2008 SPAWNING CISCO INVESTIGATIONS IN THE CANADIAN WATERS OF LAKE SUPERIOR

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Abstract

The Great Lakes Science Center of the United States Geological Survey (USGS) is working cooperatively with the Ontario Ministry of Natural Resources (OMNR) on a three-year study to develop standard procedures for acoustic and midwater trawl (AC-MT) assessments of spawning cisco *Coregonus artedi* that the OMNR can carry forward as a management activity. In year two (2008), we conducted an AC-MT survey of the northern shore from Nipigon Bay to Thunder Bay. Spawning-cisco (> 250 mm total length) densities were lowest near Nipigon Bay (<10/ha), moderate in and around Black Bay (15-30/ha), and highest in Thunder Bay (118/ha). Rainbow smelt *Osmerus mordax* densities were highest in Nipigon (2,179/ha) and Black (3,219/ha) bays, and lowest in Thunder Bay (961/ha). We combined our AC-MT survey results with commercial catch records to estimate exploitation fractions of female cisco in Thunder Bay during the 2008 fishery at 4% for ages 1-5, 8.7% for ages 6-12, and 4.4% for ages ≥ 13. Lake Superior fishery managers recently recommended that annual exploitation of adult female lake cisco be kept below 10-15%. Recruitment of cisco since 2003 has been low and there is a strong probability the Thunder Bay stock will decline into the future. Using a simple population dynamics approach we estimated that if the current total allowable catch (TAC) quota is held constant, exploitation fractions could exceed 10% by 2010 and 15% by 2011. Our 2008 collections suggested the survey of Black Bay was likely conducted before all spawners had returned there to spawn. Our data also suggested that cisco collected in Black Bay and east of this site in mid-November may be from the same stock. During November 2009 we will attempt to get better definition of the area occupied by cisco around Black Bay and also determine when surveys should be conducted at this location.

Introduction

The Canadian waters of Lake Superior support commercial fisheries for cisco *Coregonus artedi* (formerly lake herring) with annual yields from 1973-2004 averaging 0.74 million kg (Stockwell et al. 2009). Harvest mainly occurs in November when fishers target females for roe. Yield from Canadian waters has been high compared to other jurisdictions (1973-2004 averages: Minnesota = 0.11 million kg; Wisconsin = 0.08 million kg; Michigan = 0.04 million kg; Stockwell et al. 2009). To promote sustainable fisheries, the Lake Superior Technical Committee recently recommended the annual harvest of mature females should be held below 10-15% at the stock level (Stockwell et al. 2009). This safe-harvest recommendation was based on that developed for other coldwater populations in Lake Superior (wild lake trout *Salvelinus namycush* and lake whitefish *Coregonus clupeaformis*) that have been subjected to exploitation rates of 10-30% annually without negative affects (Woldt et al. 2006; Stockwell et al. 2009).

November acoustic and midwater trawl (AC-MT) surveys were first conducted in Thunder and Black Bays during 2005 to estimate spawning cisco abundance, exploitation fractions (i.e., the proportion of the total population harvested), and to enumerate rainbow smelt (*Osmerus mordax*) - an exotic species that negatively impacts cisco (Cox and Kitchell 2004; Gorman 2007; Stockwell et al. 2009; Myers et al. in press). During 2005, the Thunder Bay cisco spawning stock was estimated at 5.2 million, with exploitation fractions of market-size (≥ age-6) males and females estimated at 2.5% and 8.5%, respectively (Yule et al. 2008a). Based on temporal patterns in commercial gill net catch-per-effort (CPE) we concluded that an 18-19 November 2005 survey of Black Bay was likely conducted before a significant portion of adult cisco had returned to spawn, thus, the AC-MT stock estimate of 244,000 was likely conservative (Yule et al. 2006a).

In 2007, three additional years of funding were received from the Canada-Ontario Agreement (COA) to develop a standard operating procedure for cisco spawner assessments that the Ontario Ministry of Natural Resources – Upper Great Lakes Management Unit (UGLMU) could use as an annual assessment program. In November of 2007, two surveys of Thunder Bay (14-18 and 24-27 November) were conducted to assess repeatability of survey results. Yule et al. (2008b) reported total large (≥ 250 mm total length, TL) cisco densities did not vary significantly between these survey dates, but females did make up a larger proportion of MT catches during the late-November (68%) compared to the mid-November survey (52%). Age estimates from 2007 were not available at the time of report writing so exploitation fractions were not estimated.

During November 2008 we set out to gather baseline information on spawner densities along the northern shore and embayments of Lake Superior from Nipigon Bay to Thunder Bay, including Black Bay. Our objectives were to: 1) measure and map densities of spawning-size cisco and rainbow smelt along the northern shore; 2) combine fishery-independent survey results and commercial harvest information to estimate exploitation fractions of large cisco in different management zones; and 3) use results of the November 2005, 2007 and 2008 surveys to explore sustainability of the present annual total allowable catch (TAC) quota of 180,502 kg for Thunder Bay.

Methods

Fishery-Independent Survey

From 10-20 November 2008 pelagic fish were sampled at night along the northern shore of Lake Superior with AC-MT methods aboard the USGS R/V *Kiyi*. A total of 472 km of AC data and 30 MT samples were collected (Figure 1). To meet Objective 1, we used a systematic design with parallel transects separated by roughly 5 km. Acoustic data were collected to estimate fish densities at five different study sites (Thunder Bay, Black Bay South, East of Black Bay, Nipigon Bay East, and East of Nipigon Strait; Figure 1). Sampling was conducted where commercial catch records are summarized annually in management zones (1-4, 7, 9, 11 and 12, Figure 1).

Acoustic data collection and processing methods are described in detail by Yule et al. (2006b; 2008a; 2009). Sampling started 30 minutes after sunset and ended each night several hours before sunrise. A BioSonics DT-X echosounder (Seattle, Washington, USA) equipped with a 5.3^{o} (half-power beam width) 70 kHz circular split-beam transducer was deployed to a depth of 0.75 m on a 2-m-long tow body. Typical cruising speed was 13 km/hr, except when midwater trawling (≈ 4 km/hr). The transducer sampling rate was normally set at 4 pings per second, but sampling rates as slow as 1 ping per second were used over great depths (>150 m) to avoid cross-talk that can occur when a given sound wave is not allowed to return fully before the next wave is emitted. Pulse duration was set at 0.4 msecs. 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. On 5 November 2008 we conducted a standard sphere test which demonstrated the acoustic system was working properly so no corrective offsets were applied during post-processing.

Acoustic data were processed with Echoview Software version 4.5.47.12136 (Sonar Data, Tasmania, Australia). Thresholds for the S_v and single target echograms were set at -65 dB and -60 dB respectively. A line to exclude surface noise was set at 2-6 m depth (depending on sea state) and a line to exclude the bottom was set 0.5 m above the bottom signal. Software-defined bottom lines were examined carefully to ensure all bottom echoes were properly excluded, and all segments of echograms containing electrical or other noise (i.e., all echoes obviously not from fish) were eliminated before estimating fish densities. Total fish density (fish/ha) estimates were calculated in 20-m high by 1-km long segments of travel (hereafter cells) using echo integration methods. Fish density was calculated using formula (1) per the Great Lakes acoustic standard operating procedures (Parker-Stetter et al. 2009):

$$(1)\ \text{Fish density (fish/ha)} = ABC/\sigma \times 10^4,$$

where *ABC* is the area backscattering coefficient, σ is the mean backscattering cross-section of all targets meeting single echo detection criteria (see Yule et al. 2006b for criteria), and 10^4 is the number of m^2 in a ha. By definition $\sigma = 10^{(TS/10)}$, where *TS* is mean target strength of fish targets in a cell.

In the past, 10-m high cells were used. A change to 20-m high cells was made due to the uppermost cell in low density areas often having fewer than 20 single fish targets which is below the minimum number recommended by Rudstam et al. (2009).

Following Yule et al. (2006b), we calculated the number of single targets both less than and greater than -35.6 decibels (dB) in each cell and apportioned the total fish density in each cell to large and small fish accordingly. Yule et al. (2009) showed this empirically-derived approach of Yule et al. (2006b) provided estimates of expected and observed trawl catches of small (< 250 mm TL) and large (≥ 250 mm) fish in Lake Superior that approached unity over a wide range of densities. Stockwell et al. (2009) showed that Lake Superior cisco greater than 250 mm are typically sexually mature. Estimates of small and large fish in each cell from the surface-exclusion line to the bottom-exclusion line were summed along each 1-km interval.

Midwater trawl samples were collected periodically, targeting 3-5 tows per night. The MT had an effective fishing height and width of 10 m by 10 m with cod-end mesh of 13 mm stretch measure. Trawl stations were determined before leaving port each night. The MT was fished at 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. Sample duration was typically 20 minutes. The MT fishing depth was monitored in real-time with a NetMind (Northstar Technical, Inc., St. John's, Newfoundland, Canada) depth sensor.

Catches were sorted to species and placed in labeled plastic bags for processing either aboard the R/V Kiyi or at the UGLMU Thunder Bay laboratory the next morning. Catches of each species in each MT 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 or mature). Small catches (< 200 individuals) 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 *Coregonus kiyi*, bloater *C. hoyi*, cisco and other species < 250 mm; and large fish = female cisco, male cisco, kiyi, bloater and other species ≥ 250 mm). We estimated individual weights from length measurements using equations for Lake Superior species (Lake Superior Biological Station, unpublished data).

As in Yule et al. (2009), we linked AC intervals to nearest MT catches to (1) calculate density and biomass estimates of each size/species category along each 1-km interval, (2) calculate mean densities of each size/species category using the 1-km intervals as sample units, and (3) generate 95% confidence intervals for density and biomass estimates using a bootstrap approach to resample AC interval densities and MT catches with replacement. Density and biomass estimates were multiplied by the area of each study site (which included all bathymetric depths) to estimate total abundance (millions) and biomass (metric tons) of each size/species category. Study site areas (Table 1) were estimated using a Geographic Information System (ArcMap 9.2, ESRI Corportation, Redlands, California).

Spatial distributions of spawning-size cisco and smelt were mapped by importing AC-MT density estimates measured along 1-km intervals into ArcMap. Densities at unsampled locations were predicted using ordinary kriging with a geostatistical analyst extension following the methods of Yule et al. (2006b). 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 applied along with the theoretical variogram to predict densities at unsampled locations.

We collected otoliths from a subsample of cisco caught by midwater trawling for ageing. Age estimates were used to develop age-length keys for both males and females and these keys were used to apportion abundance estimates to year-classes. During catch 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) from each study site. Ages were estimated using the otolith crack-and-burn method (Schreiner and Schram 2001) by Jon Tost (North Shore Environmental Services, Thunder Bay, Ontario).

We targeted development of age-length keys of trawl-caught male and female cisco using 10-mm length bins at each site. These sex-specific age-length keys were first applied to estimate the age-composition of all MT-caught cisco at each site. Assuming the catches at each site represented all at-large cisco, we scaled up the age-compositions of the catches to the estimated stock size at each site. With this approach we developed abundance estimates of male and female cisco belonging to each year-class at each site.

Commercial catch data

Commercial fishing during November and early December 2008 occurred in Thunder Bay (Zones 1-2), southeast of Thunder Bay (zone 6), Black Bay south (Zone 7), East of Black Bay (Zone 9), and East of the Nipigon Strait (Zone 12). Methods of obtaining and processing cisco commercial catch data were previously described fully in Yule et al. (2008a). Briefly, commercial gillnet lift data were summarized to estimate total biomass of ciscoes harvested by management zone and these estimates were apportioned to males and females based on individual fish records in the "net run" database (i.e., samples of 10 ciscoes per lift voluntarily supplied by commercial fishers throughout the roe fishery). Each net run fish was measured to the nearest mm, weighed to the nearest gram, sexed and its maturity determined. Total numbers harvested of each sex from each zone were calculated by dividing the estimate of harvested biomass by average weight of harvested individuals. We also constructed plots of CPE (kg/km/net night) versus landing date to explore how timing of the AC-MT surveys at study sites compared to this independent measure of cisco abundance.

Otoliths of all net run fish were removed for ageing. Because of budget constraints only a subset of the 2007 net-run cisco were aged; all 2008 net-run fish were aged. Age estimates were used to generate length-age keys for both males and females each year using 10-mm bins. Because net-run cisco were collected continuously throughout the fishery, we assumed the fish were a representative sample of the commercial catch. Combining estimates of the numbers of males and females harvested with their respective age-length keys allowed us to estimate numbers of each cohort harvested during the 2007 and 2008 roe fisheries.

Exploitation fractions

We estimated exploitation fractions (Objective 2) of different age-class groupings by dividing numbers harvested (from commercial catch records and age estimates) by numbers at-large (from the AC-MT survey). We summarized exploitation fractions by grouping age-classes (age-0 to age-5; age-6 to age-12, and ≥ age-13) defined previously by Yule et al. (2008a).

Sustainability of the present TAC for Thunder Bay

To explore the sustainability of the present TAC for Thunder Bay, we conducted a simple population dynamic analysis to explore if and when exploitation fractions would likely exceed the recommended safe-harvest limits of 10 and 15% (Stockwell et al. 2009). We used abundance estimates of females in each year-class measured during our November 2008 survey as the start-up population. We estimated numbers surviving to November 2009 using an estimate of the instantaneous rate of natural mortality (0.131) reported for adult Thunder Bay females (Yule et al. 2008a). We then simulated the 2009 fishery by removing females assuming the November 2008 harvest level and year-class composition was realized again. Exploitation fractions of market-size cisco (≥ age-6) were calculated by dividing estimated numbers harvested in 2009 by the estimated number surviving to the 2009 fishery. This same suite of assumptions was used to estimate exploitation fractions for the 2010 and 2011 fisheries.

Results

A total of 10,656 fish were caught in MT samples (Table 2). A total of 627 cisco were caught of which 559 were from Thunder Bay. Cisco represented 36.54% of the Thunder Bay catch and 17.95% of the catch East of Black Bay (Table 2). Rainbow smelt represented the largest percentage of the MT catches at all five study sites: Black Bay south (99.57% by number), East Nipigon Bay (98.98%) East of Nipigon Strait (93.50%), East of Black Bay (79.49%) and Thunder Bay (61.44%). Catch rates of rainbow smelt (fish/minute of trawling; Figure 2) were highest in Black Bay South, followed by Nipigon

Bay East. Some of the lowest rainbow smelt catch rates occurred in Thunder Bay where the highest cisco catch rates were measured (Figure 2). Catches of bloater and kiyi were comparatively small (Table 2) and were limited to Thunder Bay and the two easternmost trawl sites near the town of Terrace Bay (Figure 2). Three sea lamprey *Petromyzon marinus* were caught in and around Nipigon Bay (Figure 2).

After apportioning AC densities with MT catches, densities of large cisco (males + females) were low (generally < 10/ha) in the Nipigon Bay sites (Table 3; Figure 3). Higher mean spawner densities were observed at the Black Bay South (15.3/ha) and East of Black Bay (29.6/ha) sites. Thunder Bay supported the highest large cisco density (118.4/ha) of the five sites studied. As in past years, the highest spawning cisco densities in Thunder Bay were observed along the northwest coastline (Figure 3).

Estimated AC-MT densities of rainbow smelt were highest in Black Bay South, the northernmost waters of Nipigon Bay East, and in a small portion of Thunder Bay (Figure 4). Mean rainbow smelt densities were highest in Black Bay South (3,219.5/ha; Table 3) and Nipigon Bay East (2,179.4/ha). Owing to their generally larger body size, average rainbow smelt biomass in Nipigon Bay East (15.4 kg/ha; Table 4) exceeded that of Black Bay South (8.6 kg/ha). Smelt densities in Thunder Bay averaged 960.7/ha (4.6 kg/ha).

Length distributions of male and female cisco caught in Thunder Bay during 2008 were similar to that observed in 2007 with the exception that some of the smaller individuals had grown in size (Figure 5). Of the cisco caught in Thunder Bay during 2008, 284 (50.8%) were males and 275 (49.2%) were females. During November 2007, 1,860 cisco were caught by midwater trawling of which 45% were males and 55% were females. Recruitment after 2003 has been minimal so most individuals captured during 2008 exceeded 250 mm (Figure 5). Greater catches in 2007 were the result of conducting two surveys in Thunder Bay that year.

Mean density of large cisco in Thunder Bay during November 2008 (118.4/ha) was lower than the density measured during the mid-November 2007 survey (142/ha; Figure 6), but greater than the 2005 density (78.4/ha). The increase from 2005 to 2007 can be attributed to the strong 2003 year-class growing to spawning size by the 2007 survey (Figure 5).

November sampling normally occurs under heavy cloud cover, but that was not the case during the early portion of our 2008 cruise when the moon was full and skies were sometimes clear. Under these higher light levels we observed schooling fish in surface waters (Figure 7) which we presumed, because of their large acoustic sizes, were cisco. High moonlight levels may have affected midwater catches, especially at the East of Black Bay site where MT catches of large cisco were generally low (Figure 2), but estimated AC densities were moderately high (Figure 3).

Total estimated abundance of spawning-size cisco in Thunder Bay during November 2008 was 8.8 million (Table 5) with equal numbers of males and females. Owing to their larger size, total estimated spawning female biomass (1,435.4 metric tons; Table 6) exceeded that of males (1,116.8 metric tons). Total estimated abundance of spawning-size cisco was 254,000 in Black Bay South; 778,000 at the East of Black Bay site; 24,000 in Nipigon Bay East; and 134,000 at the East of Nipigon Strait site.

Trawl-caught cisco ages

A total of 126 males (Appendix A) and 152 females (Appendix B) caught in MT samples from Thunder Bay during 2008 were aged. Trawl-captured females were predominantly age-5 (2003 year-class; 61.2%), age-10 (1998 year-class; 16.4%), and age-3 (2005 year-class; 5.9%). Trawl-captured males from Thunder Bay were predominantly age-5 (68.3%), and age-10 (19.8%). A total of 64 cisco caught during November 2008 outside of Thunder Bay were also aged. Of these, age-5 (45.3%), and age-3 (26.6%) cisco were predominant. A cisco estimated to be age-24 (1984 year-class) was caught at the East of Black Bay site. The numbers of age estimates for fish collected outside of Thunder Bay were too few to warrant development of age-length keys.

Comparison to recent survey results showed a general decline in total estimated cisco abundance in Thunder Bay (Figure 8). The total abundance of cisco (all sizes) in Thunder Bay was estimated at 16.2 million during 2005, 14.7 million in 2007, and 9.9 million in 2008. Survey results from 2005 and 2007 show that older females from the 1987-1991 year-classes were present in the stock during 2005 and 2007, but were largely absent in November 2008 samples.

Commercial catch data

Commercial fishing for cisco during November 2008 occurred in management zones 1, 2, 6, 7, 9 and 12 (Table 7). The highest cisco yields were from zones 1-2, followed by zone 7, Zone 9, Zone 6 and Zone 12. No fishing occurred in management zones 3 and 4 during 2007 and 2008. Females were predominant in commercial catches (Table 7) because they are targeted by the roe fishery.

Age estimates from cisco harvested from Thunder Bay were used to develop age-length keys for males and females harvested in 2007 and 2008 (Appendices C-F). We used these keys to apportion the total estimated harvest of males and females from Thunder Bay to year-classes (Figure 9). There has been a shift in the age composition of the commercial catch since 2005. In 2005, most of the catch was made up of the 1998, 1988 and 1989 year-classes. In 2007, the strong 2003 and 1998 year-classes were dominant in the fishery and continued to make up the bulk of the harvest in 2008. The 1988-1991 year-classes are apparently being lost to senescence because in 2008 these year classes represented only a small fraction of the harvest.

Exploitation fractions of females declined for the two oldest age groups (ages 6-12 and ages ≥ 13) between 2005 and 2007 (Figure 10) but increased for the youngest group (ages 0-5) which is consistent with the 2003 year-class entering the fishery by 2007 (Figure 9). With the lack of recruitment since 2003, the numbers of spawners declined from 2007 to 2008 (Figure 8), while harvest was similar (2007 = 341,880; 2008 = 344,303). The net result was that the exploitation fractions for all age-class groupings increased from 2007 to 2008 (Figure 10). Exploitation for female age groupings was 4% for ages 1-5, 8.7% for ages 6-12, and 4.4% for ages ≥ 13. For males, exploitation fractions were 1.6% for ages 1-5, 2.5% for ages 6-12 and 15.9% for ages ≥ 13.

Because MT catches of cisco were generally low at the other study sites (Table 2) we did not have sufficient data to calculate exploitation fractions for age groups. Dividing the estimates of numbers harvested from zone 7 during November 2008 by the observed numbers at-large in Black Bay South resulted in exploitation fraction of 29.5%. Dividing Zone 9 harvest by numbers at-large at the East of Black Bay site, resulted in an exploitation fraction of 5.3%. However, exploitation fractions for these two zones should be viewed with caution for two reasons. First, owing to inclement weather only the western half of zone 9 (Figure 1) was sampled. Second, plots of CPE versus landing date for these two zones (Figure 11) suggest the abundance of large cisco may have increased in both areas after our survey work was completed. It is possible that cisco sampled in Black Bay South and East of Black Bay may be the same stock. If this is true, exploitation during November 2008 was 11.3% (116,637 harvested/1.03 million at-large).

Sustainability of the present TAC for Thunder Bay

Based on the simple population dynamics analysis we conducted, we estimate that exploitation fractions of market-size females (≥ age 6) will approach 6.0% in 2009, 12.4% in 2010 and 17.9% in 2011. If the current TAC is held constant, our modeling suggests harvest of female cisco from Thunder Bay will be exceed the recommended safe-harvest benchmark of 10% as early as 2010 and the 15% benchmark by 2011.

Discussion

Since 2005, exploitation fractions for large females in Thunder Bay (Figure 10) have remained below the safe-harvest levels of 10-15% recommended by Stockwell et al. (2009). However, based on low recruitment after 2003, there is a high probability that stock abundance will decline in the immediate future. If the present annual TAC is met, exploitation fractions will increase in upcoming years. Exploitation fractions could exceed 10% by 2010 and 15% by 2011. Our findings to date, suggest that the current Thunder Bay cisco stock is strong, but the general lack of recruitment since 2003 is cause for concern for the future.

Spatial distribution patterns measured with the November 2008 AC-MT survey were consistent with spatial patterns of the 2008 commercial harvest. Densities of large cisco at the two Nipigon Bay sites were quite low, typically less than 10 cisco/ha (Table 3; Figure 3), where commercial harvest was essentially zero (Table 7). Higher densities of large cisco were observed in Black Bay South and East of Black Bay where moderate harvest occurred (see zone 7 and 9 harvest; Table 7). The highest densities of large cisco were measured in Thunder Bay, especially in zones 1 and 2, where commercial harvest was the highest. Given that most commercial fishers have spent years on the water, this finding is by no means unexpected.

To accurately assess spawner abundance we need to better understand the temporal patterns of when spawners arrive at the spawning grounds. Plots of commercial gillnet CPE by landing date (Figure 11) have been used to infer if AC-MT surveys have been timed properly. Data from Thunder Bay collected in 2005 (Yule et al. 2008a), 2007 (Yule et al. 2008b), and 2008 (Figure 11) suggest a mid-November survey will provide a a good estimate of spawner abundance in this bay. Whereas in Black Bay, gillnet lift records from 2005 (Yule et al. 2006a) and 2008 (Figure 11), suggest the Black Bay cisco arrive to their spawning grounds in late November. Given the highest concentrations of large cisco in Black Bay South and East of Black Bay were found in close proximity (Figure 3), we suspect they may comprise a single stock. Moreover, lift records from both zones 7 and 9 show a similar pattern of CPE increasing throughout November (Figure 11). Exploration of historic CPE data from both zones is needed to see if these patterns consistently hold.

Gill net CPE peaked in both zones after our 2008 AC-MT survey which suggests the combined abundance estimate of 1.03 million may be conservative. Conducting surveys into late November poses a challenge for the R/V *Kiyi* because her home port is at the end of shallow Chequamegon Bay which tends to freeze up early. We had to break ice to get back into our slip on 24 November 2007 and 29 November 2008. During 2009, we recommend conducting AC-MT survey work in Thunder Bay and the Black Bay region in mid-November with the R/V *Kiyi*, and use a smaller vessel to repeat AC sampling of the Black Bay region in late-November through early-December.

AC collections on 15 November 2008 at the East of Black Bay site showed the presence of schooling fish under full moon and clear sky conditions (Figure 7). When fish are aggregated in this fashion, measures of mean *TS* can be biased high (Appenzeller and Leggett 1992; Sawada et al. 1993; Rudstam et al. 2009) which lowers fish density estimates. It is impossible to quantify the degree that our November 2008 acoustic estimates at the East of Black Bay site were biased, but the estimates we report should be viewed as conservative. We recommend that future spawning cisco surveys take note of cloud cover conditions and avoid night work under full moon and clear sky conditions if possible.

Our present study found rainbow smelt densities were highest in Nipigon and Black bays and lowest in Thunder Bay (Figure 4), with the opposite pattern observed for large cisco densities (Figure 3). Recent AC-MT results have shown that Lake Superior sites that currently support large commercial cisco fisheries (i.e., Thunder Bay and the western arm) typically have large cisco densities exceeding 75/ha and rainbow smelt densities less than 1,000/ha (Table 8). Rainbow smelt are a known predator of larval cisco (Selgeby et al.

1978), and a recent bioenergetics study showed rainbow smelt could account for 15-52% and 37-100% of larval cisco mortality in Thunder and Black bays, respectively (Myers et al. in press). These recent AC-MT findings suggest that spawning cisco densities may be inversely related to rainbow smelt densities, but more work as more sites is needed to confirm this finding.

November 2009 will mark the end of our three-year study to develop an SOP for future collections. Field efforts during 2009 are scheduled to be devoted to sampling Thunder Bay for 4 nights and repeat sampling of Black Bay South and East of Black Bay for 4 nights during both mid- and late-November. Continued training of UGLMU staff in acoustic processing methods is also a goal for the upcoming year. We envision the final report will include recommendations on when to conduct surveys of Black and Thunder bays, and guidance on the amount of AC data, midwater sampling, and age estimates that are needed to provide spawning cisco estimates with an acceptable level of precision.

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Tables

Table 1. Area (hectares = ha) of five study sites sampled between 10-20 November, 2008. Area estimates include all bathymetric depths and were estimated with a Geographic Information System.

Study site	Area (ha)
Thunder Bay	73,914
Black Bay South	16,605
East of Black Bay	26,294
East of Nipigon Strait	41,868
Nipigon Bay East	34,240

Table 2. Midwater trawl catches from five study sites in Canadian waters of Lake Superior sampled between 10-20 November, 2008. The percentages (%) of fish collected sum to 100% for each study site.

Study site	Thunder Bay		Black Bay South		East of Black Bay		Nipigon Bay East		East of Nipigon Strait	
Management zone	1-4		7		9		11		12	
Midwater trawl samples	11		4		4		4		7[a]	
Species	# caught	%	# caught	%	# caught	%	# caught	%	# caught	%
Rainbow smelt	940	61.44	6439	99.57	124	79.49	2234	98.98	230	93.50
Cisco	559	36.54	16	0.25	28	17.95	17	0.75	7	2.85
Bloater	24	1.57	1	0.02	0	0.00	0	0.00	4	1.63
Kiyi	5	0.33	0	0.00	0	0.00	0	0.00	1	0.41
Threespine stickleback	0	0.00	1	0.02	0	0.00	0	0.00	0	0.00
Ninespine stickleback	1	0.07	2	0.03	4	2.56	2	0.09	2	0.81
Trout-perch	0	0.00	6	0.09	0	0.00	0	0.00	0	0.00
Chinook salmon	0	0.00	2	0.03	0	0.00	1	0.04	0	0.00
Lean lake trout	1	0.07	0	0.00	0	0.00	1	0.04	0	0.00
Slimy sculpin	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Deepwater sculpin	0	0.00	0	0.00	0	0.00	0	0.00	1	0.41
Sea lamprey	0	0.00	0	0.00	0	0.00	2	0.09	1	0.41
Total	1530	100.00	6467	100.00	156	100.00	2257	100.00	246	100.00

[a] = Includes 2 trawls collected east of this area (see Figure 1).

Table 3. Density (number/ha) of small (< 250 mm total length) and large fish measured with acoustic and midwater trawl methods during November 2008 by study site. Other small fish included threespine stickleback, ninespine stickleback, trout-perch, slimy sculpin, and deepwater sculpin; other large fish included chinook salmon, lean lake trout and sea lamprey.

Study site	Thunder Bay			Black Bay South			East of Black Bay			Nipigon Bay East			East of Nipigon Strait		
Management zone(s)	1-4			7			9			11			12		
Small fish (<250mm)	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%
Cisco (both sexes)	6.6	16.1	24.6	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.5	2.5	0.0	0.0	0.0
Bloater	80.7	148.6	217.3	0.0	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.8
Other	0.1	0.4	0.6	2.0	3.9	5.8	8.7	18.1	29.1	1.2	2.1	3.3	0.2	1.7	3.2
Rainbow smelt	876.4	960.7	1045.1	2444.4	3219.5	3927.0	342.0	427.2	511.0	1740.6	2179.4	2612.4	159.6	258.4	354.2
Kiyi	2.1	4.0	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.4
Large fish (≥ 250 mm)															
Cisco (males)	50.5	58.9	66.8	2.3	4.6	7.8	8.9	14.1	19.6	0.1	0.4	1.0	0.8	1.9	3.0
Cisco (females)	51.3	59.5	67.5	4.8	10.7	17.7	9.4	15.5	20.6	0.0	0.3	0.7	0.6	1.3	2.1
Bloater	2.4	5.5	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.1	0.3	0.0	0.1	0.1	0.0	0.0	0.0	1.3	2.8	4.3	0.6	1.3	2.5
Kiyi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4. Biomass (kg/ha) of small (< 250 mm total length) and large fish measured with acoustic and midwater trawl methods during November 2008 by study site. Other small fish included threespine stickleback, ninespine stickleback, trout-perch, slimy sculpin and deepwater sculpin; other large fish included chinook salmon, lean lake trout and sea lamprey.

Study site	Thunder Bay			Black Bay South			East of Black Bay			Nipigon Bay East			East of Nipigon Strait		
Management zone(s)	1-4			7			9			11			12		
Small fish (<250mm)	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%
Cisco (both sexes)	0.7	1.8	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0
Bloater	5.4	10.0	14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
Other	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainbow smelt	4.0	4.6	5.1	6.8	8.6	10.2	0.6	0.8	1.0	12.2	15.4	18.5	0.6	1.3	2.0
Kiyi	0.1	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Large fish (≥ 250 mm)															
Cisco (males)	13.0	15.1	17.1	0.4	0.9	1.5	2.8	4.7	6.4	0.0	0.1	0.2	0.3	0.6	1.0
Cisco (females)	16.8	19.4	22.2	1.0	2.2	3.6	3.5	6.0	8.3	0.0	0.1	0.1	0.2	0.4	0.6
Bloater	0.3	0.8	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.3	0.5	0.0	0.1	0.2	0.0	0.0	0.0	0.5	1.7	3.0	0.1	0.4	0.6
Kiyi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5. Abundance (millions) of small (< 250 mm total length) and large fish measured with acoustic and midwater trawl methods during November 2008 by study site. Other small fish included threespine stickleback, ninespine stickleback, trout-perch, slimy sculpin and deepwater sculpin; other large fish included chinook salmon, lean lake trout and sea lamprey.

Study site	Thunder Bay			Black Bay South			East of Black Bay			Nipigon Bay East			East of Nipigon Strait		
Management zone(s)	1-4			7			9			11			12		
Small fish (<250mm)	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%
Cisco (both sexes)	0.5	1.2	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Bloater	6.0	11.0	16.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Other	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.5	0.8	0.0	0.1	0.1	0.0	0.1	0.1
Rainbow smelt	64.8	71.0	77.2	40.6	53.5	65.2	9.0	11.2	13.4	59.6	74.6	89.4	6.7	10.8	14.8
Kiyi	0.2	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Large fish (≥ 250 mm)															
Cisco (males)	3.7	4.4	4.9	0.0	0.1	0.1	0.2	0.4	0.5	0.0	0.0	0.0	0.0	0.1	0.1
Cisco (females)	3.8	4.4	5.0	0.1	0.2	0.3	0.2	0.4	0.5	0.0	0.0	0.0	0.0	0.1	0.1
Bloater	0.2	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Kiyi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 6. Total biomass (metric tons) of small (< 250 mm total length) and large fish measured with acoustic and midwater trawl methods during November 2008 by study site. Other small fish included threespine stickleback, ninespine stickleback, trout-perch, slimy sculpin and deepwater sculpin; other large fish included chinook salmon, lean lake trout and sea lamprey.

Study site	Thunder Bay			Black Bay South			East of Black Bay			Nipigon Bay East			East of Nipigon Strait		
Management zones	1-4			7			9			11			12		
Small fish (<250mm)	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%	Lower 95%	Observed	Upper 95%
Cisco (both sexes)	50.4	133.0	203.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bloater	397.9	739.1	1069.6	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.1	0.5	1.0	1.8	0.4	0.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainbow smelt	298.0	337.8	379.7	113.4	143.5	168.7	16.0	21.6	27.4	0.4	0.5	0.6	0.0	0.1	0.1
Kiyi	7.1	13.3	20.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Large fish (≥ 250 mm)															
Cisco (males)	964.0	1116.8	1261.1	6.7	14.9	24.5	74.9	123.1	168.4	0.0	0.0	0.0	0.0	0.0	0.0
Cisco (females)	1243.8	1435.4	1638.4	16.6	36.9	59.0	92.3	158.3	219.3	0.0	0.0	0.0	0.0	0.0	0.0
Bloater	24.2	59.1	96.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	19.2	37.7	0.0	1.2	2.8	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Kiyi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7. Total biomass harvested (kg), average mass of harvested males and females (g), and numbers of males and females harvested from two management zones of Thunder Bay (1-2) and 4 other management zones during the roe fishery spanning 1 November to 2 December 2008. NA = not available.

Management zone(s)	Biomass harvested (kg)	Average mass of harvested males (g)	Average mass of harvested females (g)	Number of males harvested	Number of females harvested
1-2[a]	157,633	430	467	85,328	258,976
6	14,048	392	451	7,492	24,636
7	32,468	418	441	26,842	48,181
9	20,067	486	480	15,245	26,369
12	667	NA	NA	NA	NA

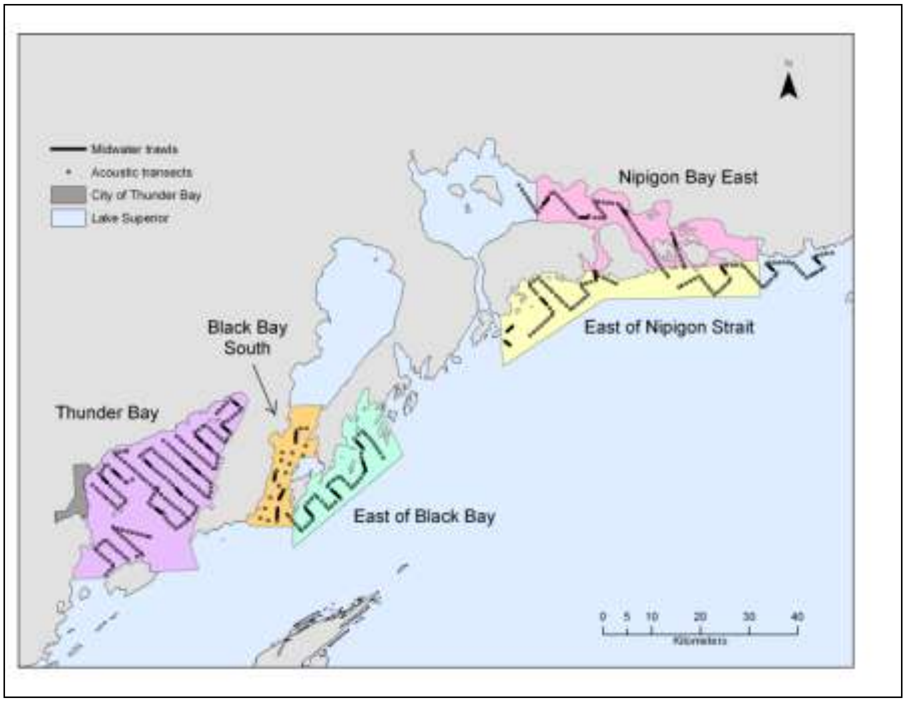
[a] = Combined harvest from zones 1 and 2. No commercial fishing for cisco occurred in zones 3 and 4 during November 2008.

Table 8. Recent mean rainbow smelt and cisco density (#/ha) estimates of Black and Thunder Bay, Ontario (ON) and the western arm of Lake Superior (Wisconsin = WI and Minnesota = MN) as measured with acoustic and midwater trawling methods.

	Black Bay, ON		Thunder Bay, ON		Western arm of Lake Superior, WI-MN		
Survey	rainbow smelt (#/ha)	large cisco (#/ha)	rainbow smelt (#/ha)	large cisco (#/ha)	rainbow smelt (#/ha)	large cisco (#/ha)	Source
November 2005	3,634	19.3	610	78.4			Yule et al. 2006a
May 2006	3,435		476				Myers et al. in press
November 2006					707[a]	93[a]	Yule et al. 2009
November 2007			1,213	142.0			Yule et al. 2008b
November 2008	3,220	15.3	961	118.4			Present study

[a] = where bathymetric depths were less than 80 m only.

A)



B)

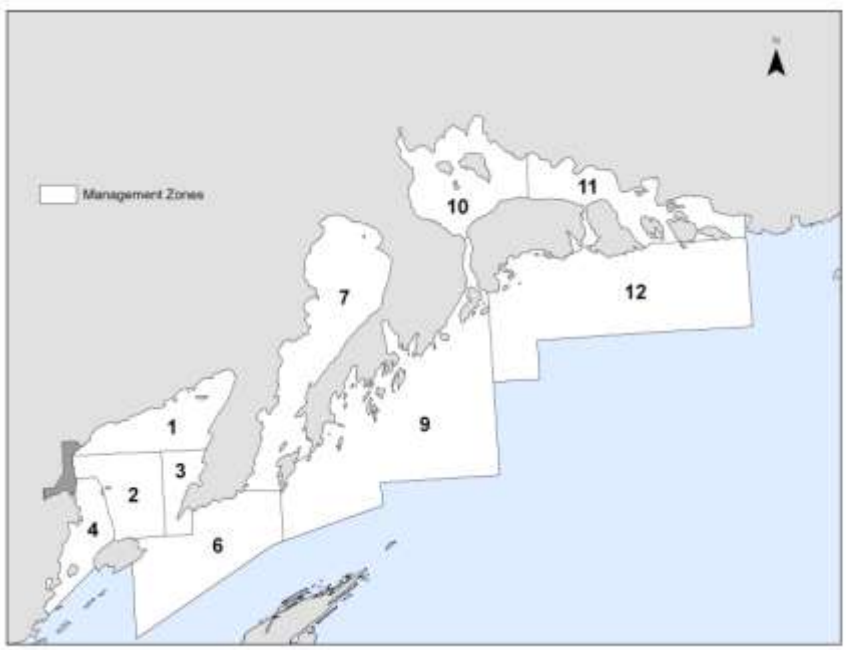


Figure 1. A) Map showing midwater trawl stations and acoustic transects in five study sites sampled between 10-20 November 2008, and B) boundaries of management zones in which commercial gill net catch statistics were summarized.

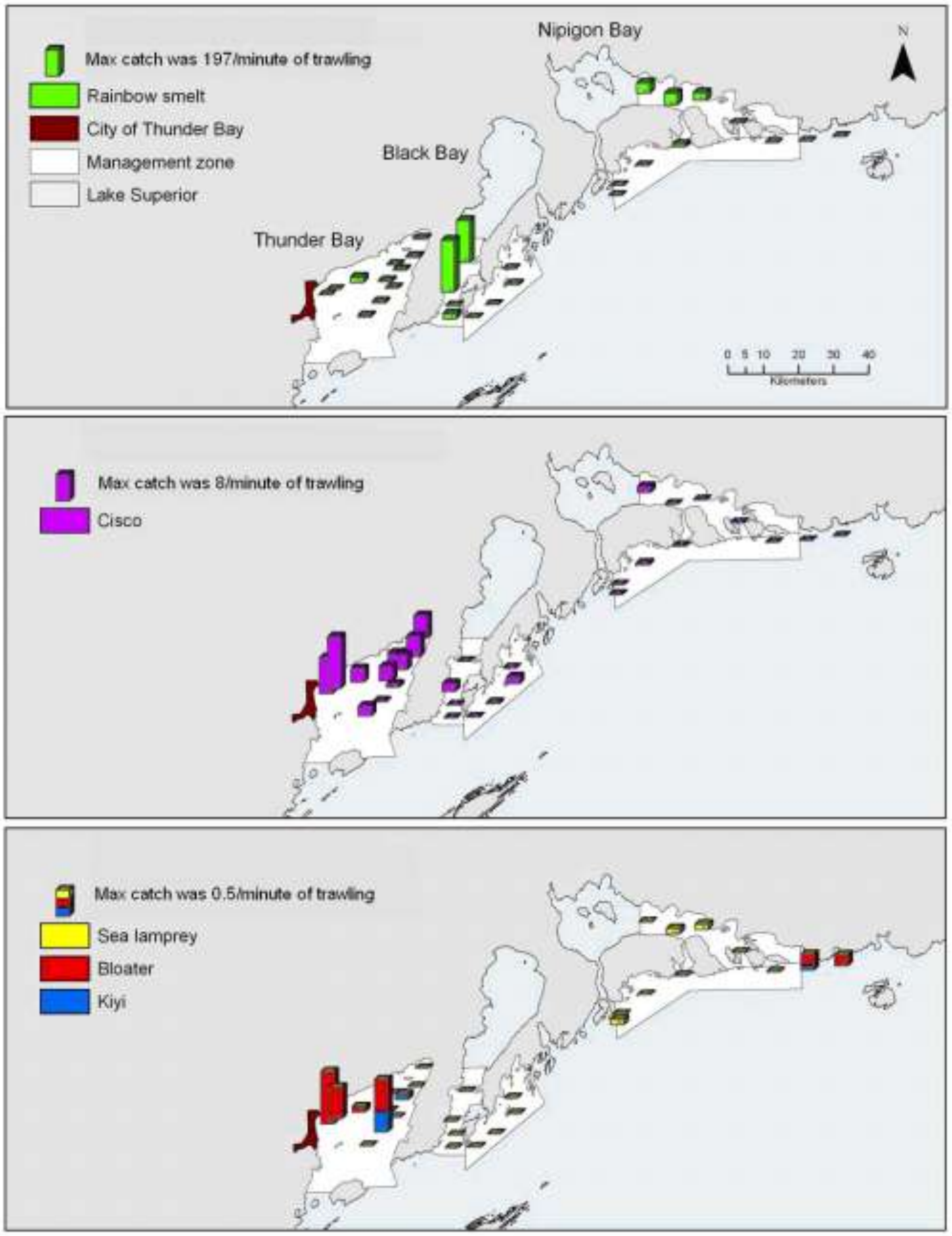


Figure 2. Map showing the numbers of rainbow smelt (top panel), cisco (middle panel) and sea lamprey, bloater and kiyi (bottom panel) caught per minute of midwater trawling between 10-20 November, 2008. Bar heights were scaled to maximum value in each panel shown in panel legends.

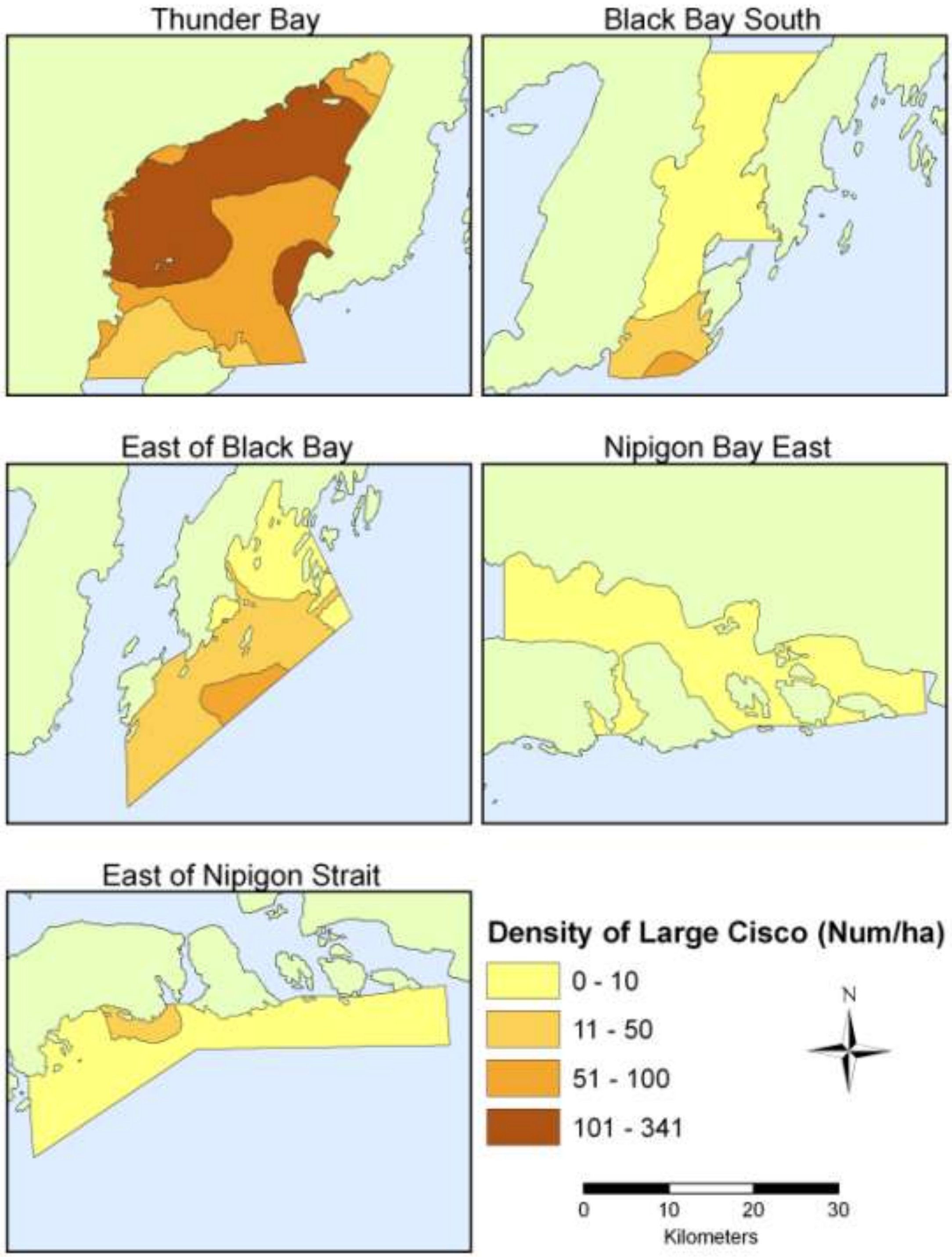


Figure 3. Maps showing densities of large (≥ 250 mm) cisco gathered during the 10-20 November 2008 acoustic and midwater trawl survey. Layers were created using ordinary kriging (see Methods for details).

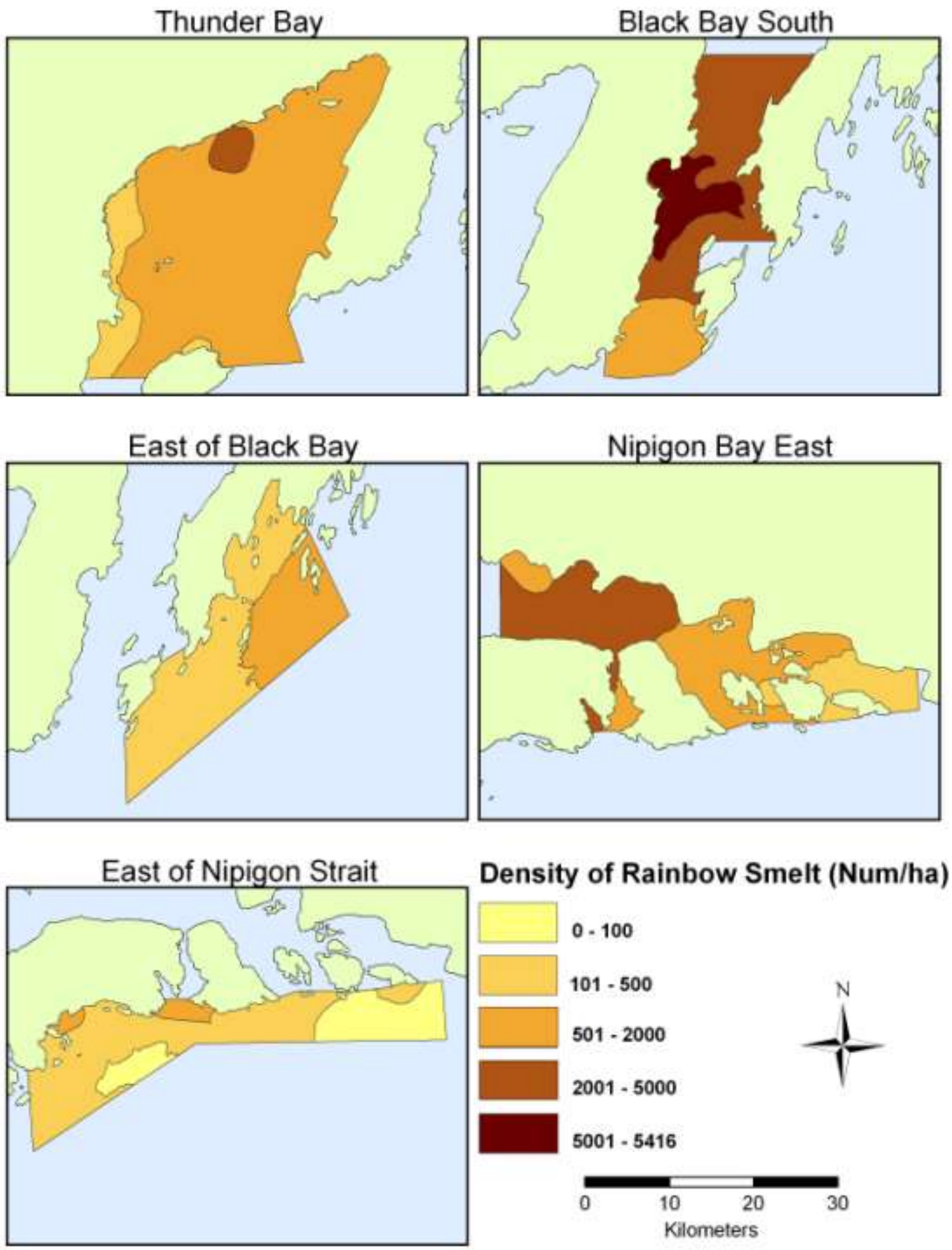


Figure 4. Maps showing densities of rainbow smelt gathered during the 10-20 November 2008 acoustic and midwater trawl survey. Layers were created using ordinary kriging (see Methods section for details).

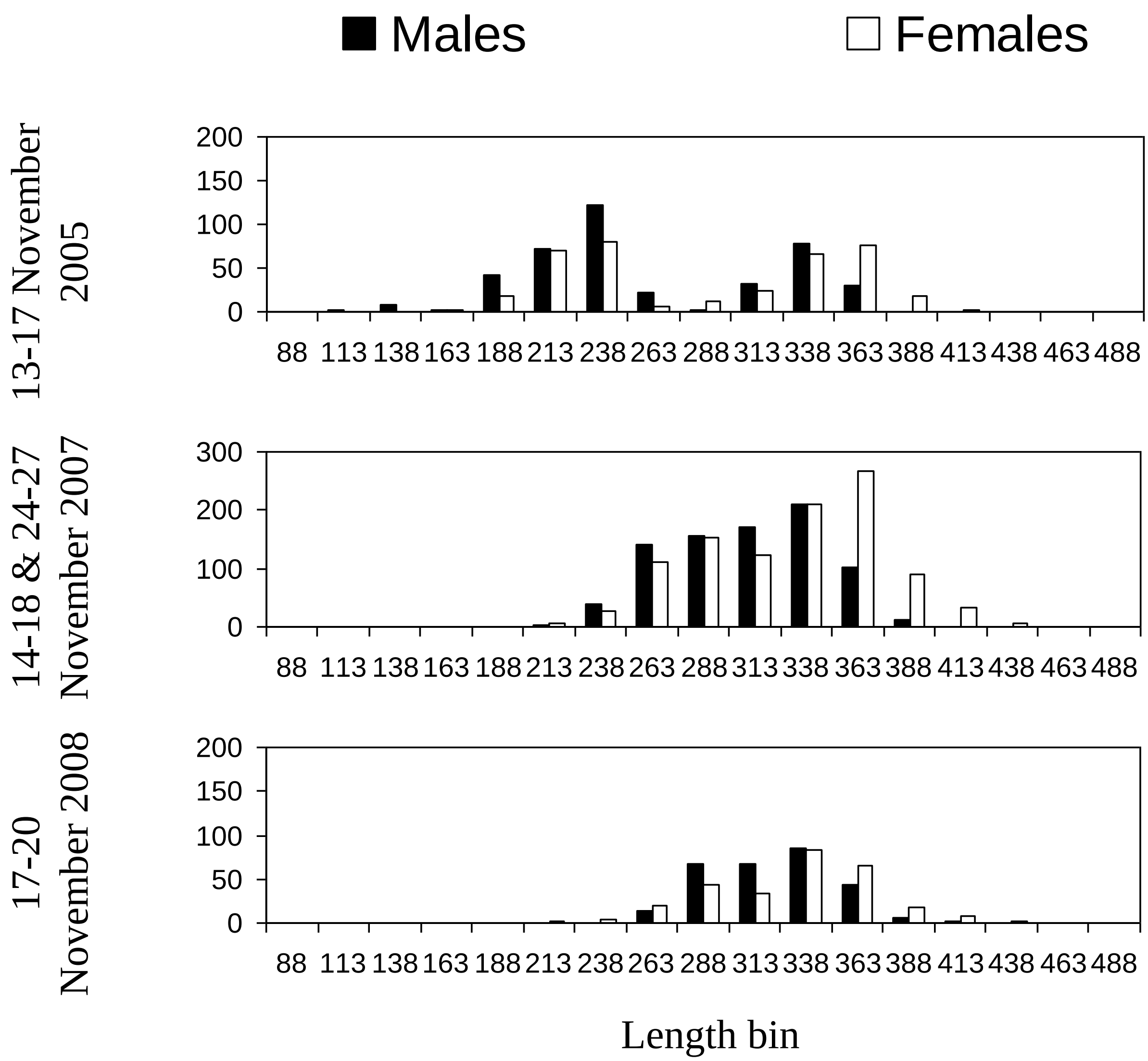


Figure 5. Length-frequency distributions of cisco captured from Thunder Bay in midwater trawl samples during November 2005, November 2007 and November 2008. Two surveys were conducted during November 2007 and catches in the middle panel were pooled.

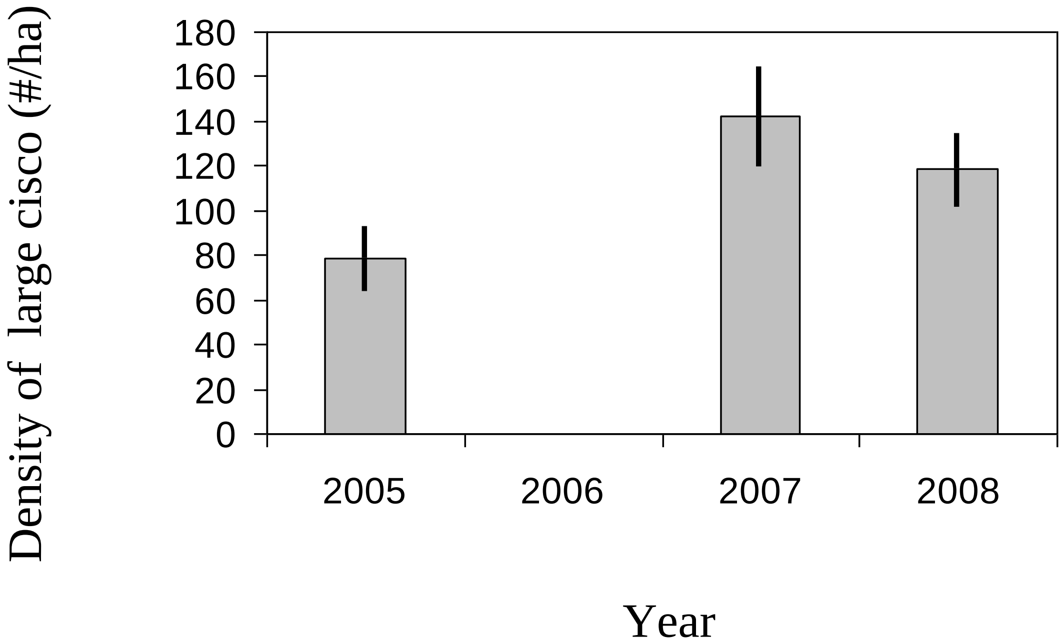


Figure 6. Density of large (≥ 250 mm) cisco in Thunder Bay during November 2005, 2007 and 2008. Error bars are 95% confidence intervals.

Example echogram showing fish schools under full moon and clear skies; presumably cisco.

Example echogram collected under heavy cloud cover.

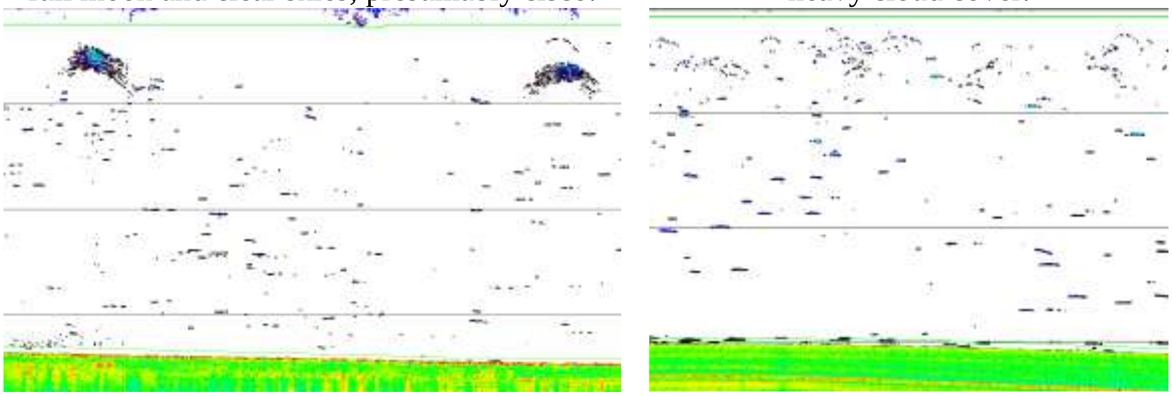


Figure 7. Example echograms showing evidence of fish schooling under conditions of full moon and clear skies on 15 November at the East of Black Bay site (left panel) compared to an example collected under heavy cloud cover during the 19 November sampling of Thunder Bay (right panel). Given their large acoustic size we presume the schooling fish were cisco.

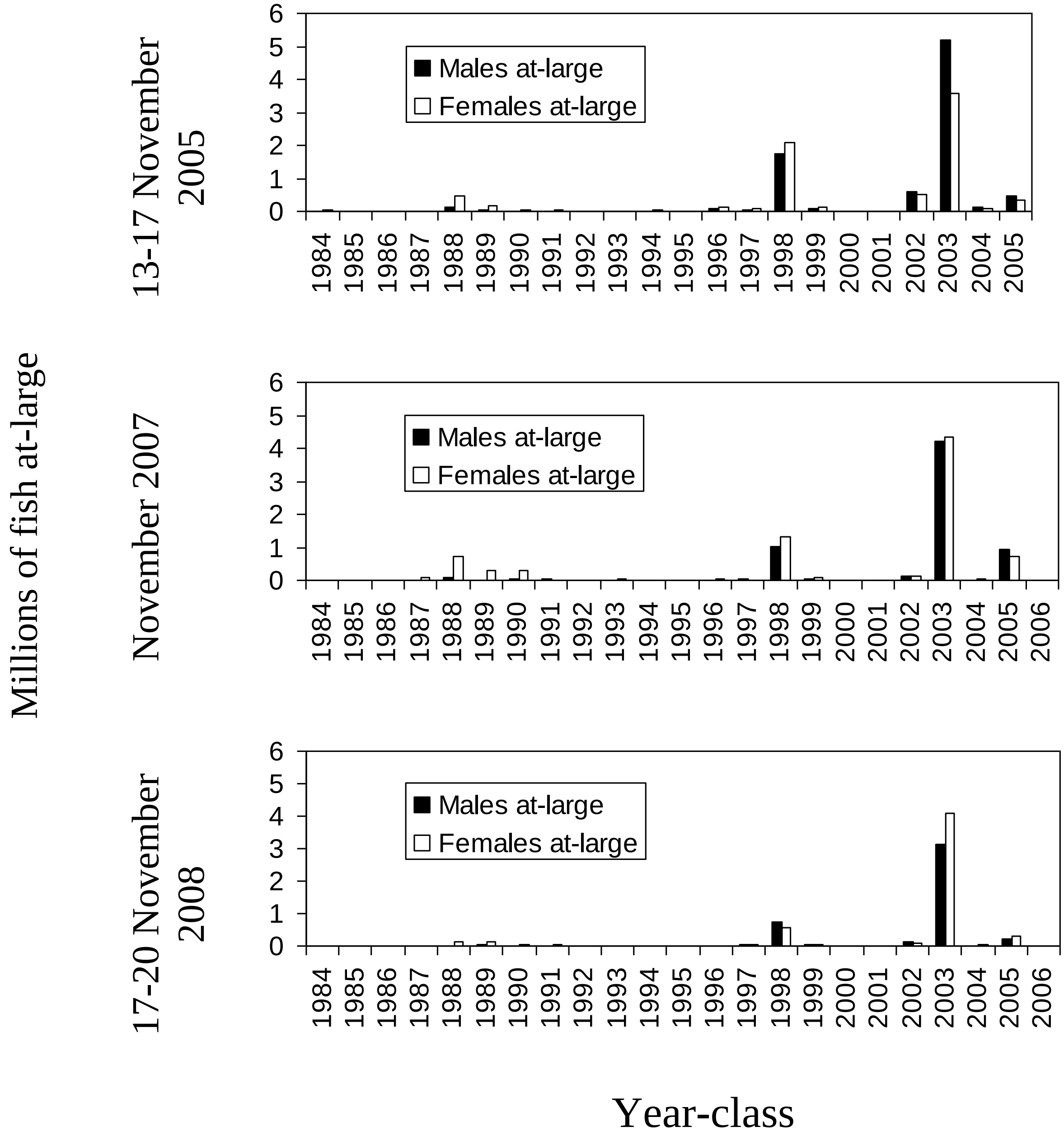


Figure 8. Estimated number (millions of fish) of male and female cisco of different year-classes at-large in Thunder Bay during November 2005, November 2007 and November 2008. The November 2007 data is based on averaging the numbers of each year-class measured during two surveys.

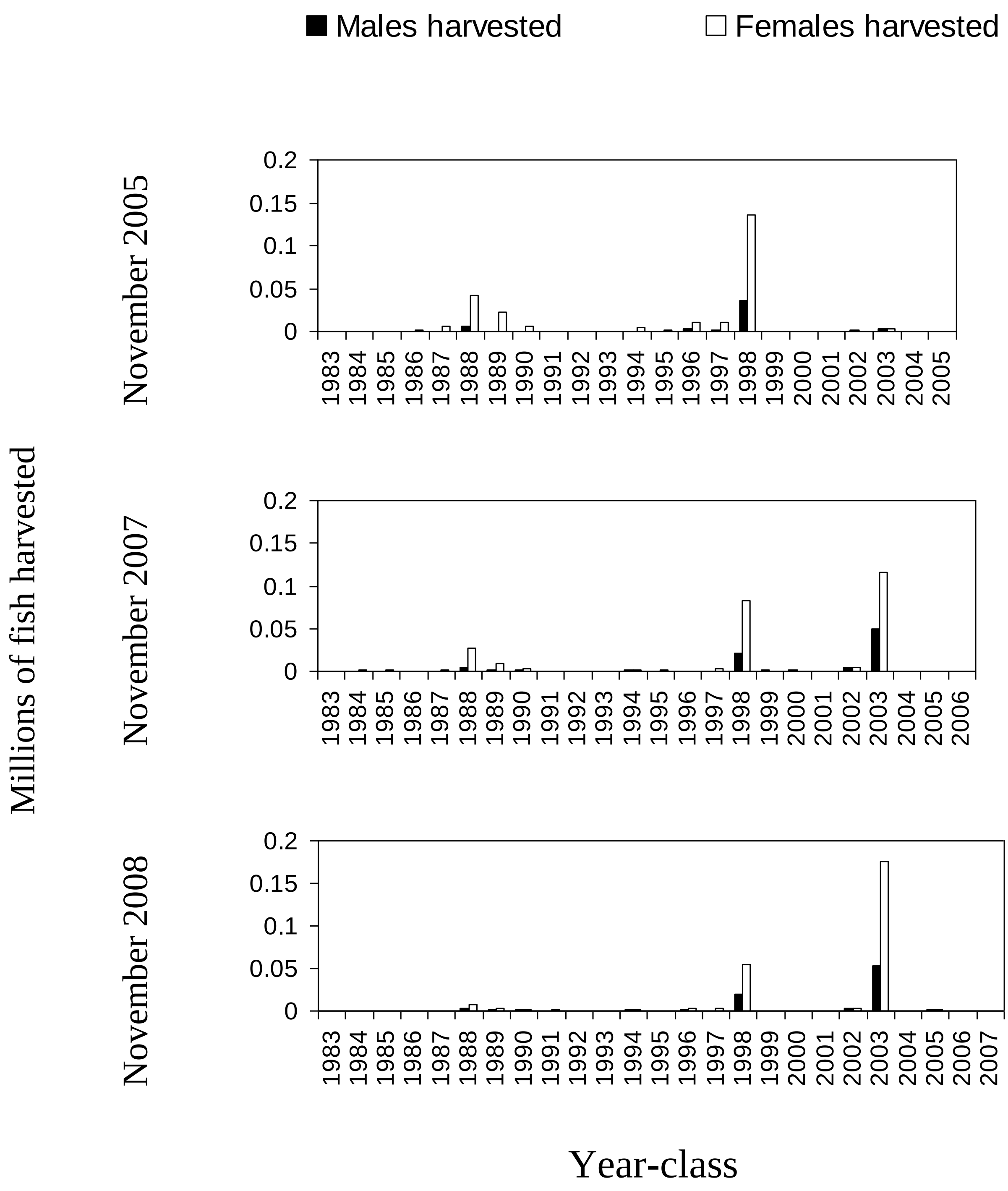


Figure 9. Estimated number (millions of fish) of male and female ciscoes of different year-classes harvested from Thunder Bay during November 2005, November 2007 and November 2008.

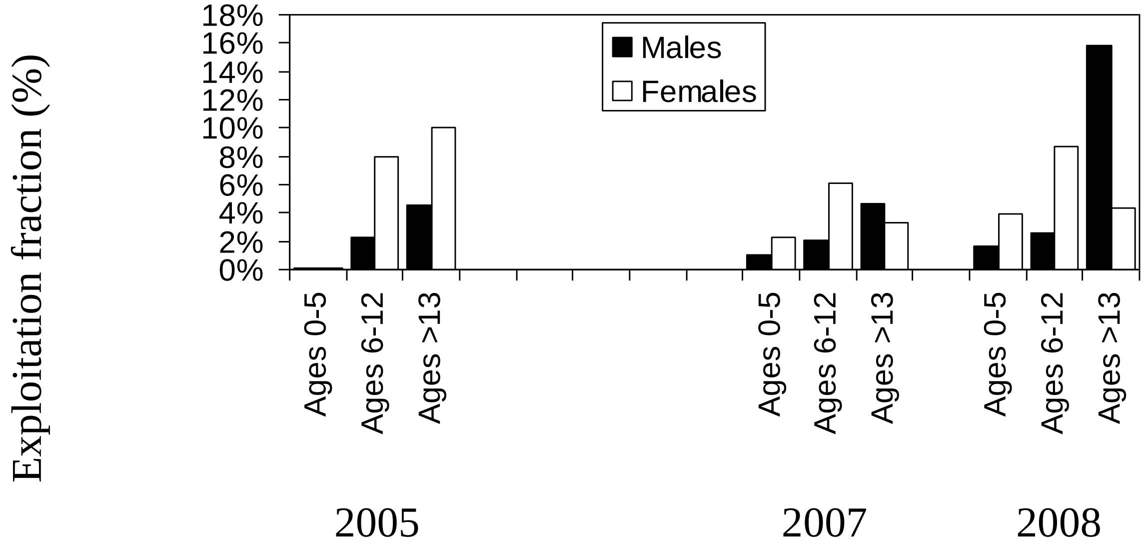


Figure 10. Estimated exploitation fractions (%) of different age-class groupings of cisco harvested from Thunder Bay during the November 2005, 2007 and 2008 roe fisheries.

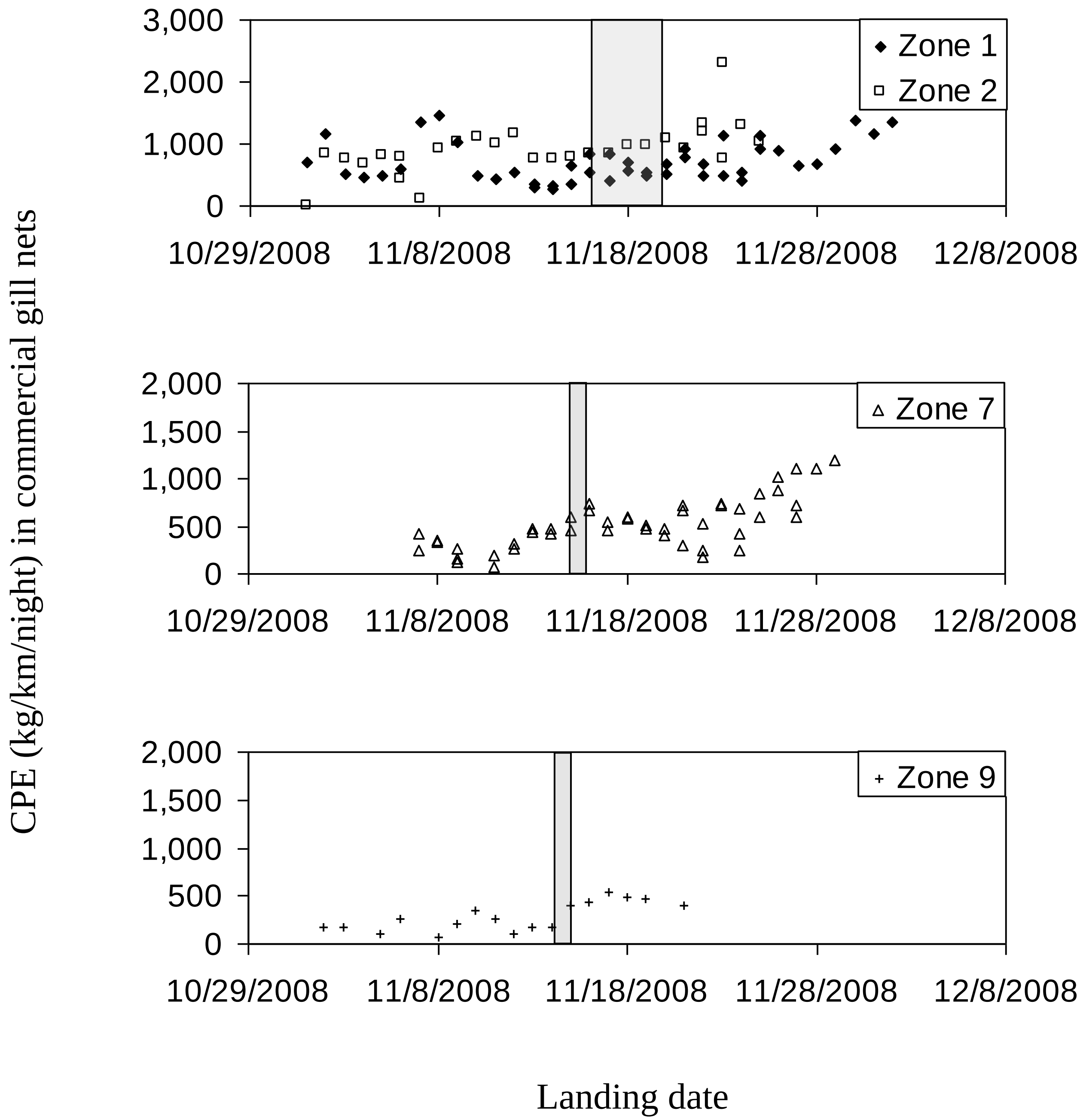


Figure 11. Catch per effort (CPE) of cisco in commercial gill nets (kg/km of net/night) by landing date from zones 1, 2, 7 and 9 during the November 2008 roe fishery. Note the y-axis of the top panel for Thunder Bay is different than the other panels. The gray rectangles show the timing of the 2008 acoustic work in each zone.

Appendix A. Length-age distribution of male cisco caught by mid-water trawling in Thunder Bay during November 2008.

	Year classes							
Length (mm)	05	03	02	99	98	97	96	89
Age	3	5	6	9	10	11	12	19
250-259		1						
260-269		1						
270-279	1	3						
280-289	1	4						
290-299	2	10						
300-309		8			1			
310-319	1	11						
320-329		14	1		2			
330-339		13	3		3			
340-349		11			6			
350-359		7			6	1		
360-369		1		1	2	1		1
370-379		1			4		1	
380-389					1			
400-409								1
Totals	5	85	4	1	25	2	1	2

Appendix B. Length-age distribution of female cisco caught by mid-water trawling in Thunder Bay during November 2008.

	Year classes											
Length (mm)	05	04	03	02	99	98	97	94	91	90	89	88
Age	3	4	5	6	9	10	11	14	17	18	19	20
240-249			3									
250-259	2		1									
260-269			4									
270-279	3		6									
280-289	1		5									
290-299	1		5									
300-309			5									
310-319			5									
320-329			10									
330-339	1	1	11	1		1						
340-349	1		11	1	1		1					
350-359		1	16			8					3	
360-369			6			7	1		1			2
370-379			3			3						1
380-389			1			1				2	2	2
390-399						2						1
400-409						1						1
410-419			1			2				1	1	
430-439								1	1			
Totals	9	2	93	2	1	25	2	1	1	3	6	7

Appendix C. Length-age distribution of male lake cisco caught by commercial gill nets in Thunder Bay during November 2007.

	Year classes											
Length (mm)	05	04	03	02	00	99	98	96	94	90	89	88
Age	2	3	4	5	7	8	9	11	13	17	18	19
270-279	1			1								
300-309			1									
320-329			2				1					
330-339			3				2					
340-349			7				3					
350-359			12		1		3					
360-369			15	1			9					
370-379			10	1	1		5		1	1	1	1
380-389			13			1	4					2
390-399		1	7	3		1	4		1		1	1
400-409			7	2			3	1			1	3
410-419			8	1			1					
420-429			1	2						1		
430-439										1		
440-449							3					
Totals	1	1	86	11	2	2	38	1	2	3	3	7

Appendix D. Length-age distribution of female lake cisco caught in commercial gill nets from Thunder Bay during November 2007.

	Year classes												
Length (mm)	05	03	02	98	97	95	94	90	89	88	87	85	84
Age	2	4	5	9	10	12	13	17	18	19	20	22	23
270-279		1											
290-299	1												
310-319		1											
320-329		4											
330-339		10	1	2									
340-349		17		5									
350-359		14	1	1									
360-369		11		8					1	2	1		
370-379		7	1	8	1				1	3			
380-389		11		6				1		2			
390-399		2		10	1		1		1	3			1
400-409		8		9		1		1	1	3		2	
410-419		4		5					1	4			
420-429				5				1	2	2			1
430-439				4					1	3			
440-449			1						1				
460-469				1						1			
Totals	1	90	4	64	2	1	1	3	9	23	1	2	2

Appendix E. Length-age distribution of males caught in commercial gill nets from Thunder Bay during November 2008.

	Year classes									
Length (mm)	05	04	03	02	98	96	94	90	89	88
Age	3	4	5	6	10	12	14	18	19	20
280-289				1						
310-319			1	1						
320-329			1							
330-339			3		1					
340-349		1	10		1					1
350-359			17		5	1			1	
360-369	1		16		9					1
370-379			25		3	1			1	2
380-389	1		17		7	1		1		1
390-399			10	1	2		1	1	1	
400-409			3		8					
410-419			2	1	2		1			
420-429			1		1					
430-439			1	1	1					
440-449									1	
Totals	2	1	107	5	40	3	2	2	4	5

Appendix F. Length-age distribution of females caught in commercial gill nets from Thunder Bay during November 2008.

	Year classes														
Length (mm)	05	04	03	02	99	98	97	96	94	91	90	89	88	85	84
Age	3	4	5	6	9	10	11	12	14	17	18	19	20	23	24
300-309			1												
310-319			1												
320-329			2												
330-339			6												
340-349			34	2				1							
350-359			59	1		7									
360-369		1	58	1		7		1		1			1		
370-379			59	1	1	17	3	3		1		2			
380-389	1		57			34		2			2		5	1	1
390-399			41	1		12			1			3	3		
400-409	1		12			17	3					2	2		
410-419			2			6							2		
420-429			1			1			1	1	1				
430-439			1	1		1									
440-449						1									
470-479													1		
Totals	2	1	334	7	1	103	6	7	2	3	3	7	14	1	1