%) of our total estimate of 69.7 billion eggs, and commercial operators harvested an estimated 3.3 billion eggs (7.40%) from these year-classes (Figure 21B). Percent egg exploitation for the 1993-1999 year-classes was 7.40% (Figure 21B). The oldest year-classes, 1984-1992, contributed 21.66 billion eggs while harvest was 1.88 billion eggs (percent exploitation of 8.68%, Figure. 21B). The most recent year-classes, 2000-2005, contributed only 5% (3.45 billion eggs) to our estimate of total egg deposition, and commercial operators harvested 0.58 % of these eggs (Figure 21B).

Discussion

Our survey results suggest that present level of commercial harvest of ciscoes from Thunder Bay will not jeopardize the persistence of the stock at least for the foreseeable future (i.e., next 5 - 10 years). We estimate exploitation of marketable-size females and their eggs at 8.5% and 8.0%, respectively. Because large ciscoes were found residing in the upper water column (top 20 m) and our ability to detect fish acoustically in the upper 3-5 m of the water column is limited, it is likely that our estimate of their abundance is conservative, making exploitation estimates liberal. Unfortunately, our present data set can not be used to quantify to what degree our abundance estimates may be biased downwards. Understanding the densities of fish that go undetected in surface waters would be difficult to assess using our midwater trawl because the headrope must be fished at least 5 m deep for the trawl mouth to open fully. Overnight gill net CPUE data gathered by fishing nets at varying depths would be one way to understand to what degree acoustic estimates may be conservative. Given the estimates of exploitation from Thunder Bay are likely biased high, and that year-classes that recruited in 1998 and 2003 are both strong and well established (Figure 17B), we believe the current annual catch quota of 170,000 kg should promote the continued existence of the Thunder Bay stock into the foreseeable future.

Given the temporal trends in CPUE of large ciscoes measured in commercial gill nets set in Black Bay (Figure 17B), it is clear that our acoustic and midwater trawl survey of this bay was conducted too early. It follows that the acoustic estimate is likely conservative and more ciscoes ultimately spawned in Black Bay than what we measured. If we only include commercial landings from Black Bay through 19 November, percent harvest equals 11.67% by number (28,475 fish harvested / 244,000, where harvested fish equals 13,127 kg harvested / an average weight of 0.461 kg). If we "scale-up" the acoustic estimate based on CPUE at the time of our survey work (0.4 kg/m) being roughly 66% of the overall mean CPUE throughout the fall fishery (0.61 kg/m), we estimate percent exploitation at 26.4% (98,379 / [244,000/(1/0.66)]. Given the uncertainty in our abundance estimate, we can not comment on the sustainability of current quotas in Black Bay. Because the summer of 2005 was rather warm and October was atypically mild, it is possible the timing of the Black Bay spawning run may have been delayed. Before conducting future spawning surveys on Lake Superior stocks, we recommend developing annual plots similar to Figure 16B for several years to determine the most appropriate time window to sample a given stock. If that time window typically occurs in late November to early December, a vessel other than the R/V *Kiyi* will be needed to conduct the survey because Chequamegon Bay where the R/V *Kiyi* winters is subject to early ice cover. Alternatively, the newly-acquired GLSC vessel, the R/V *Stickleback,* could be outfitted with a small midwater trawl which could allow sampling later into the field season provided an alternate port was found to winter this smaller vessel some years (possibly Duluth, MN).

Comparison of the densities of age-1 ciscoes captured during our annual spring trawl survey (Figure 15A) to the density estimates of different cohorts at-large during the present midwater survey (Figure 15B) were in accord in that strong year-classes detected as age-1 fish were present as older fish in our samples, while weak year-classes were not. Similar patterns were found in gillnet surveys in Wisconsin waters of Lake Superior (Ebener and Stockwell *In Preparation*). This is strong evidence that year-class strength of ciscoes is established sometime in their first year of life. The bottom trawl age-1 index is very important to the management of ciscoes in both bays because it gives OMNR managers their first look at cohorts that we have demonstrated will recruit to the commercial fishery. Unfortunately, the indices in both bays suffer from poor precision owing to small sample sizes. For example, the average relative standard errors of age-1 ciscoes densities in Thunder and Black bays over the period of record (1989-2005) equal 71% and 77%, respectively. If managers simply require an understanding of the presence or absence of strong year-classes the current trawling effort should suffice. But if managers desire age-1 density estimates for the development of a stock-recruitment model, effort will need to be increased to improve the relative standard errors to ± 30% (Walters and Ludwig 1981).

One factor that could be important to early survival of ciscoes is their vulnerability to predation by rainbow smelt (Swenson 1978; Selgeby et al. 1978; Cox and Kitchell 2004). Selgeby et al. (1978) studied rainbow smelt predation on emerging cisco larvae in Black Bay and reported that 17% of 1,195 rainbow smelt stomachs examined contained larval ciscoes. Using estimates of rainbow smelt daily rations and their estimated densities in Black Bay (368/ha based on 14 day bottom trawls), Selgeby et al.

(1978) calculated that rainbow smelt consumed 3.3-11% of the ciscoes that hatched during 1974. Selgeby et al. (1978) concluded that predation by rainbow smelt on herring larvae was not the major factor controlling or suppressing herring stocks in Black Bay. In the present study, using acoustic estimates of fish < 250 mm and the proportions of these fish that were rainbow smelt caught by midwater trawling, we estimate rainbow smelt densities in Thunder Bay at 610/ha and Black Bay at 3,634/ha. It follows that rainbow smelt densities in Black Bay are at present an order of magnitude greater than the estimate reported by Selgeby et al. (1978). This large increase in rainbow smelt densities is counter-intuitive because the Selgeby et al. (1978) estimate was collected prior to lake trout recovery in Lake Superior (Bronte et al. 2003) and these predators are known to prefer rainbow smelt as prey in the lake (Ray 2004). To address contemporary impacts of rainbow smelt on ciscoes, the USGS-GLSC Lake Superior Biological Station and the Ontario Ministry of Natural Resources (Thunder Bay) plan to repeat our acoustic and trawling effort during May 2006 with emphasis placed on quantifying rainbow smelt diets and densities. Concurrent to this effort, larval cisco densities will be enumerated with a larval netting program. From this continued research we plan to conduct a predator demand versus prey supply analysis to quantify what proportion of emerging cisco are consumed by rainbow smelt. This effort will help us understand the relative importance of commercial harvest of eggs, mortality from eggs to larvae, and rainbow smelt predation on one year-class of cisco. This study should also allow us to explore the densities of piscivorous walleye *Sander vitrues*, the once dominant piscivore in Black Bay targeted for restoration (Anonymous 2001), needed to improve conditions to promote larval cisco survival (e.g., using models presented by Krueger and Hrabik 2005).

Despite the high probability that acoustic estimates of large cisco densities are conservative, the work conducted during November 2005 represents an important step in our understanding of the sustainability of commercial roe fisheries. The calculation of abundance estimates of different year-classes in Thunder Bay and an understanding of current exploitation levels from commercial fishing now affords us an opportunity to apply a simple population dynamics model to assess the sustainability of present catch quotas. The development of this modeling framework is ongoing and will be refined as our survey results are refined for submission into a peer-reviewed journal.

Acknowledgements

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Tables

Table 1. Biomass harvested, mean length, mean weight, and numbers of ciscoes harvested from three management zones in Thunder Bay and Black Bay during the 2005 fall fishing season. The number of fish measured (*N*) is identical to the number weighed for each zone.

Management zone	Biomass harvested (kg)	Mean length of harvested cisco (mm) ± SD, *N*	Mean weight of harvested cisco (kg) ± SD	Number harvested
1	56,894	373 ± 32, 410	0.469 ± 0.113	121,376
2	68,679	371 ± 23, 235	0.454 ± 0.794	151,301
3	11,252	372[a]	0.463[a]	24,284
Totals for Thunder Bay	136,824	372 ± 29, 645	0.463 ± 0.102	296,960
Totals for Black Bay	45,380	376 ± 25, 433	0.461 ± 0.103	98,379

[a] = weighted average using mean weight and sample sizes from zones 1 and 2.

Table 2. Numbers of males and females in the net run database summarized by 5-day intervals from 1 November to 4 December, 2005. The proportions of males and females by 5-day interval are shown parenthetically.

	Thunder Bay		Black Bay	
Dates	Males	Females	Males	Females
11/1-5	26 (0.26)	74 (0.74)	15 (0.42)	21 (0.58)
11/6-10	22 (0.24)	69 (0.76)	25 (0.42)	34 (0.58)
11/11-15	25 (0.16)	129 (0.84)	28 (0.43)	37 (0.57)
11/16-20	21 (0.13)	135 (0.87)	21 (0.33)	43 (0.67)
11/21-25	9 (0.09)	87 (0.91)	16 (0.32)	34 (0.68)
11/26-31	4 (0.09)	40 (0.91)	20 (0.20)	78 (0.80)
12/1-4	-	-	7 (0.18)	33 (0.82)
Totals	107 (0.17)	534 (0.83)	132 (0.32)	280 (0.68)

Figures

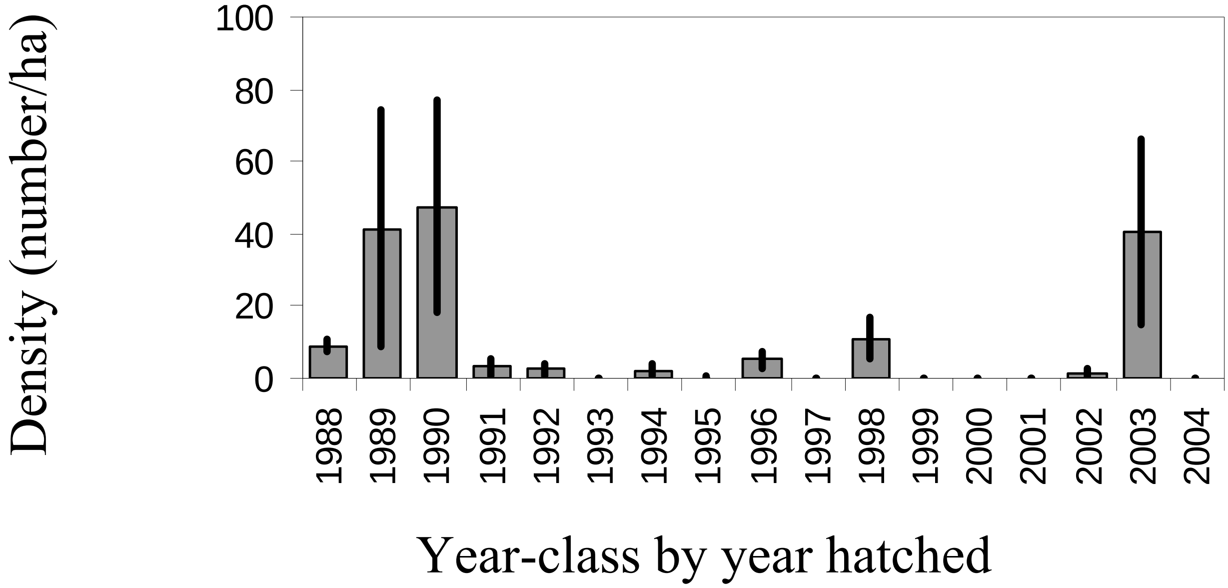


Figure 1. Mean density (number/ha) of age-1 ciscoes sampled by day bottom trawling each spring at four nearshore stations in Thunder Bay, 1989-2005. The x-axis reflects the year the cohort was hatched, not the year when density was estimated (year-class + 1). Error bars represent standard errors.

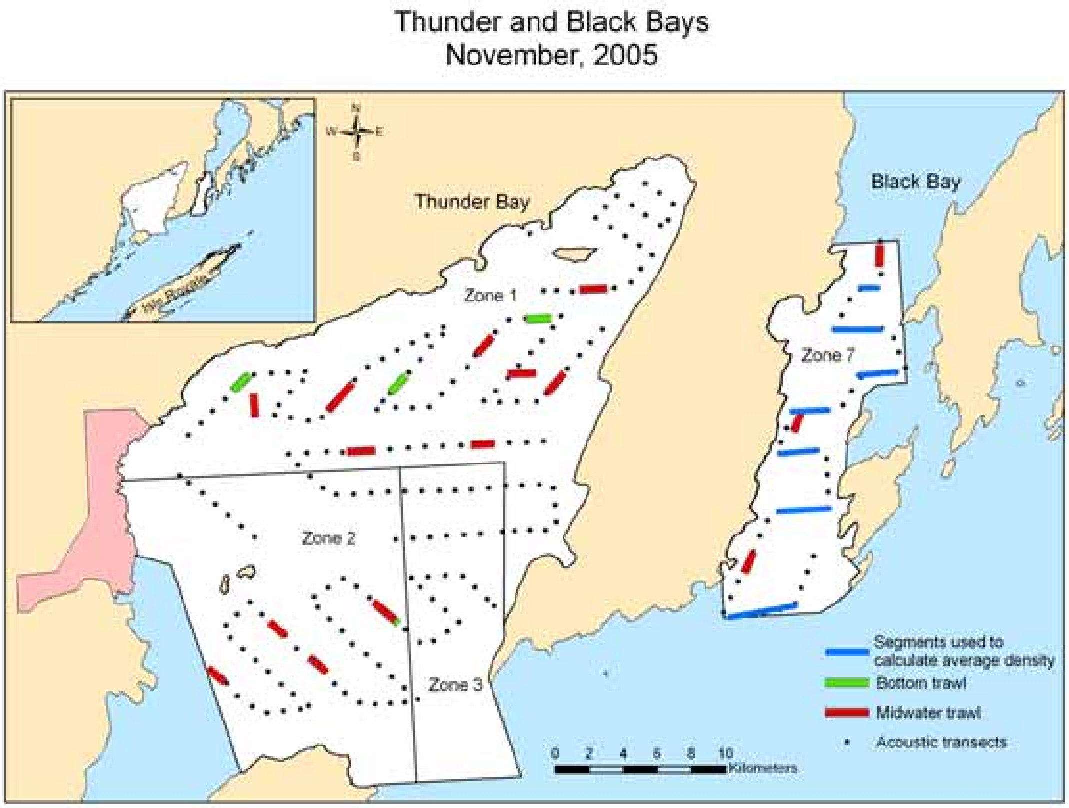


Figure 2. Maps of acoustic transects (dotted lines), midwater trawl stations (red lines) and bottom trawl stations (green lines) conducted between 13-19 November, 2005 in Thunder Bay and Black Bay, Ontario. The 7 segments of the Black Bay survey path (blue lines) were used to calculate average fish densities (see Methods for details).

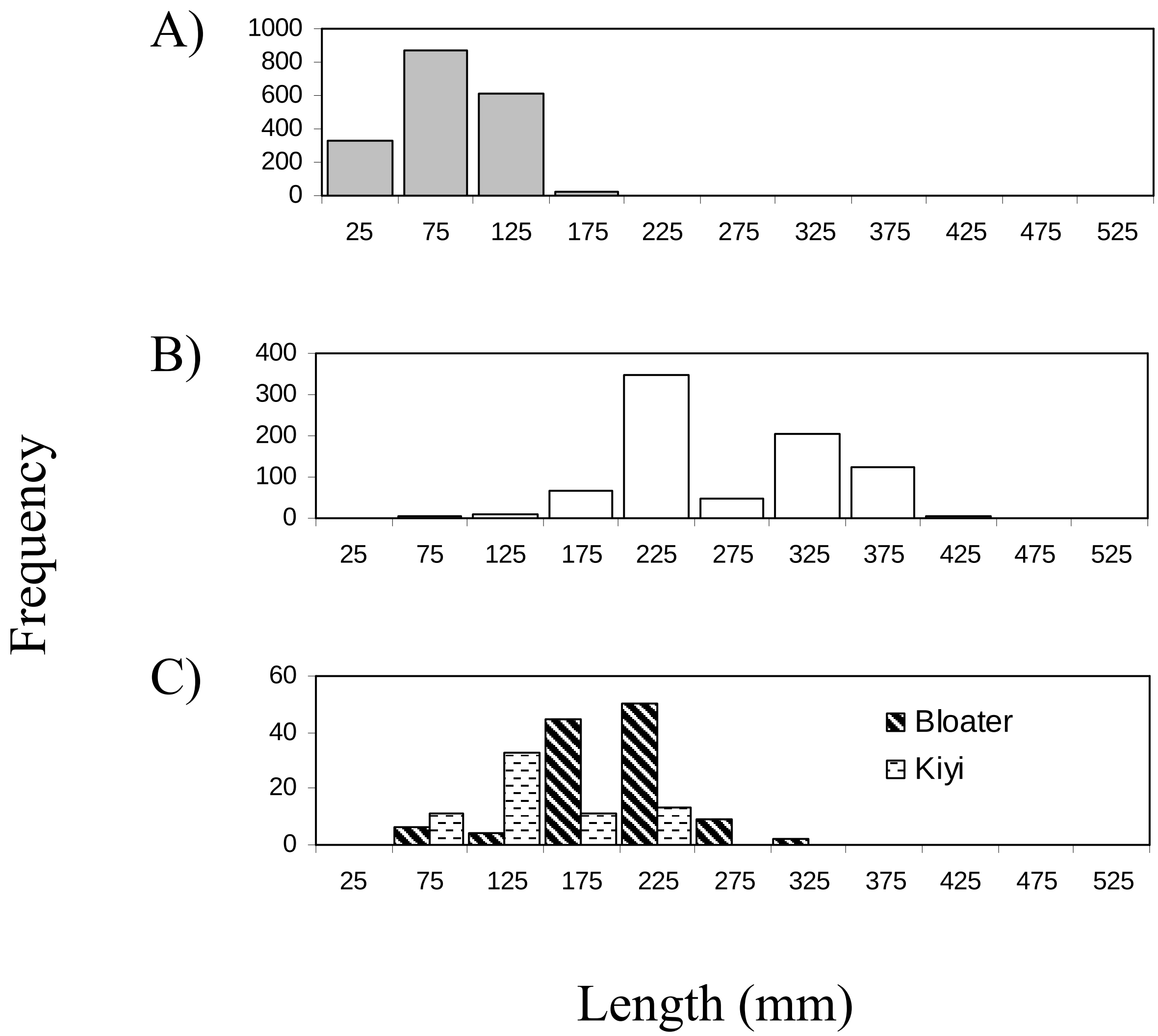


Figure 3. Length-frequency distributions of (A) rainbow smelt, (B) cisco and (C) bloater and kiyi caught in 12 midwater trawls conducted from Thunder Bay during 13-17, November 2005. The scales of the y-axis are different on each graph.

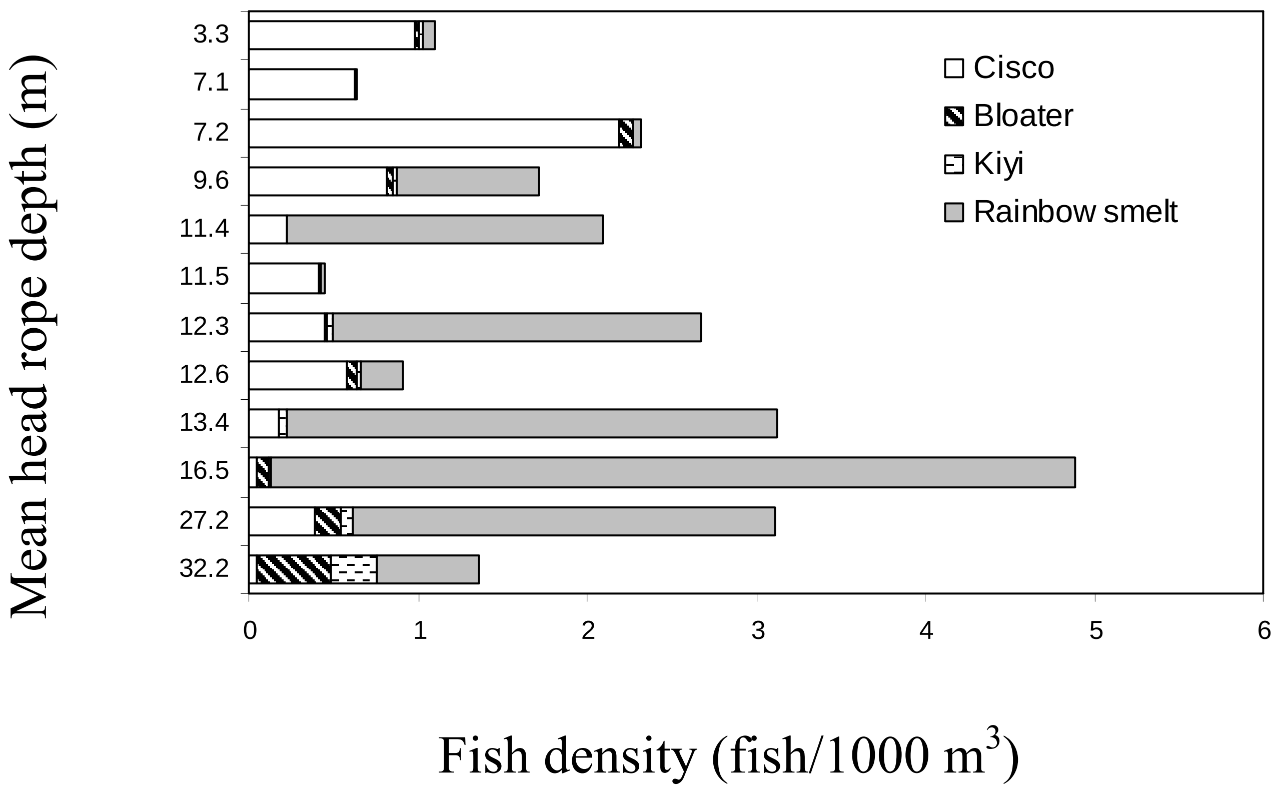


Figure 4. Fish density (fish/1000 m^3) by midwater trawl mean head rope depth (m) for 12 midwater trawl tows conducted in Thunder Bay, 13-17 November 2005. Fish density is expressed as number per 1,000 m^3 of water swept by the midwater trawl.

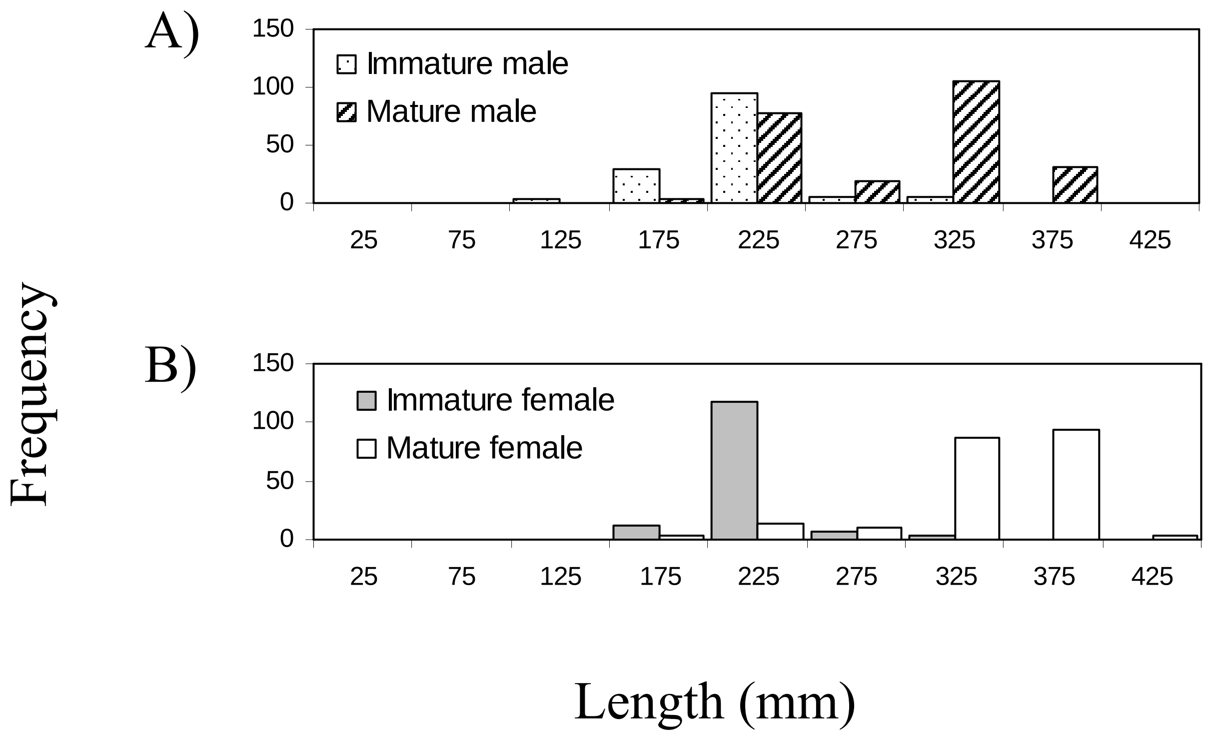


Figure 5. Maturity state of (A) male and (B) female cisco by 50 mm length bins captured from Thunder Bay, Ontario, 13-17 November, 2005.

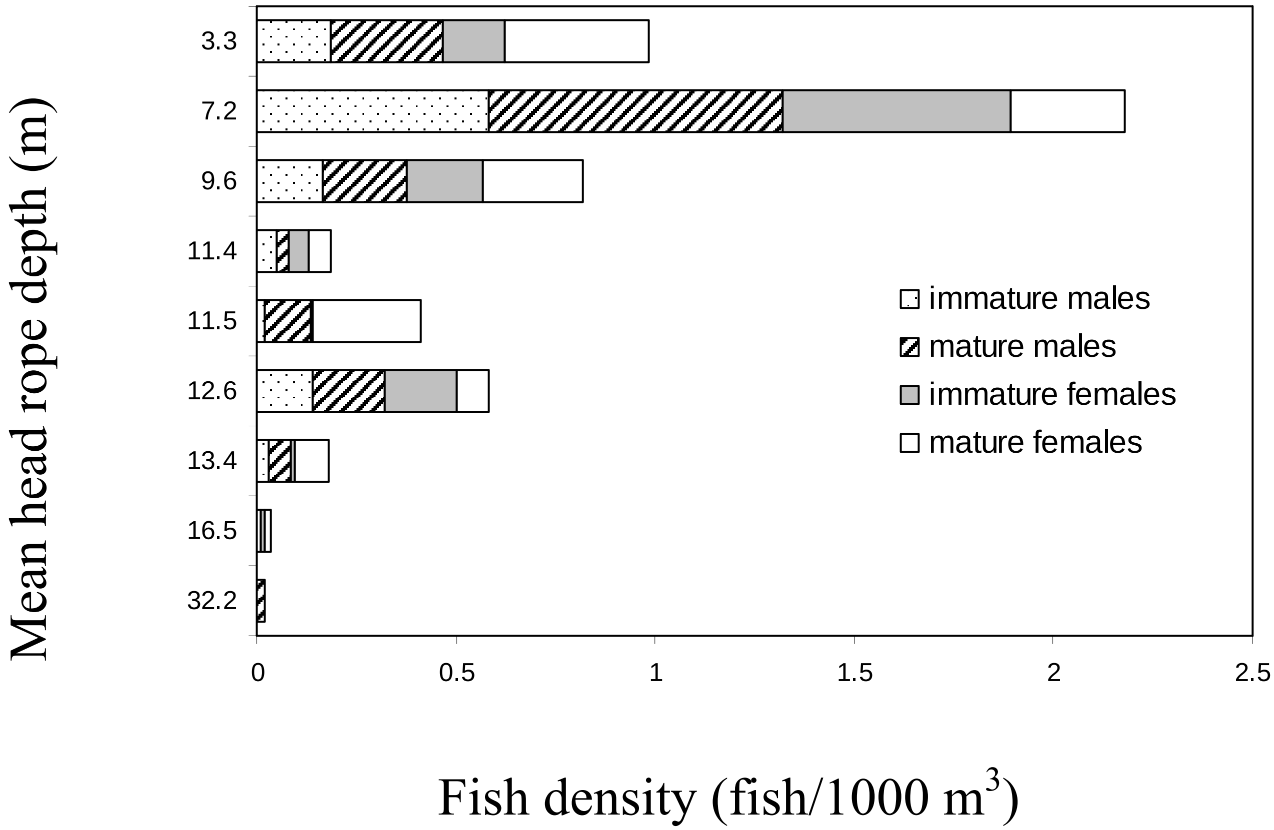


Figure 6. Density (fish/1000 m^3) of immature males, mature males, immature females and mature females in midwater trawls by midwater trawl mean head rope depth (m). The sex and maturity of cisco were only obtained for all fish in 9 of 12 midwater trawl tows conducted.

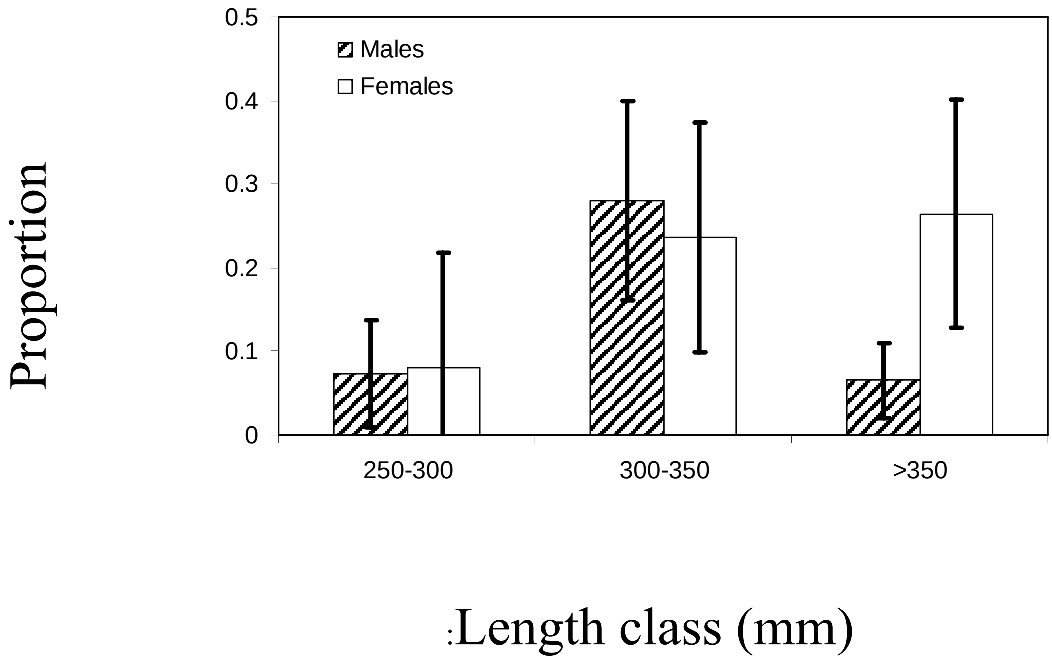


Figure 7. Mean proportion of males and females in three length classes based on 12 midwater trawl tows conducted in Thunder Bay, 13-17 November, 2005. Each trawl tow was treated as a sample unit when calculating mean proportions by sex-length class. Error bars represent standard deviations.

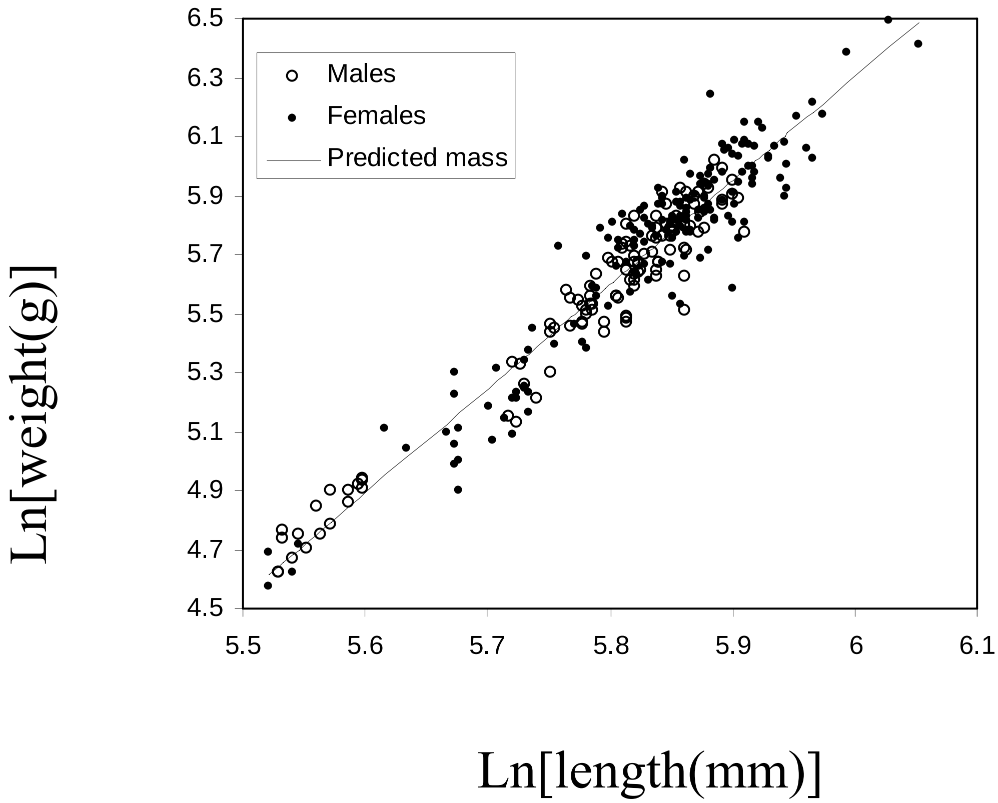


Figure 8. Length-weight relationship for Thunder Bay cisco greater than 250 mm from fish caught by midwater trawling. The best fit line equaled: ln [weight(g)] = 3.53 * ln [length(mm)] – 14.86, N = 288, R^2 = 0.92, range = 250 – 425 mm.

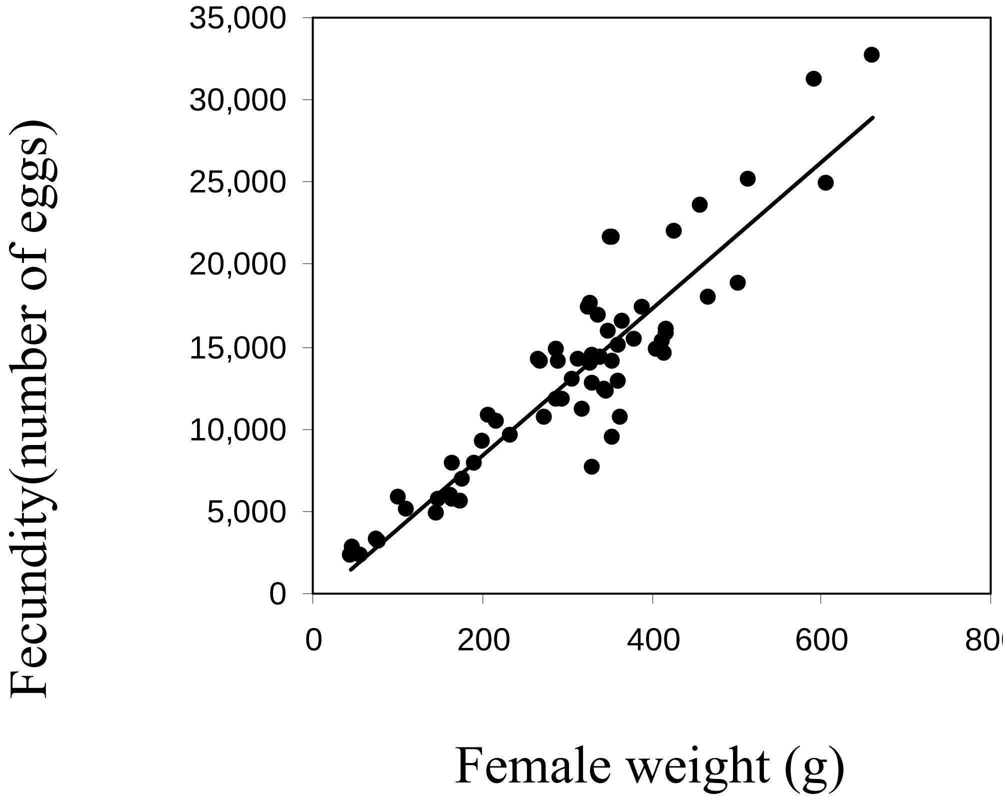


Figure 9. Fecundity (number of eggs) versus female weight (g). The best fit line equaled: fecundity (number of eggs) = 44.48 * female weight (g)) – 440.35, N = 64, R^2 = 0.84, range = 44 – 660 g.

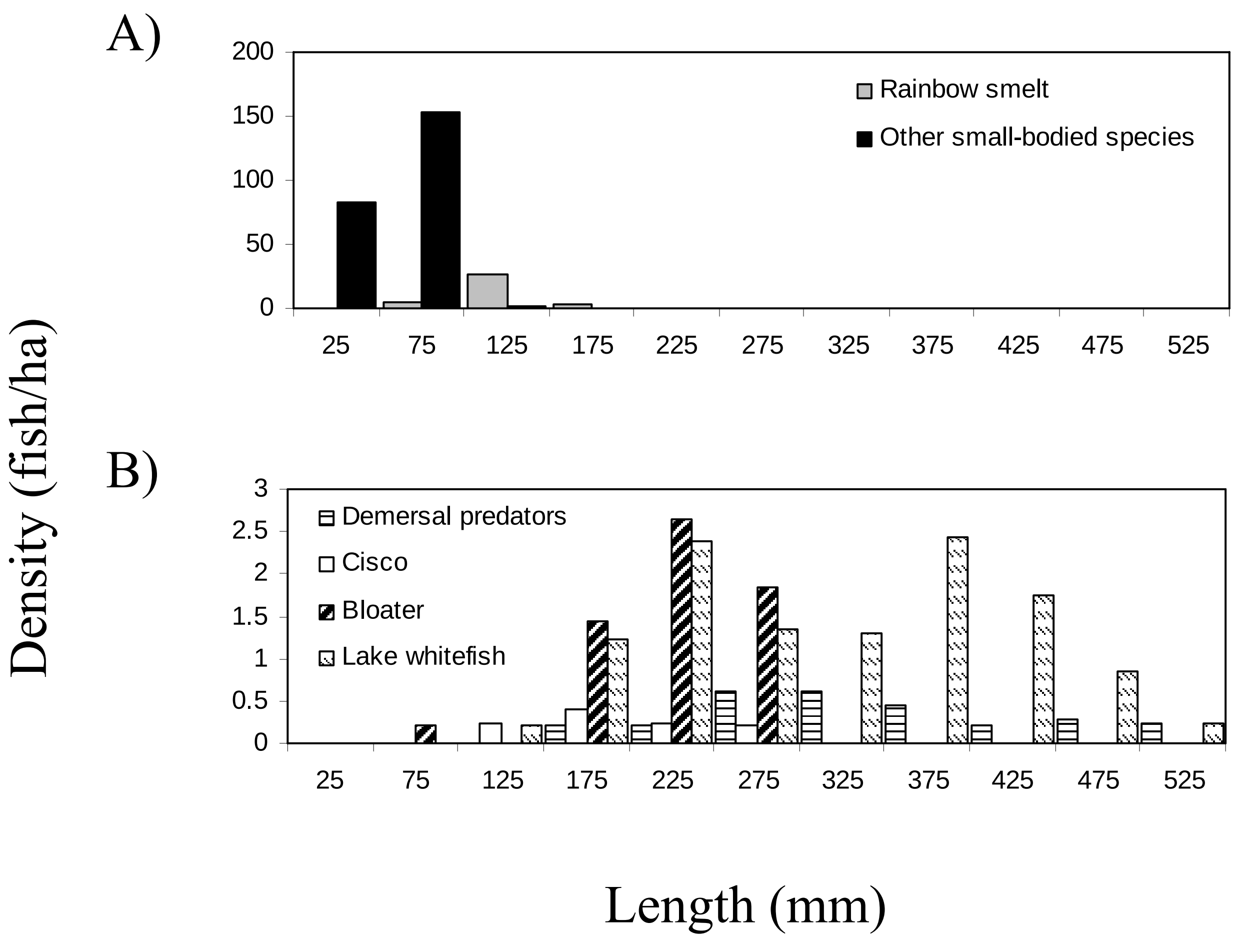


Figure 10. Density of (A) rainbow smelt and other small-bodied species, and (B) demersal predators (i.e., lake trout, siscowet and burbot), cisco, bloater and lake whitefish caught in four night bottom trawls conducted in Thunder Bay, 13-17 November. Other small-bodied species include: alewife *Alosa pseudoharengus*, deepwater sculpin, Eurasian ruffe *Gymnocephalus cernuus*, kiyi, ninespine stickleback, round whitefish *Prosopium cylindraceum*, slimy sculpin, spoonhead sculpin and trout-perch *Percopsis omiscomaycus*. The scales on the y-axis are different for each graph.

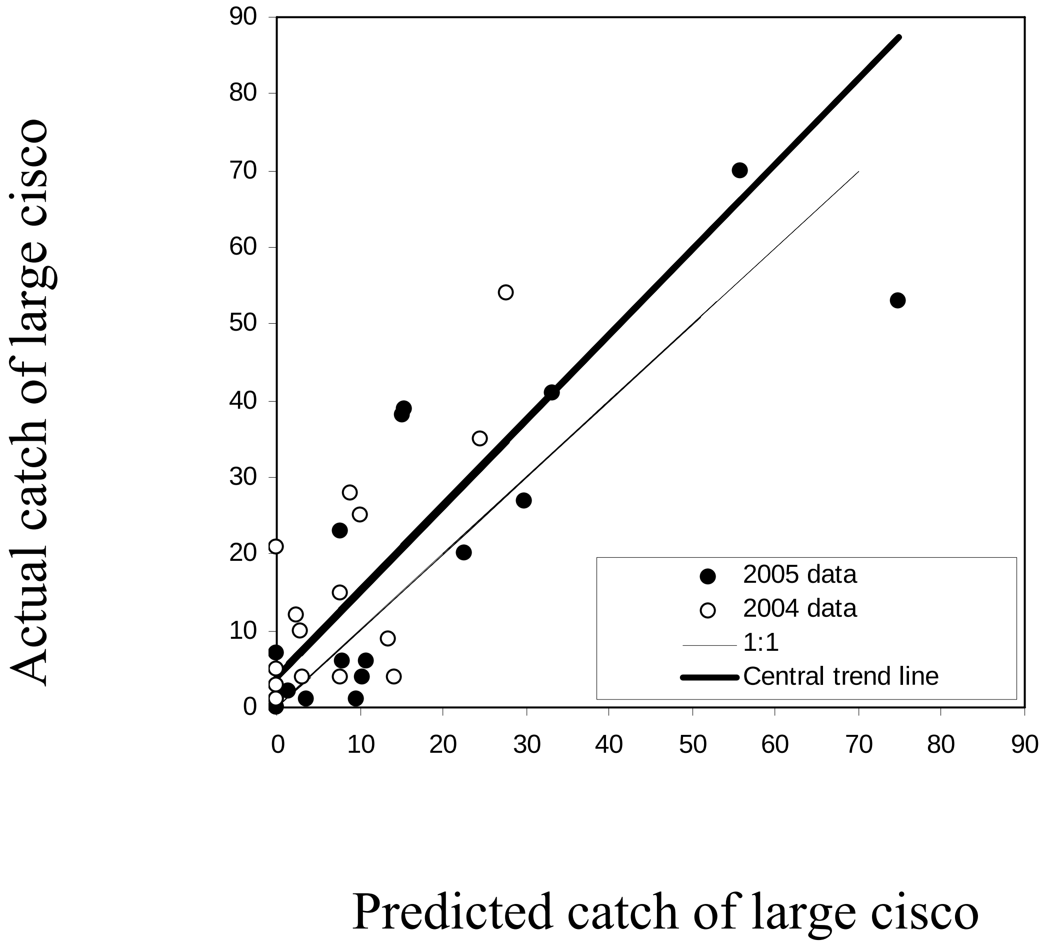


Figure 11. Predicted catches of large (>250 mm) cisco in midwater trawls versus actual catches. The central trend line equaled: actual catch of large cisco = 4.02 + 1.11 * predicted catch of large cisco.

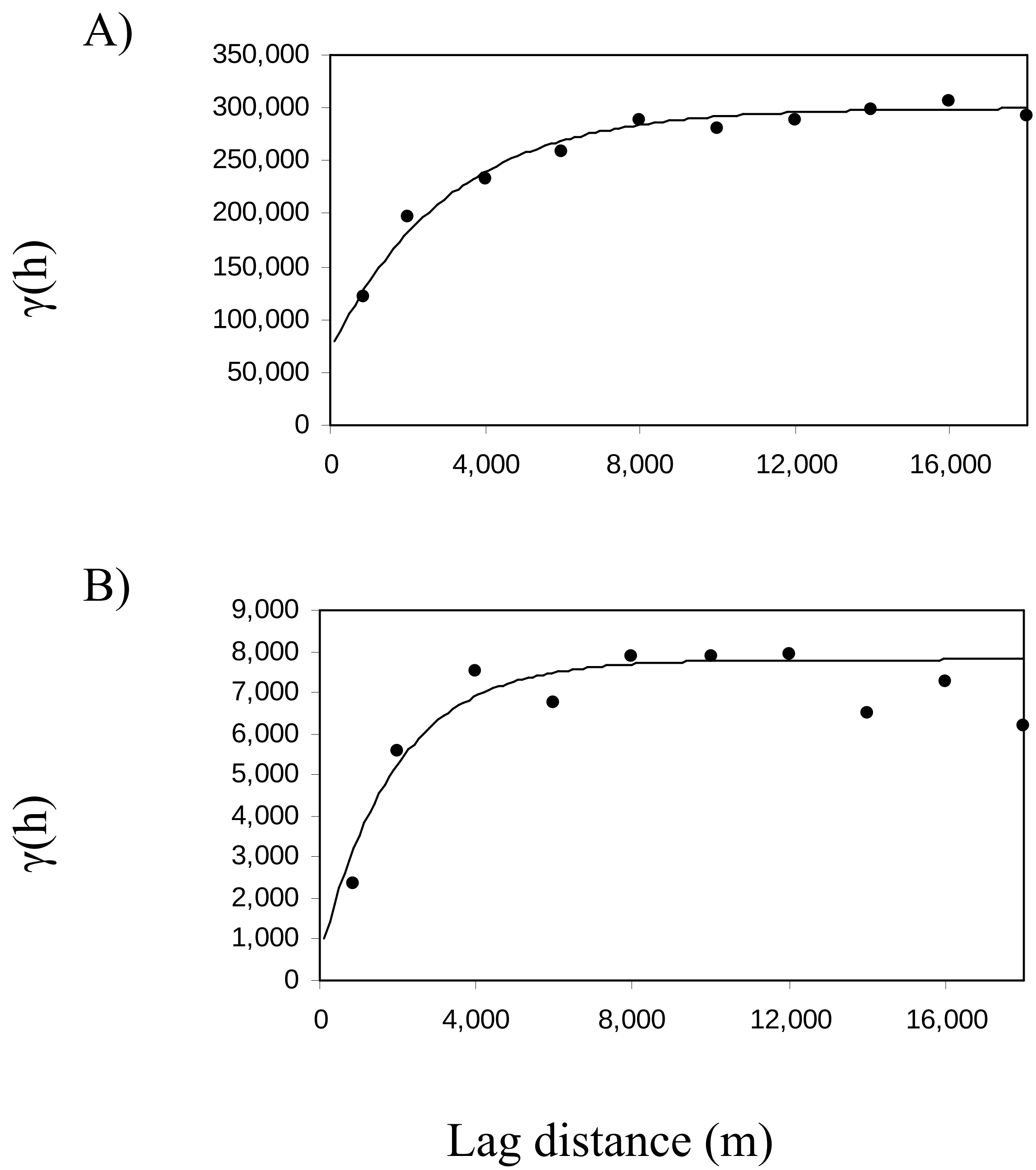
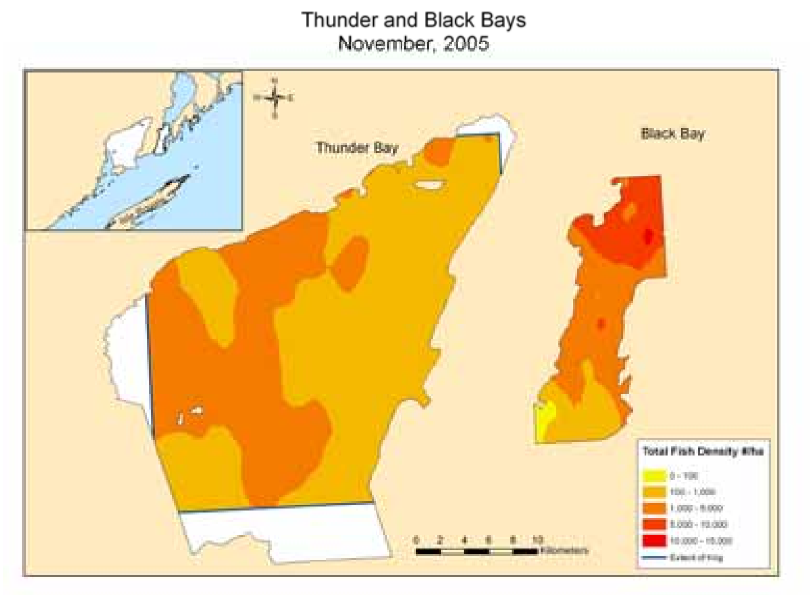


Figure 12. Empirical and theoretical variogram models for (A) total fish densities and (B) large cisco densities. The total fish density isotropic model was γ(h) = nugget (80,000) + exponential (sill = 220,000, range = 9,000 m). The large cisco density isotropic model was γ(h) = nugget (800) + exponential (sill = 6,900, range = 5,700 m). Lag distance was set at 2,000 m.

A)



B)

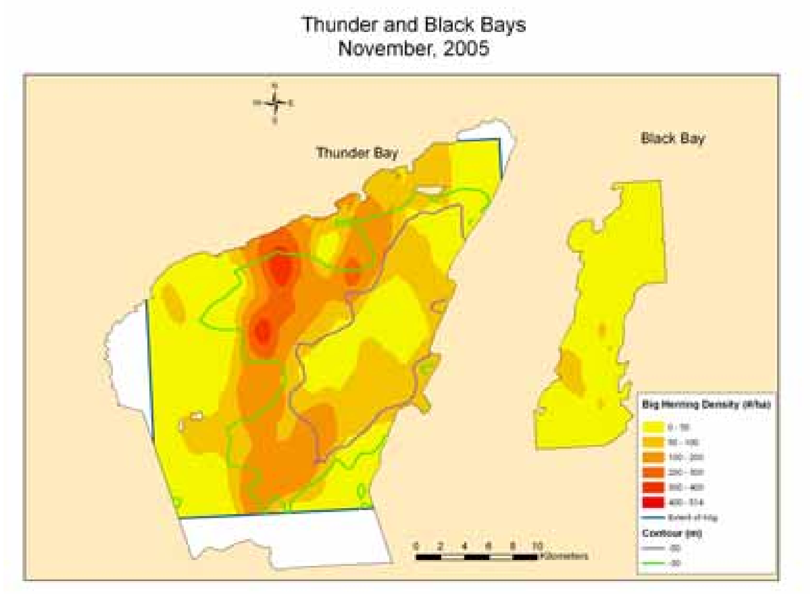


Figure 13. Maps of (A) total fish densities and (B) large (>250 mm) cisco densities in Thunder Bay and Black Bay, Ontario, 13-19 November 2005. The interpolated surfaces for Thunder Bay were created using ordinary kriging, while the surfaces for Black Bay were created using the inverse distance squared weighted interpolation method (see Methods for details). The 30- and 50-m bathymetric contours are shown for Thunder Bay.

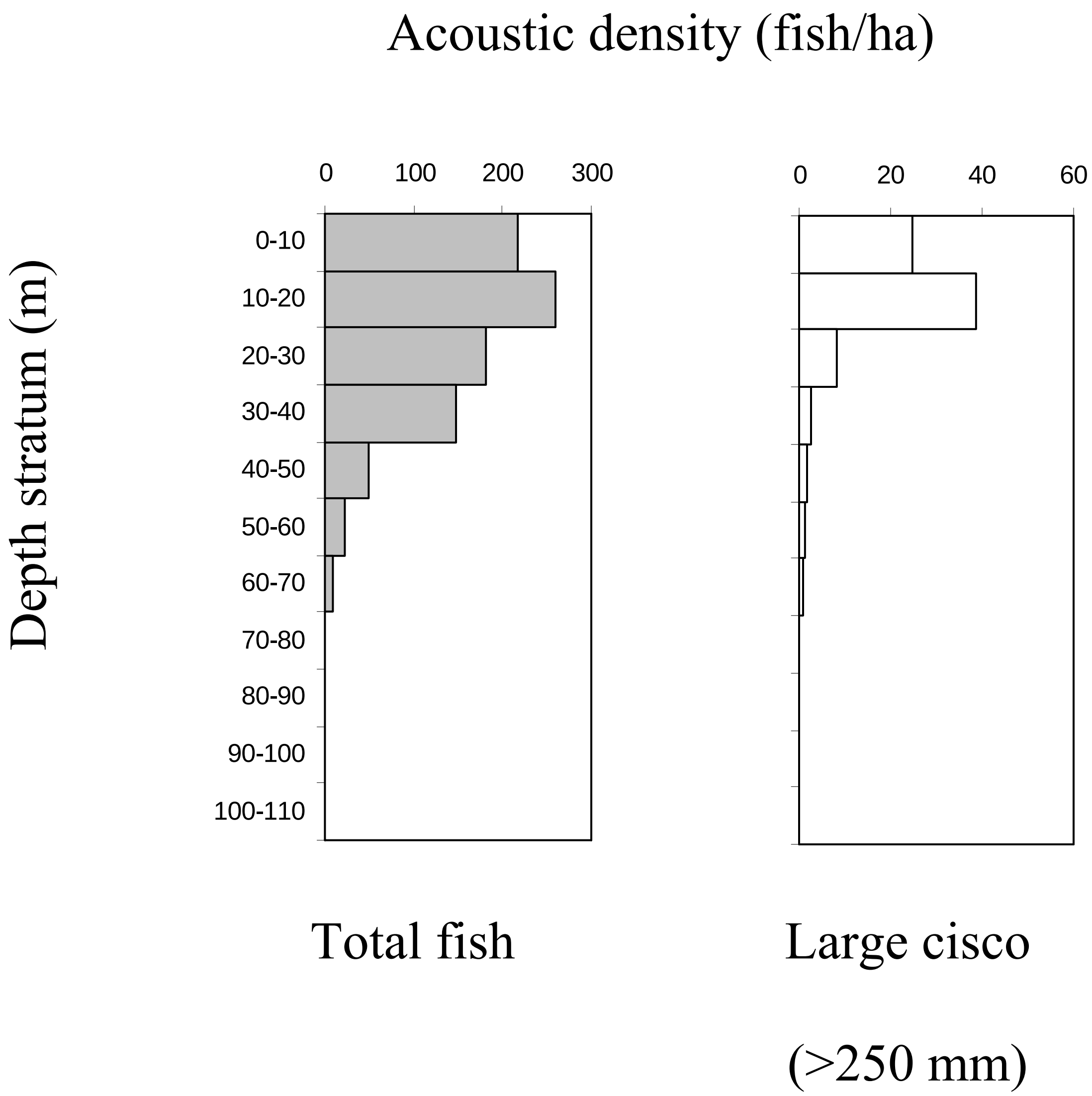


Figure 14. Vertical distribution of total fish densities and densities of large cisco by 10-m-high vertical strata.

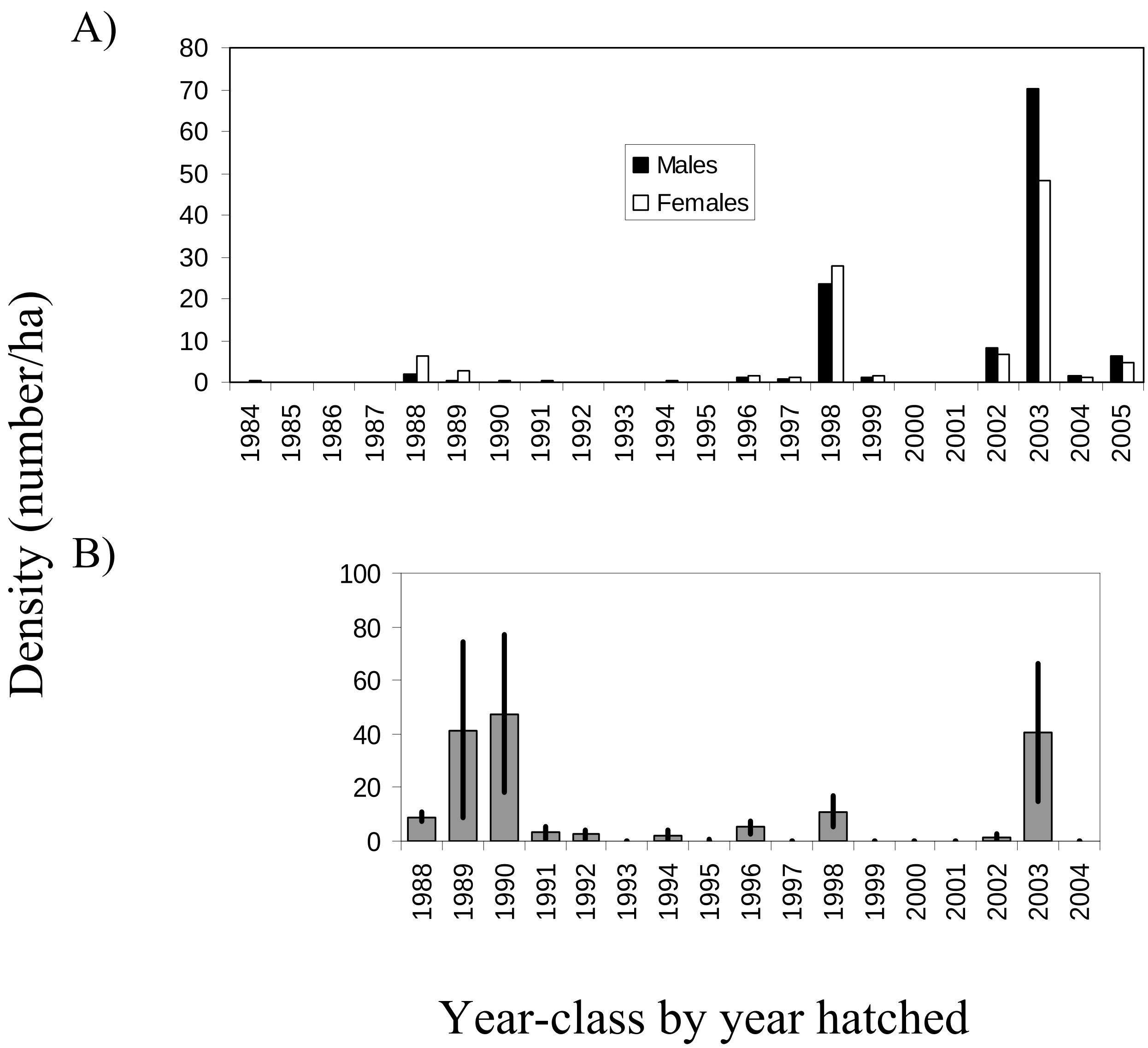


Figure 15. (A) Density estimates (number/ha) of male and female ciscoes by year-class measured during the 13-17 November 2005 acoustic and midwater trawl survey of Thunder Bay, Ontario, and (B) mean density (number/ha) of age-1 ciscoes sampled by day bottom trawling each spring at four nearshore stations in Thunder Bay, 1989-2005, plotted against year hatched (i.e., year sampled as age-1 fish – 1).

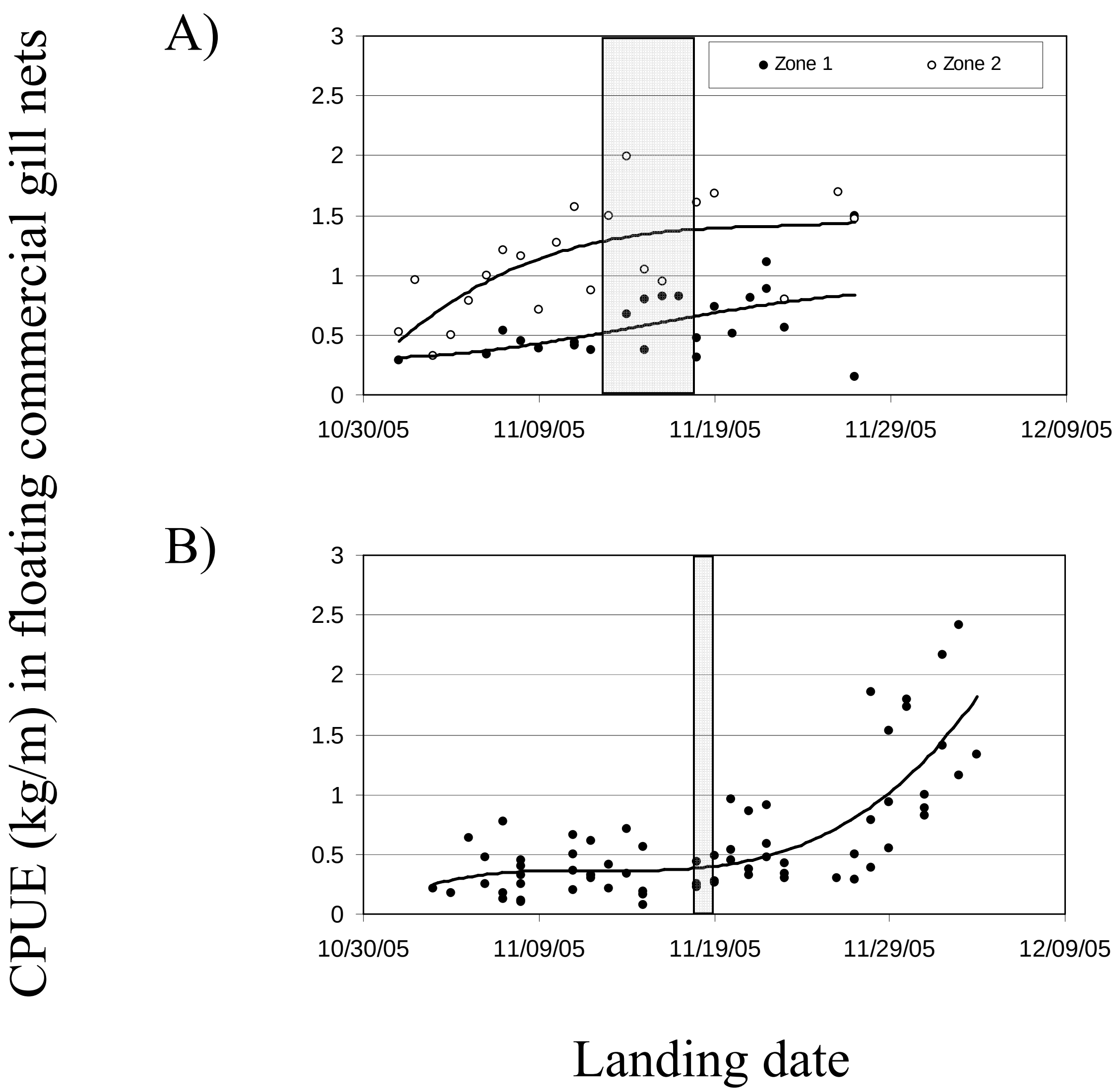


Figure 16. Plots of CPUE (kg/m) in floating commercial nets versus landing date for (A) two Thunder Bay management zones and (B) Black Bay during the 2005 fall fishing season. The timeframes of our acoustic surveys are shown in the shaded rectangles.

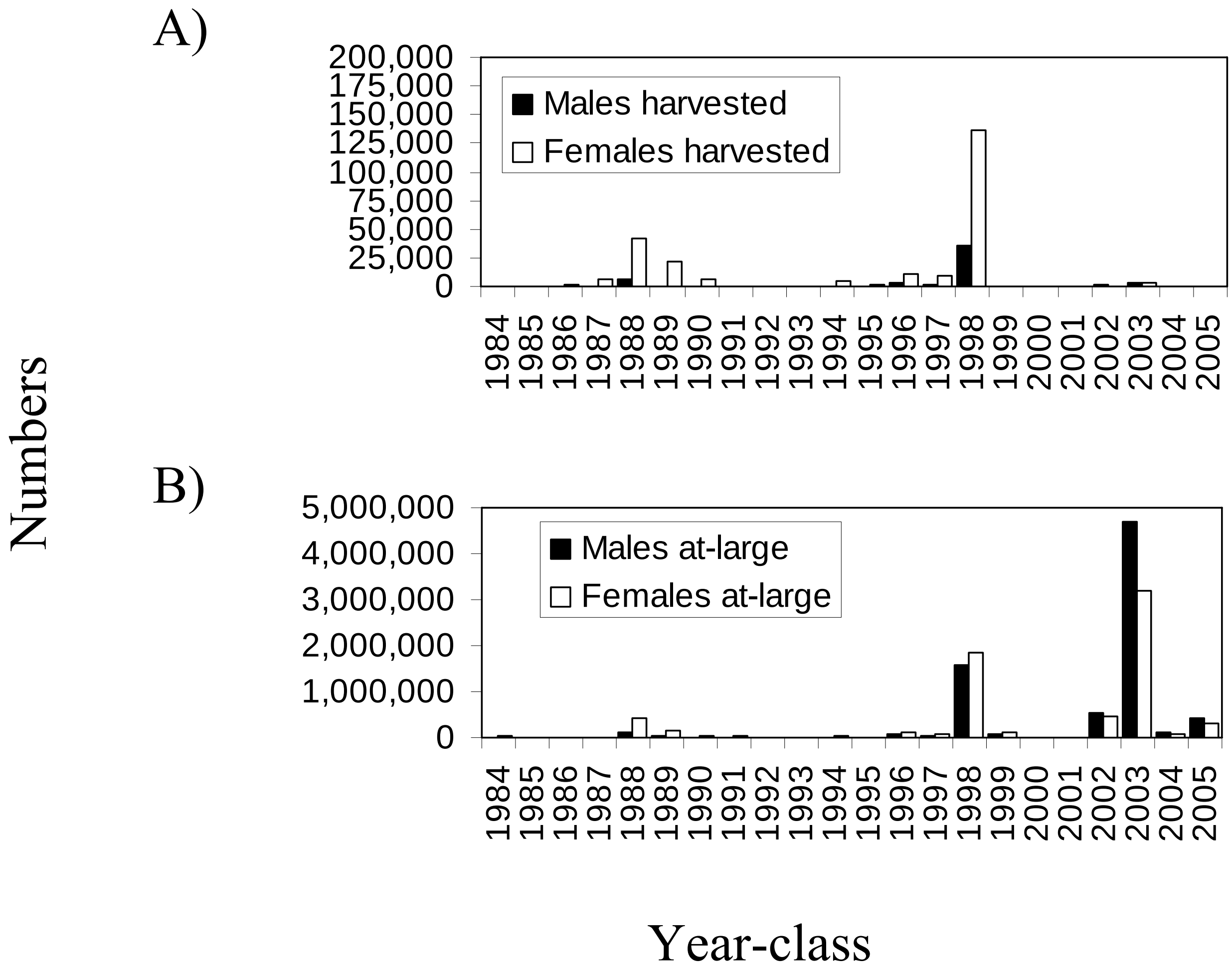


Figure 17. (A) Comparison of the estimated numbers of males and females ciscoes of different ages harvested from Thunder Bay during the 2005 fall roe fishery, and (B) estimated numbers at-large in Thunder Bay during our mid-November 2005 acoustic and trawl survey. Note the y-axes on the two charts are different.

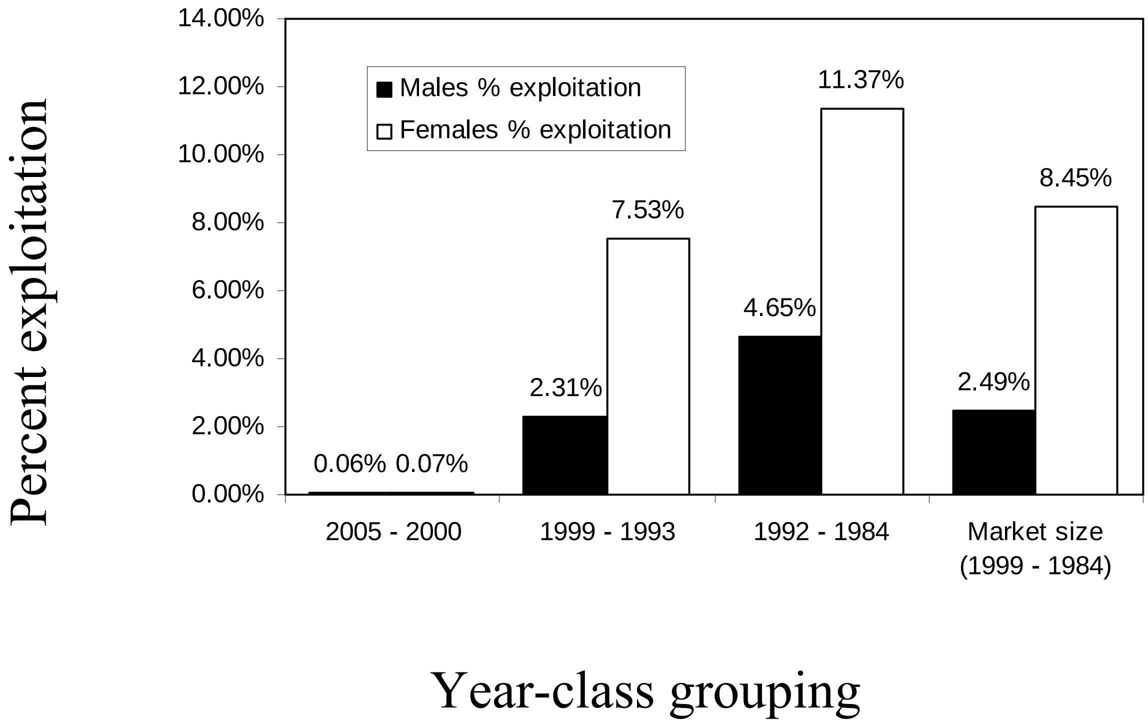


Figure 18. Estimates of percent exploitation of Thunder Bay ciscoes from the 2005 fall fishery. The percentages were calculated after first pooling data into three year-class grouping (2005-2000, 1999-1993 and 1992-1984) based on natural breaks occurring in age distributions (see Figures 17A and 17B). Market size fish were defined as year-classes that hatched between 1999 and 1984.

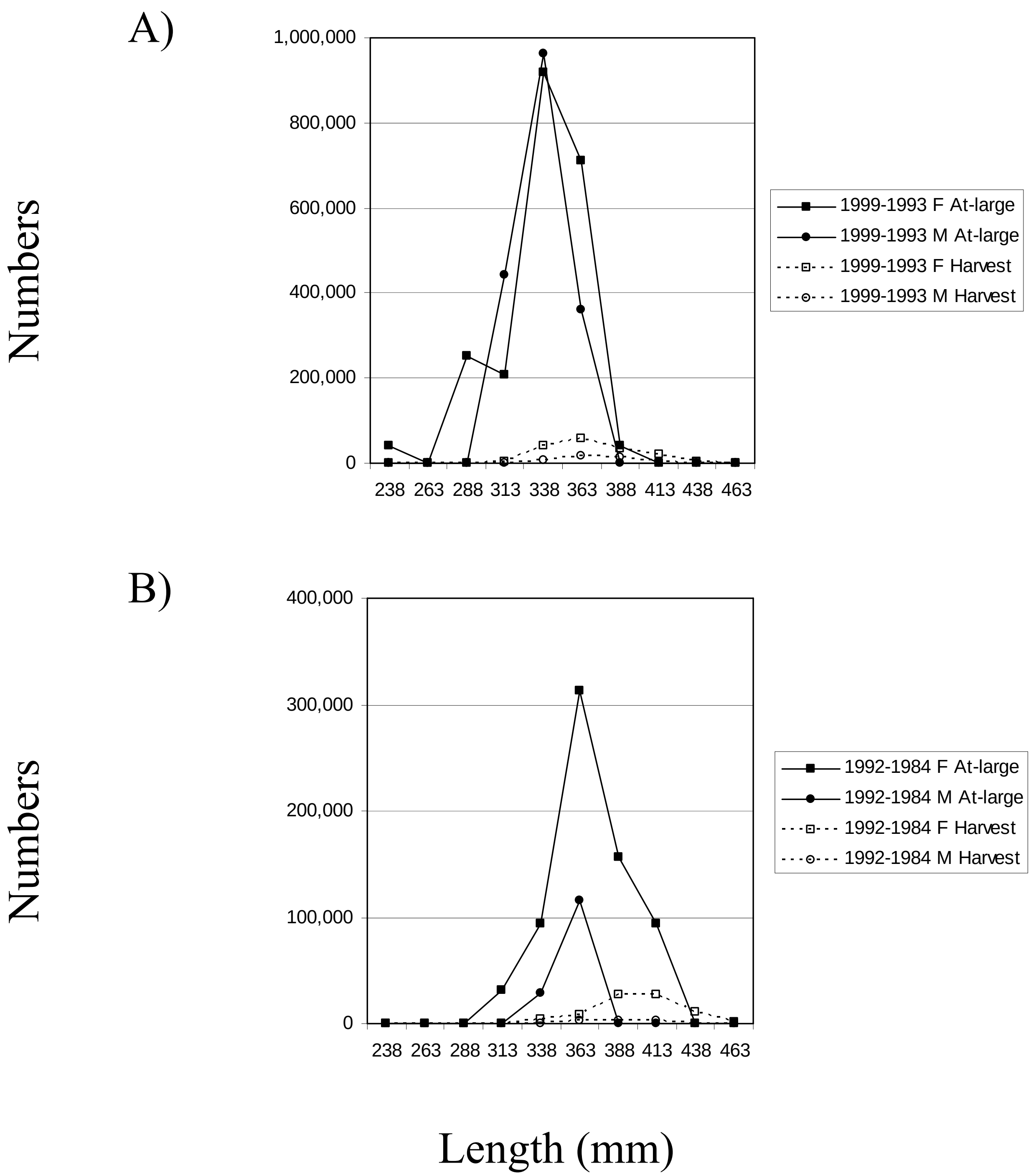


Figure 19. Comparison of the abundance of males and females at large and numbers harvested from Thunder Bay by 25 mm length bins for two different age groupings: (A) 1999-1993 year classes, and (B) 1992-1984 year classes. Note the y-axes on the two charts differ.

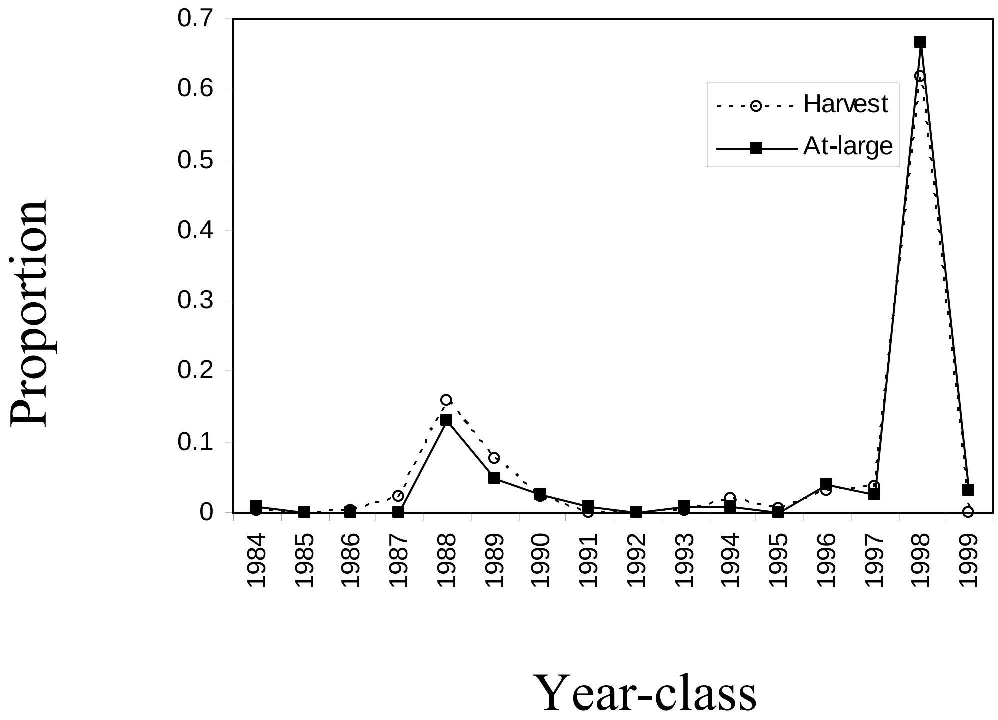
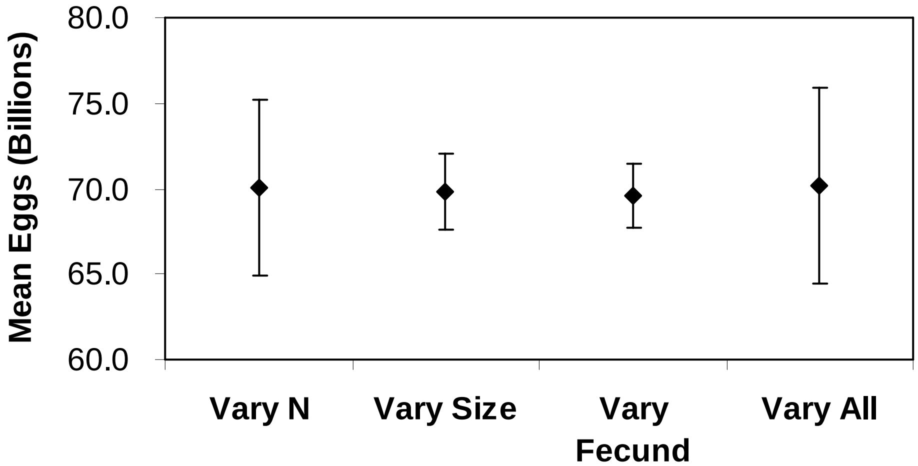


Figure 20. Comparison of the proportions of ages of ciscoes harvested from the net run database versus ages at-large from midwater trawl catches for Thunder Bay. Only fish older than the 1999 year-class were used to calculate proportions.

A)



B)

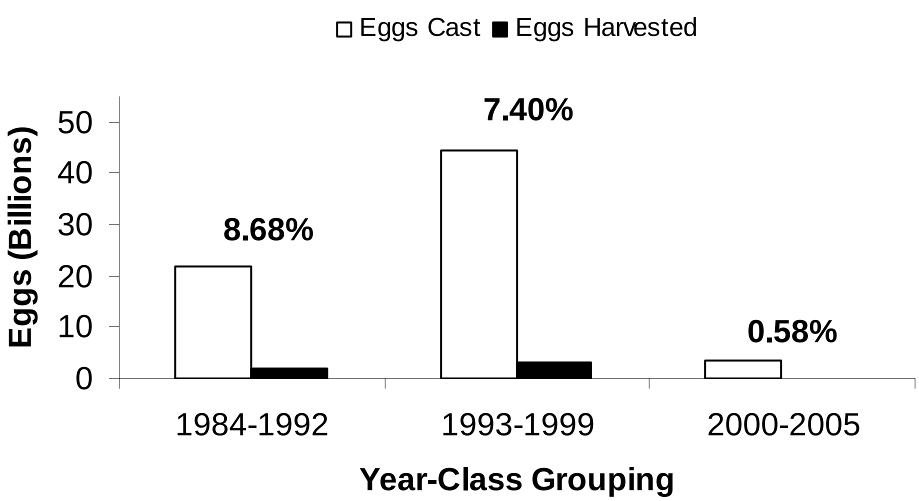


Figure 21. Panel (A) shows the mean ± SD number of eggs cast by ciscoes in Thunder Bay from 1,000 simulations varying female density (N), size structure, and fecundity one at a time as well as all three at once (i.e., Vary All). Panel (B) shows a comparison of the numbers of eggs eventually cast by females versus the numbers of eggs harvested for three age groupings (1984-1992, 1993-1999, and 2000-2005). Percent harvest is presented above each year-class grouping.

Appendix A. Length-age distribution for male and female ciscoes caught by midwater trawling by 50 mm length bin from Thunder Bay, 13-17 November, 2005.

									Males (Year-class)													
Length bin (mm)	05	04	03	02	01	00	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84
<250	4	1	20	1																		
250-299			10																			
300-349							2	31	1	1								1				
>350								8		1							1	3				
Sub-total	4	1	30	1	0	0	2	39	1	2	0	0	0	0	0	0	1	4	0	0	0	0
									Females (Year-class)													
< 250			20	4				1														
250-299			5	2			1	4														
300-349				1			1	21	1	1			1			2		1				
>350								17	1	2		1			1	1	5	11				1
Sub-total	0	0	25	7	0	0	2	43	2	3	0	1	1	0	1	3	5	12	0	0	0	1
Total	4	1	55	8	0	0	4	82	3	5	0	1	1	0	1	3	6	16	0	0	0	1

Appendix B. Length-age distribution of males and females in the net run database from Thunder Bay (management zone 1) during the 2005 fall fishing season.

					Males (Year-class)									
Length (mm)	04	03	02	98	97	96	95	94	93	90	89	88	87	84
170-179		2												
180-189		2												
190-199		1												
230-239				1										
250-259				1										
270-279				1										
280-289				2										
290-299				1										
300-309			1	4	2									
310-319				6										
320-329				9								1		
330-339				11	1							1		
340-349				5						1				
350-359				2		1								
360-369				2								1		
370-379												2		
Sub-total	0	5	1	45	3	1	0	0	0	1	0	5	0	0
					Females (Year-class)									
170-179		2												
190-199		1												
200-209		1												
270-279				1										
280-289				4										
290-299				8								2		
300-309				29								2		
310-319				50								8		
320-329				41				8		8	8			
330-339				41	5								5	
340-349				13	4						13	17	4	
350-359				18							5	8		
360-369				6								10		
370-379				4					1	1	4	2		
380-389				1								3		
390-399										1	1	2		
400-409								1			1			1
Sub-total	0	4	0	216	9	0	0	9	1	10	32	54	9	1
Total	0	9	1	261	12	1	0	9	1	11	32	59	9	1

Appendix C. Length-age distribution of males and females in the net run database from Thunder Bay (management zone 2) during the 2005 fall fishing season.

					Males (Year-class)									
Length (mm)	04	03	02	98	97	96	95	94	93	90	89	88	87	86
170-179														
180-189		1												
190-199														
230-239														
250-259														
270-279														
280-289														
290-299				2										
300-309				5										
310-319			1	9		3								
320-329				4								4		
330-339				5	1									
340-349				3								2		
350-359				2										
360-369				1		1						1		
Sub-total	0	1	1	31	1	4	0	0	0	0	0	7	0	0
					Females (Year-class)									
190-199		1												
260-269				2										
280-289				1										
290-299	1	1		8	1									
300-309				6	4	2					2	2		
310-319				22	3	3	3	3			5	3		
320-329				23		8								
330-339				19							4	15	4	
340-349				7		2				2	2	7		2
350-359				5	1						3	5		
360-369				2						2	1	1	1	
370-379					1							1		
390-399												1		
Sub-total	0	2	0	95	10	15	3	3	0	4	17	35	5	2
Total	0	3	1	126	11	19	3	3	0	4	17	42	5	2

Appendix D. Length-age distribution of males and females in the net run database from Black Bay (management zone 7) during the 2005 fall fishing season.

							Males (Year-class)												
Length (mm)	04	03	02	01	99	98	97	96	95	94	93	91	90	89	88	87	86	85	84
220-229		2																	
280-289			1			1													
290-299						4									1				
300-309			3			5													
310-319			3			32													
320-329					4	18				7				4	4				
330-339						11							7	4	4				
340-349			1	1	1	7				3				1					
350-359						4	1						1		1				
360-369			1			2		1		1				2	1				
370-379						4									2				
390-399						1	1												
Sub-total	0	2	9	1	5	89	2	1	0	11	0	0	8	11	13	0	0	0	0
									Females (Year-class)										
200-209			1																
270-279			1																
280-289			2			4													
290-299				2		4							2						
300-309			3			24									3				
310-319			4			8		4						12	8				4
320-329						26							13	6	6				
330-339			15			10		5					5	5	10			5	
340-349						21				7				4	4		4		
350-359						6				6					3				
360-369						4				2			4		4				2
370-379						6							1	1		1			
380-389							1							2					
390-399													1	1	1				
410-419												1		1					
420-429													1						
430-439																			1
Sub-total	0	0	26	2	0	113	1	9	0	15	0	1	27	32	39	1	4	5	7
Total	0	2	35	3	0	202	3	10	0	26	0	1	35	43	52	1	4	5	7