Comparing Ship-based to Multi-Directional Sled-based Acoustic Estimates of Pelagic Fishes in Lake Superior

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Ryan Christopher Grow

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Dedication

I dedicate this thesis to my late grandfather, Norm Grow, for his unwavering support of me and all of his grandchildren, and for his role in inspiring and encouraging my passion for nature, fishing, and learning. I also dedicate this thesis to the late Eric Fryman, Kyra Fryman-Bricco, Analiese Fryman-Mews, and Jansen Fryman; my heart goes out to all of them and their family, may they rest in peace.

Abstract:

Ship-based down-looking acoustic surveys are commonly used to determine the biomass and population density of commercially important fish species for resource managers and scientists, particularly in the Great Lakes and marine systems. However, there are some limitations and biases inherent in traditional down-looking surveys. I examined the use of multi-directional sled mounted acoustics equipped with up, side, and down-looking capabilities to overcome these limitations while examining the Lake Superior pelagic fish community. In the western arm of Lake Superior, I concurrently deployed the sled mounted acoustics during traditional down-looking surveys to directly compare the fish densities obtained from each gear, which I then followed with a mid-water trawl to inform my acoustic data with species composition. My findings from a two-way ANOVA showed a significant difference between fish densities detected by the sled-based survey and the ship-based down-looking survey indicating 60% of the pelagic fish community was missed by the traditional down-looking survey. This study also sought to provide a baseline for future research looking to discover which species in aquatic systems are most effected by traditional survey biases, as well as future work into using alternate forms of acoustic sampling to inform fisheries management and research.

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Introduction

Fisheries surveys are widely used to provide estimates of fish populations in many different types of aquatic systems. These surveys are crucial information for fisheries managers when making regional or local decisions on commercial and recreational fisheries. The first documented fisheries survey in the United States was conducted in Woods Hole, MA in 1871 using a simple count of observed species (Baird 1872). Since then we have transitioned to using various repeatable and standardized netting techniques such as gill netting, trap netting, and trawling to obtain fish density and biomass estimates and biological data. Acoustics have also emerged as an alternate way to obtain fish density and biomass estimations in conjunction with or in lieu of standard netting techniques, beginning with an investigative study examining fish populations within the Norwegian fjords in 1935 (Sund 1935). The use of acoustics for fish density estimations relies on the emission of high frequency sound pulses from a transducer that is able to "listen" and measure in decibels (dB) returning echoes of sound from targets like fish and solid surfaces like the seafloor (Haslett 1969). The fishes' swim bladder is the most important feature for the sound to resonate from, and can be used to estimate fish size (Foote 1980; Love 1971).

Ship based down-looking acoustic fisheries surveys have since been adopted by many fisheries researchers and managers (Kubečka et al. 2009; Simmonds and MacLennan 2008). Today, these acoustic surveys are used to provide estimates of fish population densities, stock assessments, and accurate sampling in areas where traditional gill netting or trawl netting are too impractical or invasive to the ecosystem or organism of interest (Misund 1997; Qiao et al. 2005; Warner et al. 2012; Yule et al. 2007; Yule et al. 2013). In marine systems acoustics have been shown to more accurately provide fish density estimates around reef complexes (Rudershausen et al. 2010) and provide corrective gear efficiency estimates in difficult to access demersal fishes (Doray, Mahévas, and Trenkel 2009). They have also provided a means to examine seasonal patterns of abundance in commercially significant pelagic fishes in the Baltic Sea (Axenrot and Hansson 2004).

In the Great Lakes, acoustic fisheries surveys have become an integral part of management strategies. For example, early in the use of acoustics in the Great Lakes, down-looking surveys were used to make whole food web biomass estimates and examine overall trends in Lake Michigan (Sprules et al. 1991). They have subsequently been refined and used to provide density estimates of commercially important fish species like Cisco (*Coregonus artedi*; Hrabik et al. 2006), Whitefish (*Coregonus clupeaformis*; Yule et al. 2007), and Lake Trout (*Salvelinus namaycush*; Stockwell et al. 2010). They have also been used to examine populations of introduced and invasive species like Rainbow Smelt (*Osmerus mordax*) and Alewife (*Alosa pseudoharengus*) in Lake Superior (Gorman 2007; Heist and Swenson 1983), Lake Ontario (Riha et al. 2107), and Lake Michigan (Mayor, Eckert, and Richards 2018). One reason these acoustic methods have become so common in the Great Lakes is their ability to minimize biases and error related to gear efficiency and fish availability (Hoffman et al. 2009; Jakobsen et al. 1997; Rose and Nunnallee 1998).

Gear efficiency is a bias metric based on the percentage of fish that are successfully captured by a sampling technique when they encounter it. For example, if a fish of a certain size or species encounters a trawl net and is able to evade the net better than other species, the survey would have a high gear efficiency bias (Davidson, Lara-Lopez, and Koslow 2015). Fish availability is a bias metric based on which fish are vulnerable to the sampling technique; for example, if a trawl net has mesh spaced wider than a fish's body diameter, it would not be able to capture that fish, resulting in a strong availability bias for the survey. Acoustic surveys reduce error and bias from both of these concerns because sound waves are able to sample all species and sizes of fish (with swim-bladders) without concern of net avoidance or avoidance related to mesh sizes. This allows for less biased estimations of a total biomass for the sampled area (Stockwell et al. 2007; Yurista et al. 2014). Acoustic surveys may begin to encounter efficiency bias if fish density of a sampled area is too high, causing some fish to be obscured by others and resulting in density underestimation. However, this concern is considered negligible compared to other efficiency biases in net-based trawls (Barange, Hampton, and Soule 1996) and in systems with moderate to low fish densities like Lake Superior (Stockwell et al. 2007).

There are limitations, however, to eliminating all bias when designing acoustic fisheries surveys. First, acoustic sampling reports fish size and overall biomass, but does not alone explicitly determine species composition. Some fish species may also be disturbed by the presence of a large ship and exhibit avoidance, diving, or herding behavior introducing availability bias, and ultimately leading to an underestimation of fish density of certain species (Guillard et al. 2010; Thorne 1983). In a study on shallow lakes in the Czech Republic, fish were found to have vessel avoidance behavior of up to 10m in response to a six-foot-long boat with a small two-stroke motor (Draštík and Kubečka 2005). The avoidance impact of large vessels used in the Great Lakes for down-looking acoustic surveys and the extent of vessel avoidance by pelagic fishes in these larger systems is poorly understood. However, a recent study on walleye in Lake Erie demonstrated that vessel size can impact down-looking acoustic fish density estimates with larger vessels achieving lower density estimates (DuFour et al. 2018). Also, due to a combination of near field exclusion zones, transducer deployment depth, and surface bubble interference, a portion of the water column closest to the transducer is commonly excluded from water column wide density estimates, introducing more availability bias (Rudstam et al. 2009; Yule 2000). This is commonly known as an acoustic dead zone, which is a known phenomenon that occurs both in the region near the transducer and near the bottom of the observed water body. Examinations of the bottom dead zone in oceanic systems are well documented (Hjellvik, Godø, and Tjøstheim 2004; McQuinn et al. 2005; Mello and Rose 2009; Totland et al. 2009). Researchers have observed that acoustic sampling significantly underestimates demersal ocean fishes in the North Sea when compared to paired bottom trawls (Jakobson et al. 1997). Additionally, in the Baltic Sea a study conducted on the semi pelagic species, Walleye Pollock (*Theragra chalcogramma*), was able to create a correction factor for the deep acoustic dead zone (Kotwicki et al. 2012). These studies offer a background and context for similar corrections to be made into the upper water column dead zone.

Remotely operated vehicles (ROVs) and autonomously operated vehicles (AUVs) represent a possible solution to vessel avoidance problems. ROVs and AUVs can be much quieter than large ships and lessen avoidance, but there is still concern of fish avoidance due to their operating noise (Listewnik 2013; Rountree and Juanes 2010). The ROVs and AUV's are theoretically capable of obtaining more acoustic data from the upper water column due to their smaller draft size and ability to submerge and sample vertically. In the ocean, AUV's have been used to provide better resolution of Tuna (*Katsuwonus pelamis*) schools in the upper water column (Scalabrin, Marfia, and Boucher 2009) as well as examine young of the year Cod (*Gadus morhua*) in the Barents Sea (Totland et al. 2009). ROV's have been effective in solving limitations in other areas of fisheries research including effectively estimating fish populations in and around fresh oil spills (Ajemian et al. 2015). However, ROVs and AUV's also come with limitations based on fuel and navigational capabilities, and they may not have the capacity for long-term power to run acoustic surveys (Farr et al. 2010). Additionally, some ROV's encounter issues with supporting the weight of acoustic transducers and storing the obtained data.

Up-looking surveys have been used to estimate fish density and abundance in marine systems, but they rely on predictable fish migration patterns or schooling, require large arrays of stationary mounted transducers, and shift the problem of the near field to the bottom of the water column (De Robertis, Levine, and Wilson 2017; Thorne, Hedgepeth, and Campos 1989). Some submersible tow bodies have recently been equipped with a combination of up, side, or down-looking acoustic capabilities, but few studies utilize all three sampling directions in concert to accomplish fisheries surveys. A recent survey using an up-looking acoustics survey on the Lake Ontario alewife population found that a portion of the population was being missed by traditional down-looking acoustics (Riha et al. 2017). The researchers were able to observe new diel vertical migration patterns (DVM) within this population in the previously unsampled upper layer of the water column, and they observed a higher fish density in the portion of the water column normally missed by down-looking surveys. Recent work on Lake Superior suggests that Cisco also aggregate in shallow water layers, particularly during the fall pre-spawn and spawning period (Yule et al. 2012). This behavior places them in the upper acoustic dead zone of most down looking large vessel surveys.

Cisco are a cold-water pelagic fish found in many North American lakes and are threatened across their range by increasing water temperatures from climate change and declining oxygen levels due to eutrophication in their inland lake habitats (Jacobson, Stefan, and Pereira 2010; Magnuson et al. 1997; Stefan, Fang, and Eaton 2001). In Lake Superior, Cisco are ecologically and economically important due to their participation in offshore and nearshore food webs and active movements both vertically

(Ahrenstorff et al*.* 2011) and horizontally among seasons (Stockwell et al*.* 2014). They are also threatened by climate change in Lake Superior as its water temperatures have been warming disproportionately to the surrounding area due to a combination of shorter lake ice cover duration and warmer air temperatures (Austin and Coleman 2007; O'Reilly et al. 2015); this may change the thermal habitat breadth for Cisco (Cline, Benninngton, and Kitchell 2013) .

Cisco populations are not evenly distributed spatially in Lake Superior (Yule et al. 2009). They typically stay more nearshore relative to other coregonines (Schmidt, Harvey, and Vander Zanden 2011), but are still found at bathymetric depths exceeding 100 m (Gorman et al. 2012 I&II). Cisco also typically exhibit diel vertical migration in the summer from the deeper portion of the water column in the daytime to the upper 20% at night (Ahrenstorff et al. 2011). They serve as prey for top-level predators (Sierszen et al*.* 2014) and support large-scale commercial fisheries with annual yields of over 1,000 metric tons (Pratt et al*.* 2016). Recent studies show that Lake Superior Cisco recruitment is sporadic and decreasing for unknown reasons (Vinson et al*.* 2016). Cisco populations in Lake Superior may be more acutely affected by the decreasing number of total ice cover events on Lake Superior (Myers 2015). Additionally, Lake Superior Cisco populations have been facing challenges associated with a targeted commercial roe and fillet fishery that consists of multiple management jurisdictions including Minnesota, Wisconsin, Michigan, Canada, and various tribal organizations (Pratt et al*.* 2016). For example, annual yields of Cisco in Wisconsin waters went from 200 metric tons per year in 2006-2008 to 700 metric tons annually in 2009-2011, as demand for roe by Scandinavian countries increased. These factors highlight the importance of improving our fish density estimations of Cisco in the Great Lakes setting.

Kiyi (*Coregonus kiyi*) and Bloater (*Coregonus hoyi*) are also major contributors to the planktivore biomass in Lake Superior's pelagic zone. Bloater are occasionally targeted commercially with minimal annual harvest, and Kiyi are not targeted for commercial or recreational harvest (Gorman 2012). Kiyi and Bloater are important to the functioning of the overall pelagic fish community as prey sources for Lake Trout, and as predators on mysids, amphipods, and zooplankton. Kiyi are typically found furthest offshore of all the coregonines and are relatively evenly distributed spatially throughout Lake Superior (Gorman et al. 2012 I&II; Schmidt, Harvey, and Vander Zanden 2011); they also preform strong DVM throughout the spring, summer and fall seasons (Ahrenstorff et al. 2011). Bloater are typically found close to the nearshore-offshore interface and remain deep in the water column throughout daily and seasonal changes (Gorman et al. 2012 I&II; Schmidt, Harvey, and Vander Zanden 2011). The Laurentian Great Lakes also contain the only known populations of Kiyi in the world, with the majority of their abundance in Lake Superior, making it an important species to monitor (Becker 1983; Gorman 2012; Schmidt, Harvey, and Vander Zanden 2011). There has been some disagreement on whether members of this clade are distinct species or cryptic morphotypes of Cisco (Reed et al. 1998; Todd, Smith, and Cable 1981; Turgeon and Bernatchez 2003). However, from an ecological perspective, Cisco, Kiyi, and Bloater all have distinct functions within the Lake Superior fish community (Favé and Turgeon 2008; Schmidt, Harvey, and Vander Zanden 2011; Stockwell et al. 2010).

Given significant gaps in our understanding of the vertical distribution of the fish community inhabiting the upper water column of Lake Superior as well as its economic and ecological importance, a new survey method was developed utilizing multi-directional sled mounted acoustics equipped with up-looking, side-looking, and down-looking acoustic capabilities. The sled was designed by a joint effort of the United States Geological Survey (USGS), United States Fish and Wildlife Service (USFWS), and Bellemare Subsea Engineered systems (LLC). This sled-based method was designed to address concerns related to upper water column data loss and vessel avoidance present in conventional acoustic methods. My primary objective was to determine whether significant differences exists between pelagic fish biomass estimates obtained from typical down-looking acoustic techniques and the multi-directional sled mounted acoustics. In this case, the most likely difference in biomass would occur as a consequence of losses of acoustic backscatter in the acoustic dead zone of the down looking survey and from vessel avoidance. Additionally, I deployed 14 mid-water trawls to obtain species estimates for my study region and then used a Classification and Regression Tree (CART) model to allocate species composition to the acoustic targets to identify any potential differences in species composition or density among the two survey methods.

Methods

Description of Multi-directional Sled Mounted Acoustics

The sled was equipped with an upward facing 70 kHz split-beam transducer with a 5.0° beam angle, a starboard side facing 120kHz split-beam transducer with an 8.0° beam angle, and a downward facing 70kHz split-beam transducer with a 5.0° beam angle. The ship acoustic system consisted of a single downward facing 123kHz transducer with a 7.5° beam angle. All transducers were interfaced with Biosonics DT-X digital echosounders; acoustic parameters detailed in Table 1. Its normal flying position was 8.5m to the starboard side of the ship, 58m back, and 28m deep (Figure 1).

Acoustic data received was time synced to the ship's acoustic system for direct comparison of survey estimates. The three survey directions were combined (methods described below) to create one fish density estimate for the water column to compare with the estimate from the down-looking ship based acoustic system within the surveyed areas (Figure 1). The section of the water column missed by the near field of the up and down-looking sled transducers was filled in with the fish density estimate obtained from the side-looking transducer.

Western Lake Superior Survey Design

Given that fish in Lake Superior are not evenly distributed spatially (Mason et al. 2005; Selegby and Hoff 1996; Yule et al. 2009; Johnson et al. 2004), I constructed a survey plan that covered a wide area of the western arm of Lake Superior with varying bathymetric depths (50 - 300m) and diverse ecological habitat zones (Riseng et al. 2017). I sampled six transects in the western arm of Lake Superior August 21th to August 27th 2018 (Figure 2). These transects were modeled after similar acoustic surveys completed in the western arm by fisheries managers (Yule et al. 2009). Each night of sampling began after nautical twilight and ended before dawn. I conducted each transect with the multi-directional sled mounted acoustics deployed while also running the ship-based down-looking acoustics. Each transect was approximately 60km long and was conducted at a speed of approximately 8kph. The sled was flown at a depth of approximately 28m for the duration of the transects, with some intentional raising of the sled to avoid damaging the sled array on shallower bathymetric features.

Midwater Trawl Design

For the second half of the trip I stowed the sled and collected one to four midwater trawl samples after nautical twilight at sites along each transect, starting in Sand Island on August 28th and working clockwise back to Madeline Island on August 31st (Figure 2). The midwater trawl had 15.2m headrope and footrope lines and 13.7m breast lines. The mesh graduated from a stretch measure of 152mm at the mouth to 13mm at the cod end. I used NETMIND trawl mensuration sensors (Northstar Technical, Inc., St. John's, Newfoundland and Labrador) to record the headrope depth and trawl wingspread at approximately 10s intervals during deployment. All trawl information was measured at 2s intervals using miniature depth/temperature loggers (DST's; VEMCO, Shad Bay, Nova Scotia) placed on headrope and footrope lines. I also recorded start and end Latitude and Longitude, mean surface water temperatures (°C), mean bathymetric depth (m), and time trawling (min) at every trawl location (Table 2). Additionally, a conductivity, temperature, and depth sensor (CTD) was deployed at the end of every trawl location to determine thermocline depth and ensure that no large-scale mixing event had occurred to change overall environmental conditions. There were 14 trawls in total with headrope depths ranging from 1.5m to 60m all taken at about 4.4kph. All trawls with headrope depths greater than 25m (N = 4) were fishing for 40 minutes about 3km. All trawls with headrope depths less than 25m (N = 10) fished for 20 minutes about 1.5km.

Data Analysis Methods

The data from the two acoustic methods were processed in the Echoview Software (Echoview 2017) in accordance with the Great Lakes acoustic standard operating procedure (SOP; Parker-Setter et al. 2009; Rustam et al. 2009). Field calibrations of all echosounders were carried out using a 33mm tungsten carbide calibration sphere of a known target strength [TS] (-40.7dB). After the calibrations were completed, the single target strengths 70Khz upward facing transducer was found to be approximately -1.37dB off (-5.12dB off in the mean area backscatter [Sv] realm), and the 70kHz down facing transducer on the sled was found to be approximately -2.13dB off (-5.72dB off in the Sv realm); the sled mounted 120Khz side-looking and 123Khz ship-based down-looking transducers were within the expected ranges (Parker-Setter et al. 2009). These calibration offsets were then applied to the appropriate Echoview files for all of the transects.

The ship and sled down-looking transducer data were processed by first creating an exclusion line for two times the nearfield zone (5.6m for the sled 70kHz, and 1.4m for the ship 120kHz) and one meter from the bottom (Yule 2000). Both lines were scrutinized to ensure no bad data (ship noise, false bottom/surface features, or surface noise) was included in the data. The echograms were then analyzed, and bad data were excluded by creating a region around the data and defining it as “bad data”. Single targets were identified on the TS data file with a minimum target strength detection threshold of -55dB. A minimum dB threshold of -61dB was concurrently applied to the Sv data file before echo integration. A 20-minute interval grid was applied to the dataset to ensure that each cell was an independent sample (20min at ~5knot/hr is ~3,000m cells; Hrabik et al. 2006). Any partial cells were excluded from analysis. The Sv cells were integrated and exported to a csv file, and the paired TS cells were exported as a single target analysis by cell. The mean Sv and TS from each cell were used to calculate the fish density in the R software package using the following equation:

$$Fish\ Density\left(\frac{\#fish}{hectare}\right) = \frac{\left(\frac{Mean\ Backscatter\ Strength\ (S_V)m^2/m^3}{Mean\ Target\ Strength\ (\sigma)m^2} \times Beam\ Thickness(m)\right)}{0.0001(hectare)} \quad (1)$$

(MacLennan and Simmonds 2013). In the cases where a cell had too few targets (N < 5), a mean TS value obtained from whole single targets file for each transect was then used instead of the cells mean TS. The sled-based, side-looking 120kHz transducer echograms were analyzed in a similar fashion to the method above, but data past 60m was excluded. This distance was chosen for a cut off because it is where the width of the beam is nearly equal to the width of the depth zone missed by the sled's up-looking and down-looking transducers (11.7m). The sections of the water column sampled by each transducer on the sled were compared to the corresponding sections within the traditional down-looking survey to determine whether there was a significant number of fish being missed by traditional acoustic methods. These depth sections consisted of the upper section (sled's upward facing transducer to surface; ~3m - 24m depth), middle section (width of the sled's side looking beam ~24m - 36m), and lower section (sled's downward facing transducer to lake bottom; ~ 36m and below). A two-way analysis of variance (ANOVA) followed by a Tukey HSD test was applied to the whole water column comparison and the sectioned-out depth region comparison. All statistical tests were conducted in the R Program version 3.4.0 (R Core Team 2017). Due to its non-normal distribution, fish density data were log-transformed for the statistical tests in order to meet the assumptions of normality and heterogeneity. Fish density was the dependent variable and the model tested transect (six transects), survey method (two survey methods), and an interaction between transect and survey method. There was a significant outlier identified using a studentized t-test in the "car" package (Fox and Weisberg 2011) displaying a near zero fish density value present in the ship-based data for the Grand Marais transect, so the outlier was excluded.

Species allocations were made using methods detailed in Yule et al. (2013), in which a classification and regression tree (CART) model was used to classify acoustic targets to species based on multiple predictor variables. One major assumption with the CART model is that the species catch is an unbiased representation of the acoustic data. However, this assumption is thought to be met based on previous work comparing midwater trawl to acoustic fish density estimates in Lake Superior which found that there is good agreement in estimation between the two methods for large (r = 0.79) and small pelagic fishes (r = 0.74; Yule et al. 2009). Presently there is not yet a better alternative for obtaining species composition data. There were 448 fish measured from 14 midwater trawl sites across the western arm of Lake Superior. These observations were used to predict species composition based on explanatory variables: fish length (mm), footrope fishing depth (m), mean bathymetric depth (m), mean head-rope temperature (C^o), and distance of footrope to bottom (m). The species in the Lake Superior fish community have been shown to utilize different niche spaces based on bathymetric depth, water temperature, season, and interspecific species interactions (Gorman 2012; Harvey and Kitchell 2000; Hrabik et al. 2006); therefore, the selected explanatory variables attempted to offer the model adequate options to determine species identification. The species sampled in the midwater trawls were Rainbow Smelt (N = 283), Cisco (N = 67), Bloater (N = 14), and Kiyi (N = 58). There were also 25 unidentified young of year coregonines (Kiyi, Cisco, or Bloater; < 100mm), that were too cryptic or damaged by the trawl to identify, which I also used as a classification group. Models were run with 100 cross-validations and a minimum node size of 20 observations. I pruned splits that did not increase the overall R^2 of the classification model by 1% or more. Models were run using the “Rpart” package (Therneau, Atkinson, and Ripley 2017).

In order to apply the model to my acoustic data, I estimated fish lengths from single target echo detections using a widely-accepted dorsal-ventral equation for the up-looking and down-looking transducers Love (1971):

$$Fish\ Length(mm) = 10^{\frac{TS-(0.6\times LOG\left(\frac{c}{f}\right)+24.9)}{19.4}} \times 1000, \qquad (2)$$

where c is the speed of sound through the medium in m/s, f is the frequency of the transducer in kHz, and TS is the single target strength of a given fish in dB

For the side-looking transducer, I used a similar approach to estimate fish lengths based on the side-aspect equation (Love 1971):

$$Fish\ Length(mm) = 10^{\frac{TS-(2.8\times LOG\left(\frac{c}{f}\right)+22.9)}{22.8}} \times 1000 \qquad (3)$$

Using these lengths and other explanatory predictors from the CART model, I was able to assign each acoustic target a probability of being a given species. Similar to methods described by Yule et al. (2013), probabilities of individual targets which had predicted lengths greater than the maximum allowable length (e.g., maximum length observed in past trawl surveys; Table 1 from Yule et al. (2013)) were set to zero to prevent unrealistic species length distributions. This was especially important for high TS acoustic targets because I did not capture any fish larger than 510mm in the trawls, and this length was exceeded infrequently in the acoustic data. In accordance with Yule et al. (2013) I made the maximum Cisco size 510mm and classified anything longer than that a “large fish”, which were most likely native Lake Trout. In trawl surveys conducted in Lake Superior by the USGS from 2000 – 2018, of the fish caught > 510mm, 90% were Lake Trout (Yule and Evrard 2019). Large fish made up 1.8% of all ship-based acoustic targets and 2.4% of all the sled-based acoustic targets. The predicted probabilities associated with species composition from the CART model were averaged across all targets. These averages were then used to allocate species composition to the density estimates for species-specific densities. The same CART model was applied to both the traditional down-looking survey and multi-directional sled mounted acoustic survey target strength data. I then converted each species abundance estimate (for Rainbow Smelt, Cisco, Kiyi, Bloater, unidentified young of year coregonines, and large fish) from the ship-based and sled-based surveys to their percent contribution to the whole species composition of each transect. I then used a series of Chi-Square tests on the species compositions of the ship-based and sled-based survey estimates for each transect to determine if there was a significant difference in species composition across the two survey methods in each depth region, and in the whole water column. Additionally, I created an estimate of fish density for the entire western arm of Lake Superior. I considered mean fish density from each transect to be an independent estimation and then took the mean of all six transect means to give us a pooled mean fish density estimate for each species. I then ran a Chi-Square test on the species data for the traditional acoustic survey and multi-directional sled mounted acoustic survey for the whole water column of the entire western arm.

Results

Data collected on six acoustic transects across the western portion of Lake Superior were summarized for fish density and species composition. There was a significant difference between survey methods, F (1, 239) = 95.37, p < 0.001, and transects, F (5, 239) = 2.69, p = 0.022; with the interaction between survey method and transect being significant, F (5, 239) = 2.80, p = 0.018. Based on the Tukey HSD test, I found that mean fish densities obtained from the multi-directional sled mounted acoustics were significantly higher than the traditional down-looking acoustic survey in three of the six transects (*ps* < 0.05). Fish densities were not significantly different among methods in the Knife River ($p = 0.652$), Madeline Island ($p = 0.127$), and Sand Island transects ($p = 0.450$; Figure 3), but the trend for those transects was that the sled-based survey found higher fish densities then the ship-based survey. For the down-looking ship-based acoustic survey, Sand Island had the highest mean fish density estimate at 95 fish/hectare and Grand Marais had the lowest fish density estimate at 39 fish/hectare. For the multi-directional sled-mounted acoustic survey, Taconite Harbor had the highest mean fish density estimate at 228 fish/hectare and Knife River had the lowest fish density estimate at 119 fish/hectare (Figure 3).

To identify possible differences in the location of fish scattering layers between the two different methodological approaches, I compared the density estimates found in each of the sleds three directional zones (upper, middle, and lower) using a two-way ANOVA with the same depth zones for the down-looking data. In the upper water column, there was a significant effect of survey method, F (1, 239) = 82.58, $p < 0.001$, and a significant interaction, F (5, 239) = 6.04, $p < 0.001$, but there was no significant effect of transect, F (5, 239) = 2.20, $p = 0.055$. The Tukey HSD indicated that the fish density in the upper section of the water column (~3m-24m) was significantly higher in the sled-based survey compared to the ship-based survey for every transect (*ps* $<$ 0.001) except the Knife River ($p = 0.964$) and Sand Island transects ($p = 1.00$; Figure 4). The fish density in the middle section of the water column (~24m-36m) was not significantly different between survey methods for any transect, F (1, 239) = 0.00, $p =$ 0.999 (Figure 5), nor was there a significant interaction between survey method and transect, F (5, 239) = 0.24, $p = 0.947$. But there was a significant difference between transects, F (5, 239) = 7.88, $p < 0.001$. The fish density in the lower section of the water column (~36m and below) was not significantly different between survey methods for every transect, F (1, 239) = 0.39, $p = 0.533$ (Figure 6). There was no significant interaction between survey method and transect, F (5, 239) = 0.62, p =0.688, but there was a significant difference between transects, F (5, 239) = 7.78, $p < 0.001$.

Based on the CART model, fish length and mean bathymetric depth beneath the trawl were the only two explanatory variables that were significant for fish species apportionment (Figure 7). Fish smaller than 50mm were almost exclusively Rainbow Smelt. Fish between 50 and 88mm were a mix of age-0 coregonines including Cisco, Bloater, and some I could not conclusively identify to species. Fish between 88 and 153mm were predominantly Rainbow Smelt where bathymetric depths < 164m and a mix of Rainbow Smelt and Kiyi where depths > 164m. Fish > 252mm were predominantly Cisco. Fish between 153 and 252mm were a mix of Rainbow Smelt, Bloater, and Kiyi where bathymetric depths were < 124m and exclusively Kiyi at depths > 124m.

Subsequently, for the upper section of the water column I found that the ship-based and sled-based species composition estimates were only significantly different in the Grand Marais transect, X^2 (5, N = 12) = 11.24, $p = 0.046$; all other transects did not have significantly different species compositions, X^2 (5, N = 12) < 5.00, $ps > 0.05$ (Figure 8). For the middle section of the water column I found the ship-based and sled-based species composition estimates for all of the transects did not have significantly different species compositions, X^2 (5, N = 12) < 0.25, $ps > 0.05$ (Figure 9). This was true for the lower section of the water column as well, X^2 (5, N = 12) < 2.00, $ps > 0.05$ (Figure 10). For the whole water column (sections summed) I found that the ship-based and sled-based species composition estimates for all the transects did not have significantly different species compositions, X^2 (5, N = 12) < 10.39, ps > 0.05 (Figure 11).

Additionally, I examined the estimate of fish density for the entire western arm of Lake Superior. I found that the ship-based and sled-based species composition estimates for all of the transects did not have significantly different species compositions, X^2 (5, N = 12) = 1.36, p = 0.929 (Figure 12). Based on the CART model, the multi-directional sled mounted acoustic survey obtained approximately 3.0 times more Rainbow Smelt, 2.2 times more Cisco, 2.6 times more Kiyi, 1.6 times more Bloater, 2.9 times more unidentified young of year coregonines, and 3.2 times more large fish then the traditional ship-based survey in the western arm of Lake Superior (Table 3).

Discussion

Observed differences in fish density between acoustic survey methods showed that the multi-directional sled mounted acoustic survey detected significantly more fish than the traditional down-looking, ship-based acoustics. Three of the six transects had significantly higher fish densities from the sled-based survey when compared to the concurrent traditional ship-based survey. In the most extreme case, the Taconite Harbor transect, the multi-directional sled mounted acoustics detected a greater mean fish density that was 3.7 times more fish per hectare than the traditional down-looking acoustics. The Sand Island, Knife River, and Madeline Island transects did not display a significant difference between the estimated fish densities of the two survey methods. However, on average the sled-based survey obtained 60% more fish than the ship-based acoustic survey (Figure 9). Within the broader scope of understanding fish density estimate bias in current survey methods, it is pertinent to note that this 60% increase in estimated density is very similar to other studies comparing bottom trawl netting to down-looking acoustic surveys. It is generally accepted that bottom trawls miss 50% or more of the biomass estimated by traditional down-looking acoustic surveys (Davidson, Lara-Lopez, and Koslow 2015, Hoffman et al. 2009; Jakobsen et al. 1997; Mason et al. 2005; Stockwell et al. 2007). These findings suggest that underestimation of prey fish may be occurring when traditional down-looking acoustic surveys are used to estimate fish density, potentially due to those fish being undetectable by the traditional gear in the upper water column.

Patterns in the fish density estimates in specific depth layers indicate the sled had significantly higher fish density estimates in four out of the six transects in the upper layer of the water column (3m-24m, Figure 6). This suggests that fish are being missed within the upper water column of Lake Superior by traditional down-looking surveys. This phenomenon of a surface acoustic dead zone has been shown using mobile up-looking surveys on alewife populations in Lake Ontario (Elliott 2018; Riha et al. 2017), and stationary up-looking surveys in marine environments (De Robertis, Levine, and Wilson 2017; Thorne, Hedgepeth, and Campos 1989). Another explanation for the sled-based acoustics detecting higher fish densities in this upper region of the water column compared to the vessel-based acoustics, that may be happening independently or in conjunction with the acoustic dead zone, may be vessel avoidance behavior by the pelagic fishes (DuFour et al. 2018). The sled was deployed at 6m starboard and 50m aft of the ship, so it could have been sampling in undisturbed or herded distributions of fish that were not available to the traditional ship-based acoustics. Vessel avoidance may play an important role in acoustic surveys, and more work is needed to verify its contribution to fishery survey estimates.

The fish density estimates obtained by the multi-directional sled mounted acoustics from the middle layer (24m-36m) and the lower layer (36m-lakebed) of all six of the transects were not significantly different than the traditional down-looking survey (Figure 7 & 8). These results are supported by past research as traditional down-looking surveys are thought to have adequate sample volumes at these depths (Rudstam et al*.* 2009; Yule 2007).

Additionally, the results from the CART model indicate that there is no difference in inferred species composition between the traditional ship-based and multi-directional sled mounted acoustic survey methods, with the species composition difference detected in the upper section of Grand Marais being the only significant exception; due primarily to a larger proportion of Rainbow Smelt being detected by the sled. This, combined with the fact that the multi-directional sled mounted acoustic survey is obtaining significantly more fish per hectare than traditional ship-based surveys, implies that the fish density for all pelagic species is being underestimated by traditional methods in the western arm of Lake Superior (Table 3). This also highlights the importance of considering a multi-directional sled mounted acoustic survey, such as the one used in this study, as a new lens with which we can view and obtain more accurate species density estimates.

A recent study by Fisch (2018) highlights the need for accurate acoustic estimates. Their approach assumed a traditional down-looking acoustic estimate was an index of absolute spawner abundance, but stated that this assumption was conservative and could be improved with more detailed information. While conservative estimates are often preferred and effective in fisheries management, improving our ability to accurately estimate fish populations can aid in informing better conservation and economic management decisions. This is further supported when considering down-looking acoustics have been used to set commercial quotas for Cisco populations in Lake Superior. During November 2006, Yule et al. (2009) used the then newly-developed methods to estimate spawning Cisco biomass in the western arm of Lake Superior at 15,700 metric tons, so fishing-induced mortality at the time was considered trivial. Since then, additional lake-wide surveys have suggested spawner biomass has been trending downward, which is consistent with the decline noted by the recruitment index (Pratt et al. 2016). Additionally, Stockwell et al. (2009) recommended that harvest of spawning Cisco not exceed 10-15% of female biomass as estimated by acoustic surveys, and this guideline was adopted by the Minnesota Department of Natural Resources and the Ontario Ministry of National Resources in subsequent years to set quotas. Obtaining improved density estimates for fisheries like these can allow for maximization of their commercial and recreational value while also providing the crucial population estimates needed to maintain a sustainable fishery.

The underestimation of fish density in the upper water column also has ecological implications. Upon examining the CART apportioned sled-based acoustic survey species density estimates, there appears to be approximately a three-fold increase in Rainbow Smelt, coregonines, and Lake Trout in the western arm of Lake Superior. This indicates that there is more production within the secondary and tertiary consumers than previously documented. However, due to the coregonines obtaining sizes that exceeded Lake Trout's gape width many of them are unavailable for consumption (Mason, Johnson, and Kitchell 1998). This indicates that there may be increased predation pressure on rainbow smelt as they typically don't achieve sizes that allow them to escape Lake Trout predation. This is consistent with other studies on Lake trout feeding habits in Lake Superior as it has been reported that in the spring Rainbow Smelt made up 80% of Lake Trout diets (Ray et al. 2007).

Additionally, the presence of higher fish densities in the upper layer implies that there is some ecological benefit associated with it; whether it be abiotic or biotic in nature. Temperature, light intensity, and prey abundance (of primary producers, zooplankton, and small fish) may all play a role in this observation. Temperature plays an important role in fish growth and development and accessing the warmer upper layer nightly in the summertime may allow for metabolic processes to be accelerated (Pauly 1980). There is also more light available in surface waters at night which could indicate that planktivorous and piscivorous fish must enter this layer in order to forage. Moonlight opens up a considerable portion of the water column to foraging for Lake Trout in Lake Superior (Keyler, Matthias, and Hrabik 2019). This interaction when coupled with the fish density results also support previous work on fishes undergoing DVM in Lake Superior (Ahrenstorff et al. 2011; Hrabik et al. 2006; Stockwell et al. 2010). My findings indicate that there may be more feeding opportunities for piscivorous fishes in the upper layer, making the DVM patterns stronger than previously estimated. More targeted studies of interactions between fish, zooplankton, and primary producers in the upper water column of Lake Superior will be beneficial to unpacking the upper water columns full ecological significance to the whole lake. Further, better understanding the role and function of the upper water column in Lake Superior is of utmost importance to determining how its species dynamics may change in response to climate change.

Though not the focus of this study, it is also pertinent to note that I observed significant spatial differences in fish density and species composition across the different transects that I sampled in the western arm of Lake Superior with both survey methods. This reinforces the importance of using widely spread spatial data if lake-wide management strategies are to be implemented (Mason et al. 2005). It also points to an opportunity for the utilization of specific local management practices to improve the overall effectiveness of fisheries management (Berkes 2003; McConney and Charles 2008). One such example of a localized management practice currently in use within the

Wisconsin waters of Lake Superior is the maintenance of the Gull Island Shoal Refuge. The refuge has been effective at increasing the local Lake Trout populations in the Apostle Islands of Lake Superior (Johnson, Hansen, and Seider 2015). I also found that the spatial variation of fish density across transects was not the same between survey methods. This indicates that there may be a mismatch between fish density estimates in specific areas and management regulations set within those areas, particularly due to the fish populations within the upper water column.

With this study I provide support for the importance of refining and improving acoustic techniques since standard down-looking approaches may be underestimating pelagic fish population densities. Improved acoustic techniques could be applied to marine and freshwater systems and could help fisheries researchers and managers improve their understanding of aquatic systems and the accuracy of their studies and management. This study also provides context for future research on the behavior and role that aquatic organisms occupying the upper water column play within their respective aquatic systems and how that could be affected by climate change. My findings offer a baseline for future studies seeking to identify species that are most effected by vessel avoidance. The results of this study provide a context to better inform management decisions about ecologically, commercially, and recreationally important local fisheries, such as the Cisco fishery in Lake Superior, as well as on the other freshwater and marine fisheries assessed using standard survey techniques.

Tables and Figures

Table 1. Parameters for the traditional ship-mounted acoustics and sled-mounted multi-directional acoustics. All transducers are split-beam Biosonics units. The ship used a Biosonics portable DT-X echosounder and the sled used a Biosonics submersible DT-X echosounder. Ping rate was set at 2 pings per second but 1 ping per second was realized.

Frequency (kHz)	Orientation	Survey Method	Beam Angle	Realized Ping Rate (ping/s)	Pulse Width (ms)	Collection Threshold (dB)
70	Up-looking	Sled	5.0°	1	0.4	-100
70	Down-looking	Sled	5.0°	1	0.4	-100
120	Side-looking	Sled	8.0°	1	0.4	-100
123	Down-looking	Ship	7.5°	1	0.4	-100

Table 2. Information for the 14 sites trawled in the Western Arm of Lake Superior. All trawls were done after nautical twilight. TR2 and TR11 were not accomplished due to weather conditions restraining time.

Trawl ID	Transect ID	Date (Month/Day/ Year)	Begin Latitude and Longitude	End Latitude and Longitude	Tow Distance (km)	Mean Bathymetric Depth (m)	Trawl Mean Headrope Depth (m)	Trawl Time (min)
TR1	SI	8/27/2018	46°57.709; -91°04.195	46°56.322; -91°05.550	3.07	64.3	32.9	40
TR3	SI	8/27/2018	46°58.691; -91°15.326	46°57.995; -91°15.994	1.54	135.5	12.9	20
TR4	KR	8/28/2018	46°53.505; -91°25.090	46°53.046; -91°26.104	1.56	108.5	4.3	20
TR5	KR	8/28/2018	46°53.808; -91°35.442	46°53.381; -91°37.621	2.88	112.0	29.5	40
TR6	KR	8/28/2018	46°55.322; -91°45.390	46°55.087; -91°46.488	1.45	161.0	8.2	20
TR7	SB	8/28/2018	47°01.077; -91°16.879	47°00.948; -91°17.976	1.42	172.0	9.6	20
TR8	SB	8/28/2018	47°11.171; -91°17.711	47°11.009; -91°18.847	1.46	284.0	14.8	20
TR9	SB	8/29/2018	47°09.193; -90°57.308	47°09.010; -90°58.288	1.27	150.5	3.4	20
TR10	TH	8/29/2018	47°28.268; -90°52.516	47°28.146; -90°53.706	1.51	248.0	7.2	20
TR12	GM	8/29/2018	47°38.163; -90°21.399	47°38.860; -90°20.819	1.50	166.5	17.9	20
TR13	GM	8/29/2018	47°28.970; -90°20.026	47°30.567; -90°19.943	1.98	158.0	43.9	40
TR14	GM	8/30/2018	47°19.554; -90°18.475	47°18.540; -90°18.440	2.77	110.0	60.1	40
TR15	GM	8/30/2018	47°08.395; -90°18.775	47°09.037; -90°18.117	1.45	82.4	1.4	20
TR16	MA	8/30/2018	46°49.912; -90°31.347	46°49.180; -90°31.799	1.50	57.7	8.9	20

Table 3. Species specific density estimates for the western arm of Lake Superior. Each species specific fish density estimate represents a pooled mean that was obtained from the mean fish density estimates of six ~60km long sampling transects in the western arm. The fish density estimates obtained by multi-directional sled mounted acoustic survey are higher for all species present.

	Rainbow Smelt Density (Fish/Hectare)	Cisco Density (Fish/Hectare)	Kiyi Density (Fish/Hectare)	Bloater Density (Fish/Hectare)	Unid. YOY Coregonine Density (Fish/Hectare)	Large Fish Density (Fish/Hectare)
Traditional Ship-based Survey	21.2(*SD* = 1.72)	16.8(*SD* = 1.35)	7.1(*SD* = 1.91)	8.3(*SD* = 1.97)	1.4(*SD* = 1.43)	0.9(*SD* = 2.07)
Multi-directional Sled-based Survey	64.2(*SD* = 1.37)	37.2(*SD*= 1.39)	18.2(*SD* = 2.15)	13.2(*SD* = 1.24)	4.2(*SD* = 1.81)	2.9(*SD* = 2.15)
Sled-based: Ship-based ratio	3.0	2.2	2.6	1.6	2.9	3.2

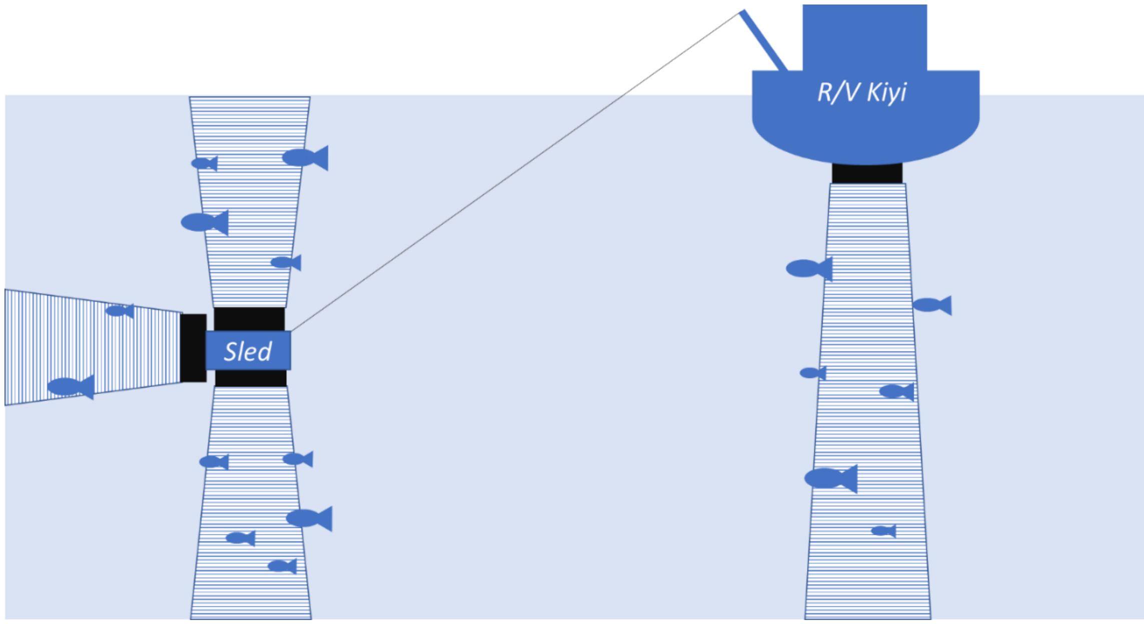

Figure 1. Acoustic sampling methods. The typical down-looking survey is shown on the right and the multi-directional sled mounted acoustic survey is on the left. The sled is 49m behind the ship, ~6m off the starboard side, and 30m deep at 5knots/hr.

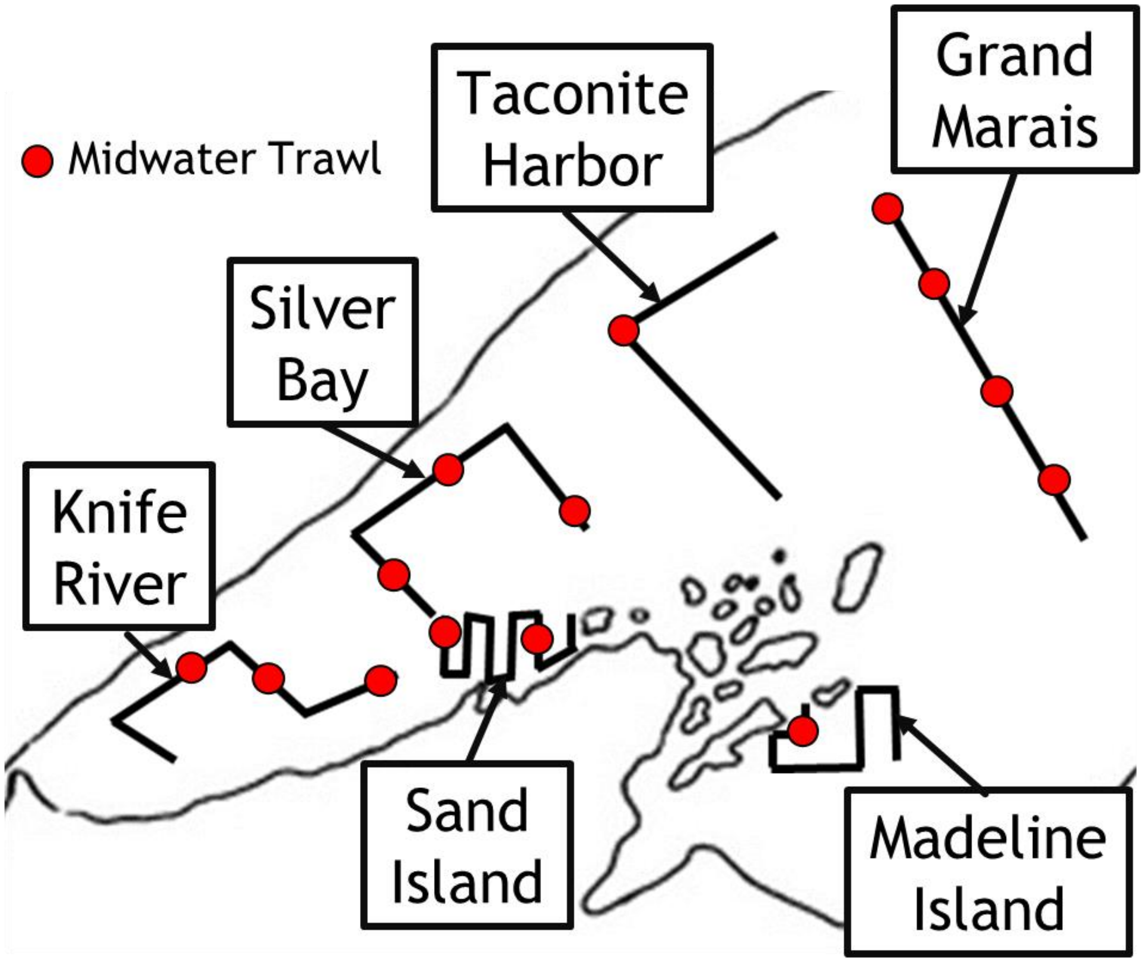

Figure 2. Map of surveyed transects in the western arm of Lake Superior. Each transect (shown in black lines) was approximately 60km in length. All transects were done in August 2018. Red circles indicate approximate locations of midwater trawls.

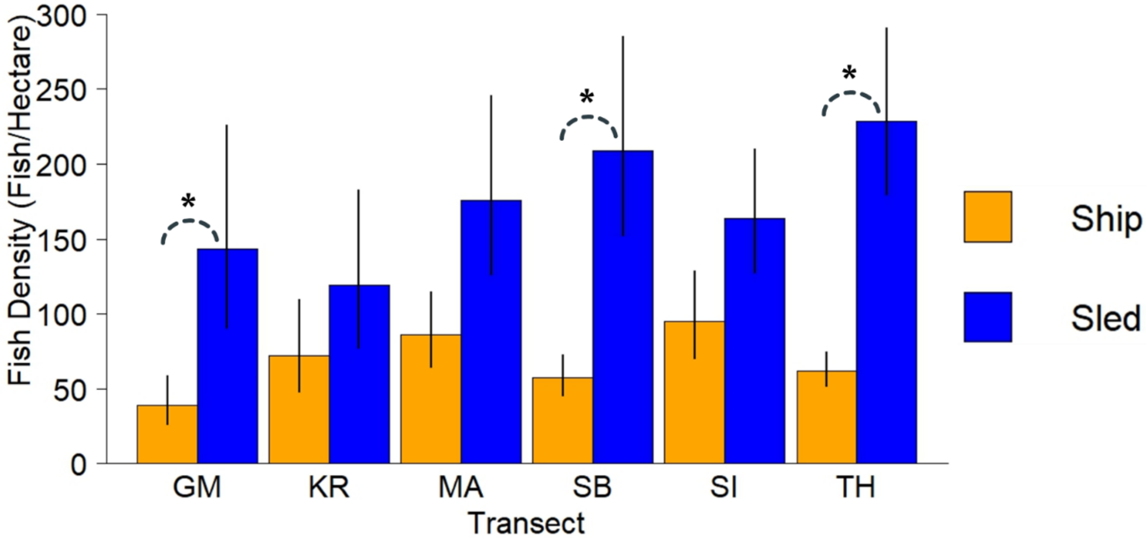

Figure 3. Comparison of mean fish density detected in the whole water column (approximately 3m - 0.5m above lakebed) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. Bars represent mean fish density per hectare from ~20 different 3,000m long sections of the water column on the six western arm sampling transects. The six transects are Grand Marias (GM), Knife River (KR), Madeline Island (MA), Silver Bay (SB), Sand Island (SI), and Taconite Harbor (TH). The error bars represent the 95% confidence intervals around each mean. There was a significant difference between survey methods on fish density. Asterisks indicate significant comparisons across survey method within transects ($p < 0.05$) from a Tukey HSD.

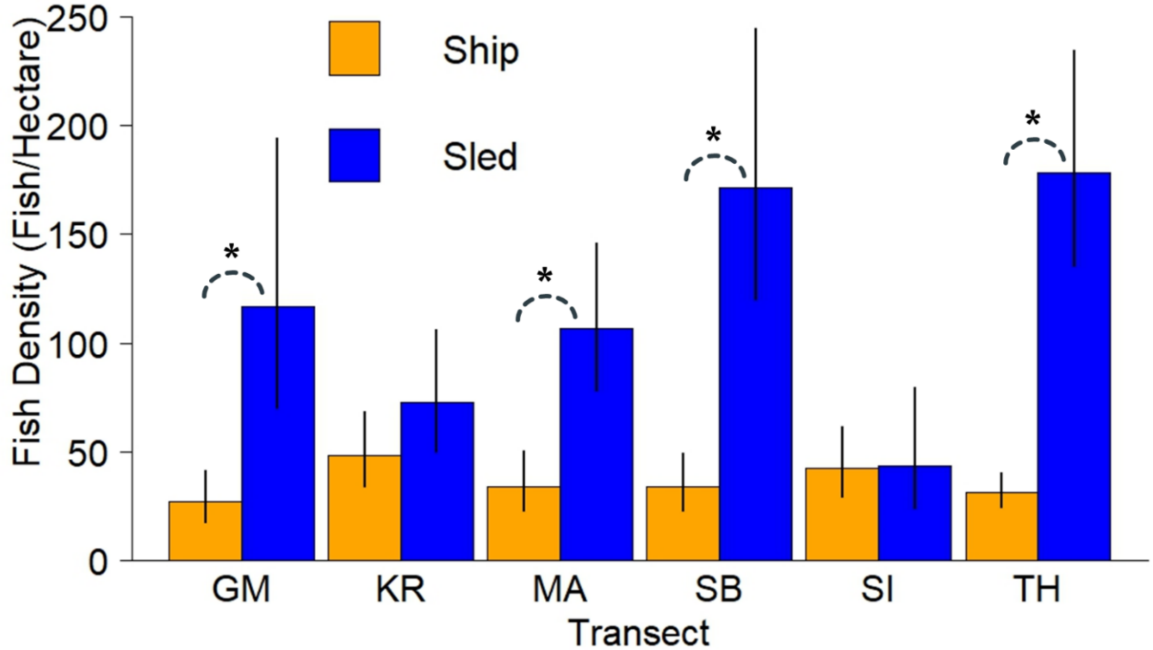

Figure 4. Comparison of mean fish density detected in the upper portion of the water column (approximately 3m-24m) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. Bars represent mean fish density per hectare from ~20 different 3,000m long sections of the water column on the six western arm sampling transects. The six transects are Grand Marias (GM), Knife River (KR), Madeline Island (MA), Silver Bay (SB), Sand Island (SI), and Taconite Harbor (TH). The error bars represent the 95% confidence intervals around each mean. There was a significant difference between survey methods on fish density. Asterisks indicate significant comparisons across survey method (p < 0.05) from a Tukey HSD.

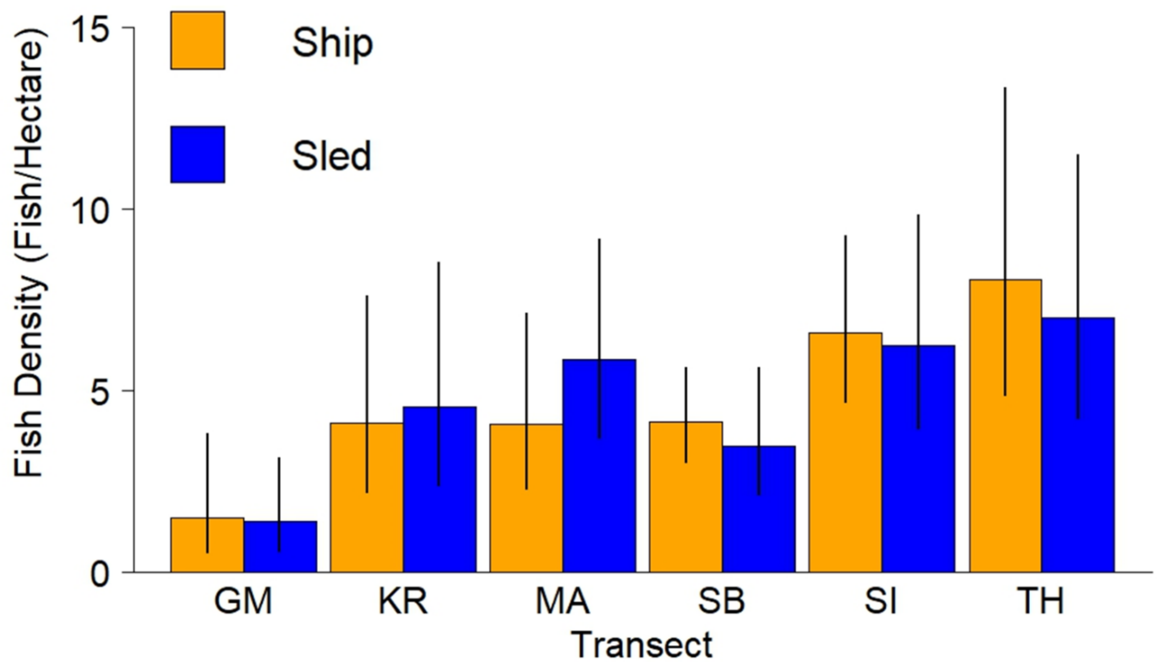

Figure 5. Comparison of mean fish density detected in the middle portion of the water column (approximately 24m-36m) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. Bars represent mean fish density per hectare from ~20 different 3,000m long sections of the water column on the six western arm sampling transects. The six transects are Grand Marias (GM), Knife River (KR), Madeline Island (MA), Silver Bay (SB), Sand Island (SI), and Taconite Harbor (TH). Mean fish density estimates were not significantly different between survey methods for all transects. The error bars represent the 95% confidence intervals around each mean.

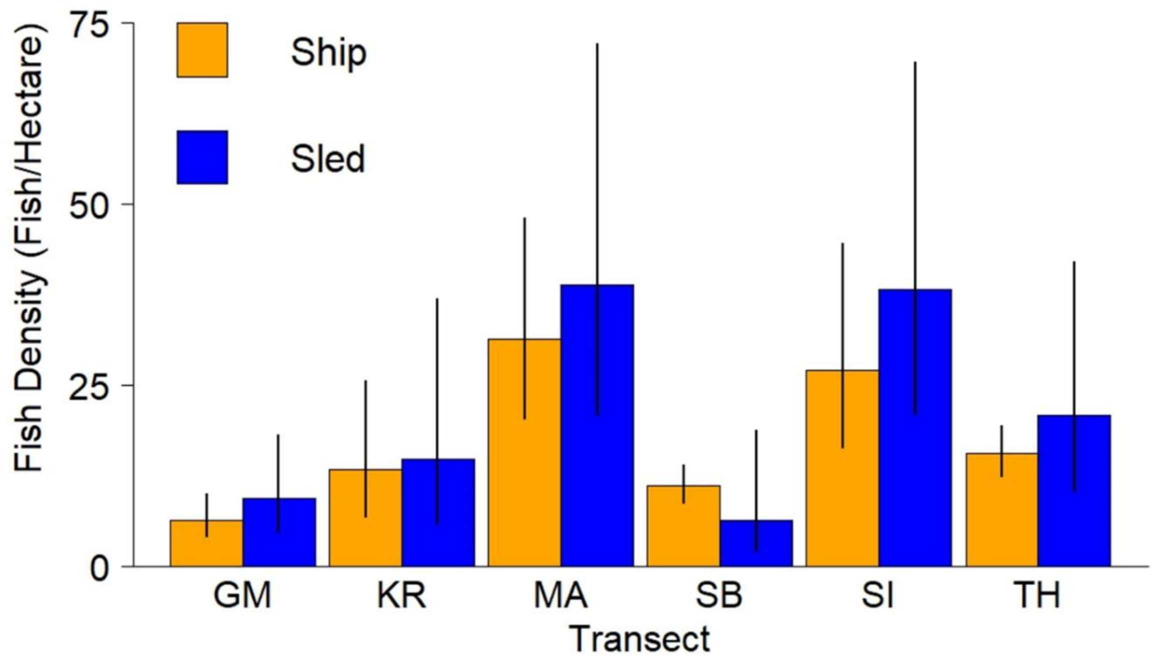

Figure 6. Comparison of mean fish density detected in the lower portion of the water column (approximately 36m- 0.5m above lakebed) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. Bars represent mean fish density per hectare from ~20 different 3,000m long sections of the water column on the six western arm sampling transects. The six transects are Grand Marias (GM), Knife River (KR), Madeline Island (MA), Silver Bay (SB), Sand Island (SI), and Taconite Harbor (TH). Mean fish density estimates were not significantly different between survey methods for all transects. The error bars represent the 95% confidence intervals around each mean.

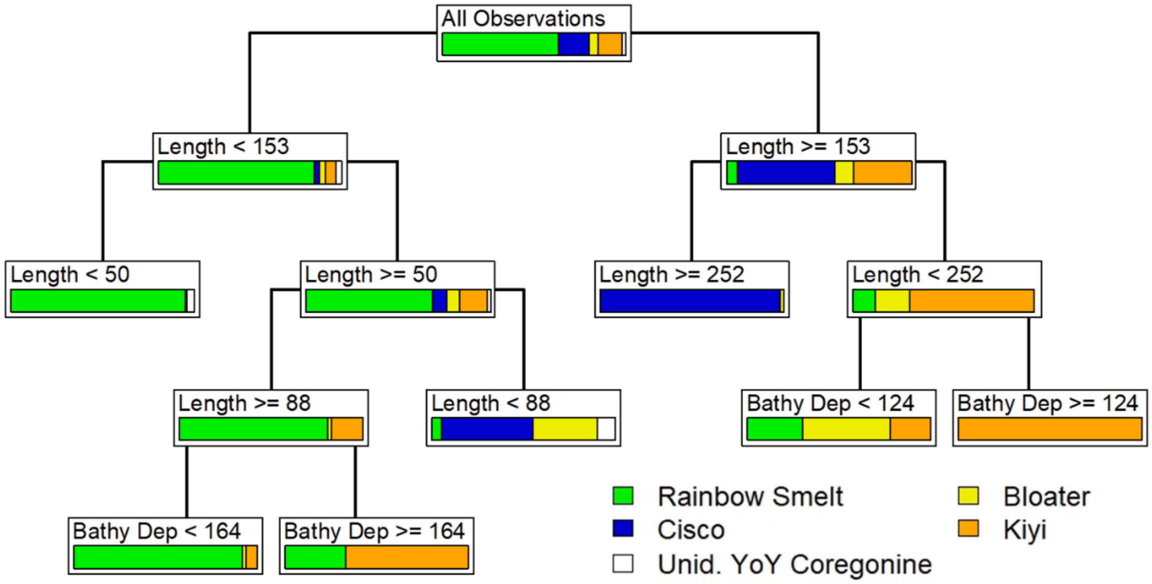

Figure 7. Dendrogram of the CART model used to assign species to single targets for all acoustic data. The Unid. YoY Coregonine group represents young of the year coregonines (Kiyi, Cisco, or Bloater) that were too cryptic or damaged by the trawl to identify. The explanatory variables provided to the CART model were: fish length (mm), footrope fishing depth (m), mean bathymetric depth (m), mean head-rope temperature (C^o), and distance of footrope to bottom (m). The CART model selected two of the five explanatory variables I provided it: fish length and mean bathymetric depth beneath the trawl.

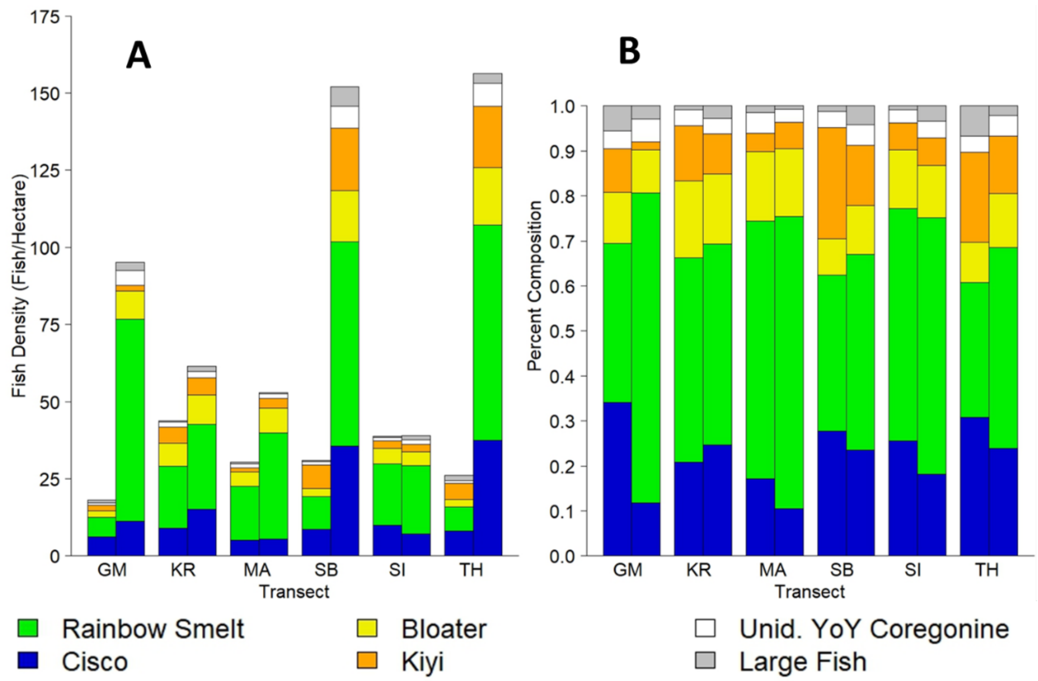

Figure 8. Comparison of mean fish density by species (A) and percent species composition (B) detected in the upper water column (approximately 3m - 24m) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. The Unid. YoY Coregonine group represents young of the year coregonines (Kiyi, Cisco, or Bloater) that were too cryptic or damaged by the trawl to identify. The Large Fish group were any single targets that had an estimated length that exceeded 510mm. Bars in graph A represent mean fish density per hectare from approximately 20 3,000m long segments from six western arm sampling transects and bars in graph B indicate percent species composition for those same transects. Ship estimates are the first bar and sled estimates are the second bar for each transect. The six transects are Grand Marias (GM), Knife River (KR), Madeline Island (MA), Silver Bay (SB), Sand Island (SI), and Taconite Harbor (TH). The ship-based and sled-based species composition estimates are only significantly different in the Grand Marais transect. All other transects do not have significantly different species compositions.

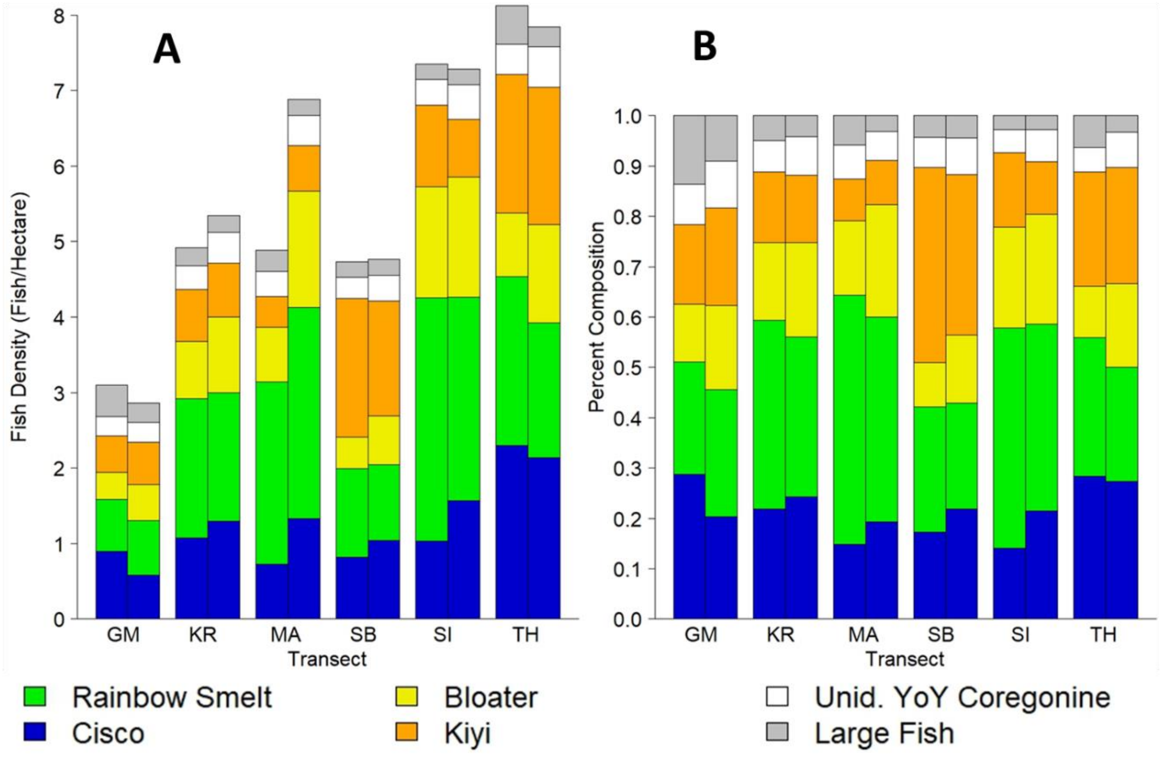

Figure 9. Comparison of mean fish density by species (A) and percent species composition (B) detected in the middle portion of the water column (approximately 24m - 36m) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. The Unid. YoY Coregonine group represents young of the year coregonines (Kiyi, Cisco, or Bloater) that were too cryptic or damaged by the trawl to identify. The Large Fish group were any single targets that had an estimated length that exceeded 510mm. Bars in graph A represent mean fish density per hectare from approximately 20 3,000m long segments from six western arm sampling transects and bars in graph B indicate percent species composition for those same transects. Ship estimates are the first bar and sled estimates are the second bar for each transect. The six transects are Grand Marias (GM), Knife River (KR), Madeline Island (MA), Silver Bay (SB), Sand Island (SI), and Taconite Harbor (TH). The ship-based survey and sled-based survey do not have significantly different species compositions for all transects.

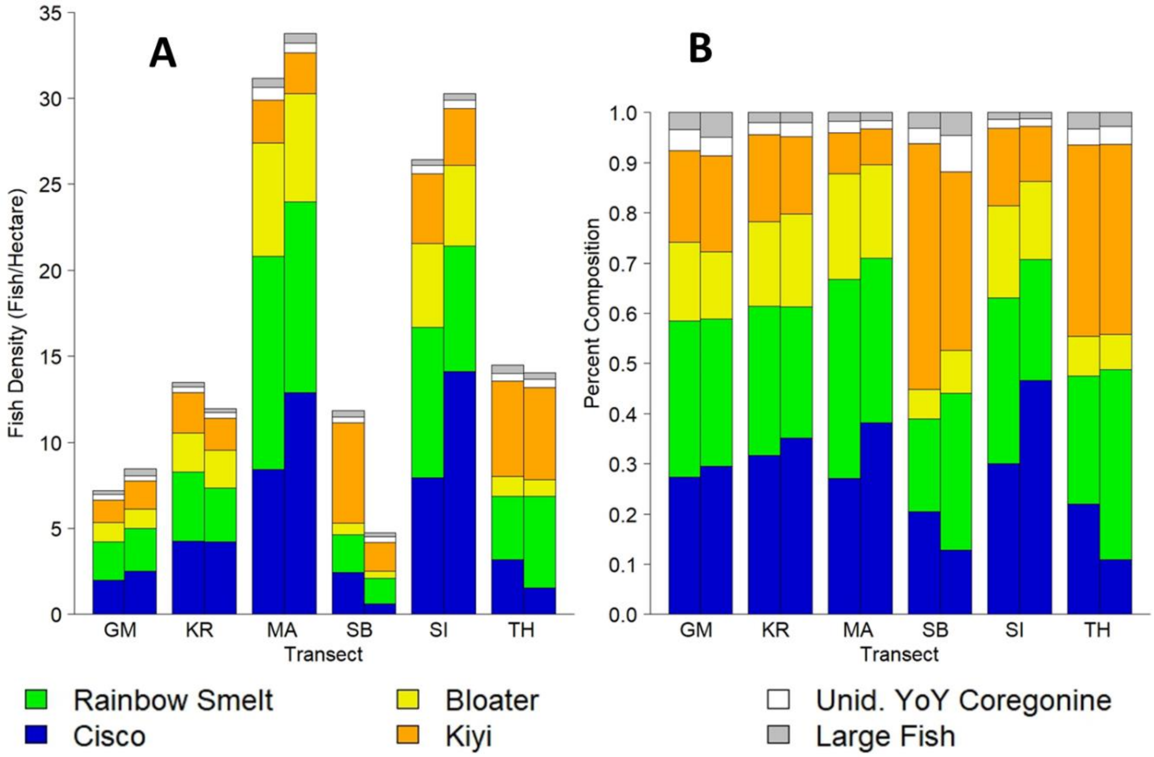

Figure 10. Comparison of mean fish density by species (A) and percent species composition (B) detected in the lower water column (approximately 36m – 0.5m above the lakebed) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. The Unid. YoY Coregonine group represents young of the year coregonines (Kiyi, Cisco, or Bloater) that were too cryptic or damaged by the trawl to identify. The Large Fish group were any single targets that had an estimated length that exceeded 510mm. Bars in graph A represent mean fish density per hectare from approximately 20 3,000m long segments from six western arm sampling transects and bars in graph B indicate percent species composition for those same transects. Ship estimates are the first bar and sled estimates are the second bar for each transect. The ship-based survey and sled-based survey do not have significantly different species compositions for all transects.

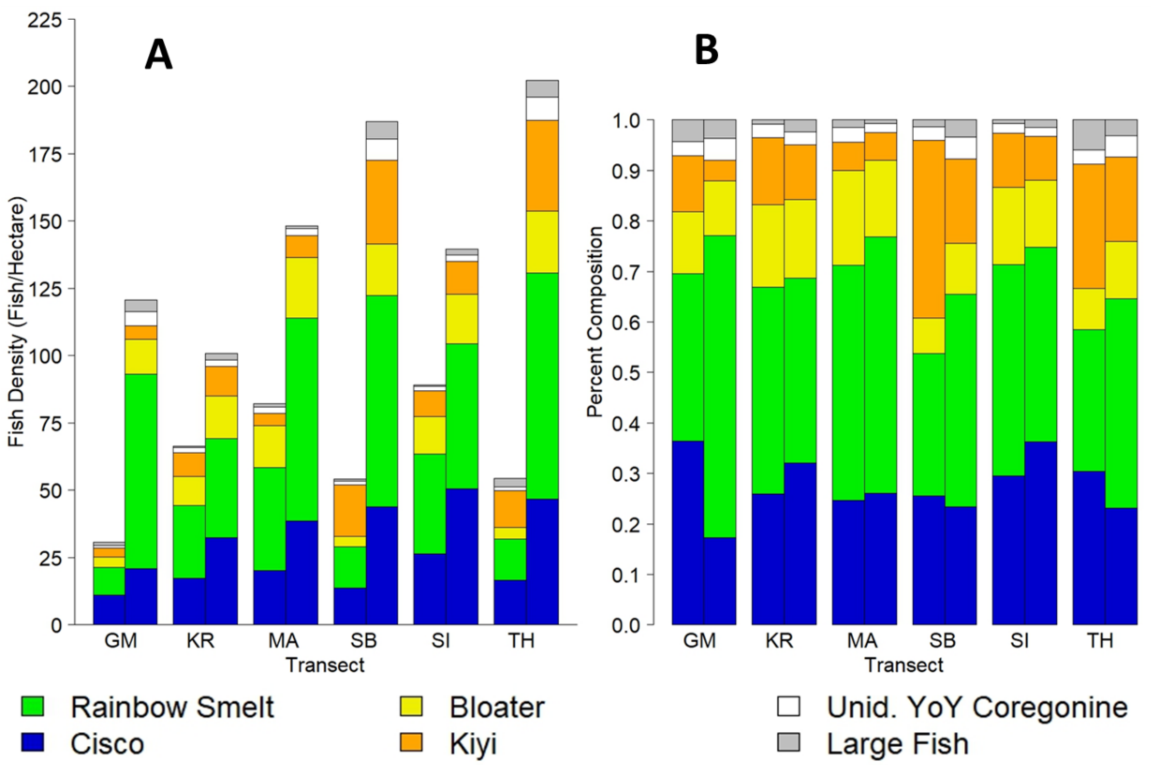

Figure 11. Comparison of mean fish density by species (A) and percent species composition (B) detected in the whole water column (approximately 3m – 0.5m above the lakebed) by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. The Unid. YoY Coregonine group represents young of the year coregonines (Kiyi, Cisco, or Bloater) that were too cryptic or damaged by the trawl to identify. The Large Fish group were any single targets that had an estimated length that exceeded 510mm. Bars in graph A represent mean fish density per hectare from approximately 20 3,000m long segments from six western arm sampling transects and bars in graph B indicate percent species composition for those same transects. Ship estimates are the first bar and sled estimates are the second bar for each transect. The ship-based survey and sled-based survey do not have significantly different species compositions for all transects.

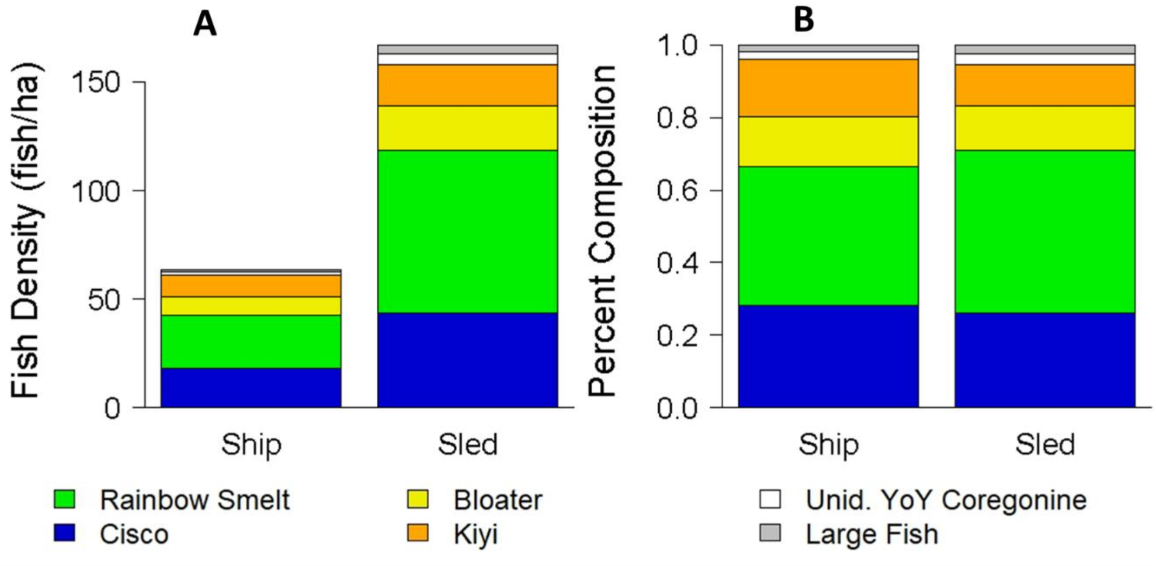

Figure 12. Comparison of mean fish density by species (A) and percent species composition (B) detected in the whole water column (approximately 60m – 0.5m above the lakebed) of the western arm of Lake Superior by the multi-directional sled mounted acoustic survey and the traditional down-looking survey. The Unid. YoY Coregonine group represents young of the year coregonines (Kiyi, Cisco, or Bloater) that were too cryptic or damaged by the trawl to identify. The Large Fish group were any single targets that had an estimated length that exceeded 510mm. Bars in graph A represent mean fish density per hectare from six 60km long western arm sampling transects and bars in graph B indicate percent species composition for those same transects. Ship estimates are the first bar and sled estimates are the second bar for each transect. The ship-based survey and sled-based survey do not have significantly different species compositions.

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