Spatial Assessment of Pelagic Fish in the Toronto and Region Area of Concern in September 2016

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Spatial Assessment of Pelagic Fish in the Toronto and Region Area of Concern in September 2016

by

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Split-beam hydroacoustic and mid-water trawling surveys of the Toronto and Region Area of Concern (AOC) were undertaken in the fall of 2016. The primary objective of these surveys was to compare the spatial distribution of pelagic fish density and abundance within the AOC, with particular focus on differences between the central waterfront (inner and outer Toronto Harbour) and more exposed coastal areas. Since surveys were completed during the day, the majority of fishes were in schools. Results suggest pelagic fishes are unequally distributed throughout the AOC, with areas of high density (0.12-0.39 $\#/m^3$) and biomass (0.55-2.06 g/m^3) within and adjacent to the central waterfront. Mid-water trawling had generally low CPUE throughout the AOC with Alewife (*Alosa pseudoharengus*) dominating much of the catch. Round Goby (*Neogobius melanostomus*) were also frequently encountered, which was likely the result of the trawl net hitting bottom and catching this benthic species. Overall, results highlight the importance of the central waterfront and adjacent waters both within the AOC as well as in western Lake Ontario as a habitat for pelagic forage fish that can in turn support the higher tropic species that are targets of the RAP and are of commercial, recreational, and aboriginal importance throughout Lake Ontario.

RESUME

Midwood, J.D., Leisti, K.E., Milne, S.W., Doka, S.E., 2018. Spatial Assessment of Pelagic Fish in the Toronto and Region Area of Concern in September 2016. Can. Tech. Rep. Fish. Aquat. Sci. 3286: viii + 54 p

Des relevés hydroacoustiques à faisceaux divisés et des relevés au chalut pélagique dans le secteur préoccupant de Toronto et de la région ont été entrepris à l’automne 2016. L’objectif principal de ces relevés était de comparer la répartition spatiale de la densité et de l’abondance des poissons pélagiques dans le secteur préoccupant, en mettant l’accent sur les différences entre le front d’eau central (intérieur et extérieur du port de Toronto) et les zones côtières plus exposées. Puisque les relevés ont été effectués pendant la journée, la majorité des poissons étaient en bancs. Les résultats laissent entendre que les poissons pélagiques sont inégalement répartis dans l’ensemble du secteur préoccupant, avec des zones de densité élevée (0,12-0,39 $\#/m^3$) et de biomasse (0,55-2,06 g/m^3) dans le front d’eau central et ses environs. La pêche au chalut pélagique a généralement été caractérisée par de faibles prises par unité d’effort dans l’ensemble du secteur préoccupant, le gaspareau (*Alosa pseudoharengus*) dominant une grande partie des prises. Le gobie à taches noires (*Neogobius melanostomus*) a également été fréquemment rencontré, ce qui est probablement dû au fait que le chalut de fond a touché le fond et capturé cette espèce benthique. Dans l’ensemble, les résultats soulignent l’importance du front d’eau central et des eaux adjacentes dans le secteur préoccupant et dans l’ouest du lac Ontario en tant qu’habitat pour les poissons fourrages pélagiques, qui peuvent à leur tour soutenir les espèces des niveaux trophiques supérieurs qui sont des visées par le plan d’action d’assainissement et qui ont une importance commerciale, récréative et autochtone dans le lac Ontario.

1.0 INTRODUCTION

Two important beneficial use impairments (BUI) for the Toronto and Region Area of Concern (AOC) are the *degradation of fish and wildlife populations* (BUI #3) and the *loss of fish and wildlife habitat* (BUI #14). Since much of the loss of habitat occurred through infilling of wetlands and coastal habitats, the littoral zone (<2 m) has been a key area of focus for restoration actions and habitat and fish community assessments (RAP 2016). This includes targets to increase native piscivore biomass and habitat suitability for warm and cool water fishes such as Northern Pike (*Esox lucius*), Smallmouth Bass (*Micropterus salmoides*), and Walleye (*Sander vitreus*). While assessment strategies are well established for these nearshore fishes through electrofishing and trap netting efforts (Hoyle et al., 2018), less work has been done on forage fishes that occur in adjacent limnetic waters (herein referred to as "pelagic fish"). This is despite their potential importance as a prey base for some of the aforementioned native piscivores.

Recent acoustic telemetry efforts in the Toronto and Region AOC have documented frequent use of limnetic waters by Northern Pike and Walleye as well as prolonged movements by Walleye outside of the central waterfront (Midwood, unpublished data). For Walleye, these forays into Lake Ontario are suggestive of a reliance on pelagic forage fishes as a food source. Therefore, a healthy and productive pelagic fish community is essential for supporting higher trophic levels and a detailed assessment of spatial differences in the density and biomass of pelagic fish would contribute to overall assessments of fish population status within the AOC.

In the fall of 2016, the Great Lakes Laboratory for Fisheries and Aquatic Sciences (GLLFAS) of Fisheries and Oceans Canada (DFO) with the assistance of the Toronto and Region Conservation Authority undertook hydroacoustic and trawling surveys of the Toronto and Region AOC. The objective of these surveys was to assess the distribution of pelagic fish in the AOC. The hydroacoustic and trawling data were analyzed by Milne Technologies who prepared a detailed report on the methodology and a summary of the results (DFO GLLFAS, 2017). The objective of the current report is to compare the spatial distribution of pelagic fish among regions of the Toronto and Region AOC, with special focus on their density, biomass, and depth distribution. Additionally, temperature and depth profiles are presented to help describe habitat conditions among regions. The 2016 hydroacoustic and trawling survey loosely followed similar surveys that were conducted in Toronto Harbour by GLLFAS in 2009 and 2010 (DFO GLLFAS 2010, DFO GLLFAS 2011, DFO GLLFAS 2012), but the extent was expanded to include more exposed areas east and west of the harbour.

2.0 METHODS

2.1 STUDY SITE

Hydroacoustic surveys and trawling were completed between September 6 – 9 and 19 – 22, 2016 within the Toronto and Region AOC extending from Etobicoke Creek to the west and the Rouge River to the east (Table 1; Figure 1). All surveys were completed within the daytime period (08:00-19:00). The survey area included many different habitat types and levels of development. The north shore of the Inner Harbour area (INNH) is the primary industrial, shipping and tourist region and is juxtaposed against the more natural Toronto Islands to the south. This central waterfront area accepts the inflow of the Don River, one of four large river systems that empty into the survey area. Two of the other systems are located to the west, with the Humber River (HBNR) providing important spawning habit for several potamodromous fish species and Etobicoke Creek (ETOB) representing a more degraded urban system. The last river system, the Rouge River (ROGE), is situated to the east and supports remnant cold-water fish populations in its headwaters, and warm-water fishes in its lower reach. The Eastern Headland region (EHDL) is located to the east of the main harbour and includes the long jut of landfill known as the Leslie Street Spit that extends out to Tommy Thompson Park. The area east of the spit extending through the "The Beaches" is characterized by its wind-swept sand and gravel beaches. It is important to note that this area also includes the Ashbridge's Bay wastewater treatment plant, the largest sewage treatment facility in Canada. The sheltered waters on the northwest side of the spit, known as the Outer Harbour (OUTH), include several marinas and docking facilities for recreational boaters. Waters along the southern coast of the Toronto Islands (OUTI) and Tommy Thompson Park (TTPK) are more influenced by Lake Ontario and include portions of the Toronto Scarp where depths drop off quickly from 20-60 m. Further east, the shoreline topography becomes steeper towards the Bluffers Creek survey area (BLUF) descending to lower elevations by Rouge Park (Figure 1).

2.2 SURVEY DESIGN AND METHODOLOGY

The 2016 Toronto Harbour hydroacoustic survey design included acoustic transects both with and without concurrent mid-water trawling. The survey design followed three methods. First, in the ETOB, HBNR, EHDL, and BLUF areas, transects were generally run perpendicular to the depth contours (Figure 1). Transect lengths varied based on bathymetry and transects in HBNR and EHDL loosely followed tracks from the 2009 and 2010 surveys. The same perpendicular transects were also planned for the ROGE, but due to high wind and wave action transects were shifted to run approximately parallel to the depth contours in an attempt to minimize movement of the acoustic transducer. Time-based (20 minutes) mid-water trawling with concurrent acoustics was undertaken on a portion of these transects (alternating between nearshore and offshore trawls for successive parallel transects), while the remainder was surveyed only with hydroacoustics. The second method involved depth stratified transects that followed specific depth contours related to the previous 2009 and 2010 bottom trawling sites at OUTI, OUTH, and INNH. Surveys in TTPK were not specifically planned for 2016, but one transect from EHDL crossed into this sector. Finally, supplementary surveys were completed within INNH on September 8, 2016 to investigate fish activity and behaviour associated with a plume of turbid water discharging from the Don River (Figure 1); however, these data will not be discussed in the present report.

2.2.1 Temperature and Dissolved Oxygen Profiles

At the start of each trawling transect, a YSI Sonde EXO multiprobe (YSI Inc., Yellow Springs, OH) was lowered into the water and measurements of water temperature (°C) and dissolved oxygen (DO; mg/L) were recorded at 1-m intervals (until a thermocline was evident after which intervals were increased to 5-m), up to a maximum depth of 60 m. The main objective of these profiles was to verify the presence of a thermocline and document its depth.

2.2.2 Mid-Water Trawling

A small-mesh, pelagic mid-water trawl (built by CanTrawl Nets Ltd., BC) was used for acoustic target verification and to collect information about the species and size composition of the Toronto and Region AOC fish communities. Trawls were run concurrently with hydroacoustics unless weather conditions interfered with hydroacoustic equipment, in which case the surveys were then completed separately. The trawl headline was 7.2 m wide and had an overall length of 13.6 m. The design was modified from Emmrich et al. (2010) and was constructed from 38.0 mm (1.5") and 19.0 mm (0.75") netting with a 9.5 mm (3/8") knotless nylon liner in the cod-end. Mid-water doors (0.5 m x 1.0 m) were constructed from rolled aluminum and door spread was estimated from the observed distance between surface floats attached to the upper wing tips.

The trawl was deployed using a single warp line and trawl depth was estimated from a known relationship between warp length and vessel speed. Onset level-loggers were attached to the foot-rope and head-line of the trawl to provide an estimate of the trawl mouth height. The depths of the trawls varied and were chosen by the acoustic survey crew to sample specific areas and layers where targets of interest were observed. The total trawl sampling volume (and area) was estimated from the observed vessel track and trawl duration. Fish caught were enumerated and identified to species. Total length (TL; mm) and wet mass (g) were recorded for up to twenty fish of each species per trawl. If there were more than twenty fish of a species in the trawl, the remainder were counted, bulk weighed and the total length of the approximately largest and smallest fish within the bulk sample were recorded.

2.2.3 Hydroacoustics

Hydroacoustic data were collected using the BioSonics (BioSonics Inc., Seattle, WA) DTX echo-sounder system multiplexed with two split beam transducers (6.9^{o} X 6.9^{o} 200 kHz and 7.7˚ X 7.7˚ 120 kHz). The transducers were mounted on a custom designed "dead-weight" tow body and deployed along-side the CCGC Kelso at mid-ship to avoid hull cavitation and prop-wash. The downward-looking transducers and tow body were deployed approximately 1.0 m below the surface. GPS data were provided to the acoustic system from an external Garmin GPS Map 78s (Garmin Ltd., Olathe, KS). Parameter settings for data acquisition and detailed calibration information can be found in DFO GLLFAS (2017).

The hydroacoustic data were processed by Milne Technologies using Echoview processing software (Echoview Software Pty. Ltd., Hobart, Tasmania). To be consistent with the 2009/2010 surveys, only the 200 kHz data were analyzed. Given that the Toronto and Region AOC survey areas included a diverse range of water depths, wind exposure, shoreline development, and meso-habitats, the survey area was partitioned into nine separate analysis sectors (Figure 1). The areas were chosen using several habitat criteria including depth, bottom complexity, and basin isolation. The 2016 acoustic analyses used the same analysis sectors as defined in the 2009 and 2010 Toronto Harbour reports (DFO GLLFAS 2010, DFO GLLFAS 2011). It is important to note that, in 2016, several of the analysis sectors in the Toronto and

Region AOC were modified to include transect segments that were observed to be outside the previously defined sectors. Specifically, HBNR, OUTI, TTPK and EHDL sectors were expanded to include more offshore areas. Three new analysis sectors were also defined for ETOB, BLUF and ROGE. Within each analysis sector, the backscatter energy was integrated over the cruise track in 50 m segments or Elementary Distance Sampling Units (EDSUs), which is consistent with the 2009 and 2010 analysis. Echo integration estimates of fish density were binned in two manners, 1.0 m bins (1.0 m depth strata bins from the surface to the bottom) and summed values across the entire water column.

Fish schools were analyzed separately as detailed in DFO GLLFAS (2017). After excluding the schools, echo integration estimates were derived for the remainder of the data and partitioned into six fish size classes (Table 2). These general fish size class categories were chosen to standardize the size-stratified fish density estimates with previous acoustic surveys (i.e. 2009/2010 Toronto surveys). We used Love's (1971a, 1971b) target strength model to estimate the equivalent target strength of the class limits for each of the six fish size categories. The DFO-GLLFAS (2017) report describes in detail the process for estimating fish density and biomass from echo integration.

Inspection of the 2016 acoustic survey echograms revealed the presence of gas bubbles throughout the water column of several transects, particularly in the central waterfront (Appendix 1). The bubbles appear within the echograms either as single targets or as stacked columns of individual targets extending up from the acoustically detected bottom. Gas bubbles are problematic for acoustics as they often share the same acoustic properties as small fish targets and therefore fish density estimates can be biased (Ostrovsky 2009). Two methods were used to detect and remove the acoustic backscatter that was caused by these bubbles and they are described in greater detail in Appendix 1.

2.3 DATA ANALYSIS

All analyses were undertaken separately for datasets that excluded schools ($TH_{(NoSchools)}$), only included schools (i.e., no non-schooling fish; $TH_{(Schools)}$), and included both schools and non-schooling fish ($TH_{(All)}$). The relative size of fish schools in the Toronto and Region AOC were estimated based on their trace length. The school trace length was defined as observed length of a school in the horizontal dimension (also referred to as the school width) and was computed by using the Pythagorean theorem to subtract the GPS coordinates of the first pixel encountered in the defined region from the last one encountered. (Diner 1998; Milne et al. 2005; Dunlop et al. 2010). Differences in fish density ($\#/m^3$) and biomass (g/m^3) could not be compared statistically as all datasets were zero-inflated (many or most data points were zero). Instead, these data are presented as mean with standard error as well as plotted spatially and results are interpreted descriptively. To explore spatial differences in fish distributions, we compared the distribution of fish encounters within a sector to a null hypothesis that fish were equally distributed across the entire sampling region. To accomplish this, the proportion of EDSU where fish were present within each sector was compared to the regional proportion of EDSU where fish were present using a Fisher's Exact test ($\alpha = 0.05$ for all tests). Regional values varied by dataset and were lowest for $TH_{(Schools)}$ (fish detected at 8.8% of EDSU) and highest for the combined dataset ($TH_{(All)}$; fish detected at 42.0% of EDSU); $TH_{(NoSchools)}$ was slightly lower at 37.5% of EDSU. All data preparation and analyses were completed in R Studio (RStudio, Inc., Boston, MA).

3.0 RESULTS

At times, weather conditions and boat traffic impeded the progress of surveys, resulting in reduced sampling effort, a change in orientation of the sampling surveys (to limit rocking of the boat), or detours around obstacles for some of the survey locations (Figure 1). Given the wide range of water depths that were sampled, effort (measured as volume of water surveyed per analysis sector, m^3) was variable among analysis sectors. Table 1 summarizes the time, dates, and distances covered during the 2016 survey while Table 3 provides information on the area coverage.

3.1 TEMPERATURE AND DISSOLVED OXYGEN PROFILES

Since Toronto and Region AOC profiles were collected solely during the late summer, thermoclines were primarily evident at deeper sites (>30 m) setting up between 20-30 m (see Figures 2a and 2b for mean profiles and Appendix 2 for individual profiles). Thermoclines were also present at all sites in the Inner Harbour and some of the Outer Harbour sites (Appendix 2 Figures A2a-e), with lower DO levels below the thermocline at some of the Inner Harbour sites (i.e., Figure 2b). For the remaining sites, at the time of sampling, a thermocline was not evident and was likely sitting at a deeper depth than the survey location.

3.2 MID-WATER TRAWLING

A total of 41 trawls were completed for the Toronto and Region AOC survey with the number of trawls by analysis sector ranging from one in TTPK to nine in OUTH (Table 4). Weather conditions and time constraints contributed to the inconsistency in sampling effort, which translated into high variability in the trawl area swept per sector (Figure 3). With the exception of a trawl transect in OUTH, all other trawl transects were only sampled once during the survey period. The depths of the trawls ranged from 2 to 24 m with the bulk of the fish caught between 6 and 13 m (Table 4). Fish catches in many of the trawls were low with just under two thirds of the trawls reporting no catch and only nine trawls with catches in excess of 10 fish. No fish were caught in BLUF, HBNR and TTPK. Of the 2040 fishes caught, 71% were caught in OUTH and 21% were caught in INNH and these sectors also recorded the highest CPUE values. Species richness was also low, ranging from one in EHDL, ETOB and ROGE to five in OUTH.

With the exception of Alewife (*Alosa pseudoharengus*) in the INNH, Round Goby (*Neogobius melanostomus*) had the highest rates of capture across all analysis sectors (Figure 4) and comprised 58% of the total catch by species (Table 5). The largest fish caught was also a Round Goby (124 mm). Based on adult fish total lengths by species as reported in Eakins (2017), all of the Alewife and Rainbow Smelt (*Osmerus mordax*) captured in the trawls were juveniles. A mix of juvenile and adult Brook Stickleback (*Culaea inconstans*) and Threespine Stickleback (*Gasterosteus aculeatus*) were also captured during the survey.

3.3 HYDROACOUSTICS

During the 2016 Toronto and Region AOC surveys, a high proportion of the observed fish density and biomass occurred within schools. Overall, daytime estimates of mean fish density (numbers per m^3, >2.9 cm TL) and biomass (g/m^3) by analysis sector for schooling fish were between 4 and >560 times higher than estimates where schools were excluded (Figures 5a-c). Observed schools were variable in size with a mean trace length of 9.1 ± 12.8 m (uncorrected for beam-width). The largest school was observed in INNH and was over 129.0 m long. There was also considerable variability in the effort among analysis sectors (reflected as the number of EDSU), ranging from a low of 36 EDSU at TTPK and a high of 356 EDSU at EHDL (Table 6).

3.3.1 Spatial Differences

For fish not in schools, mean fish density appeared to be highest in INNH and OUTH (Figure 5a). OUTH appeared to have the highest density for schools; however, there was considerable variation among EDSU in this sector that was driven by a single EDSU with a density estimate of over 50 fish /m^3. When this value was excluded, the mean density at OUTH was comparable to OUTI and INNH (Figure 5b). Density estimates for schools were an order of magnitude higher than non-schooling fish. Consequently, patterns in the pooled dataset ($TH_{(All)}$) were nearly identical to the school only dataset (Figure 5c).

When the non-schooling fish density data were categorized into fish size classes, the smallest fishes (29 to 58 mm TL) had the highest mean densities across all sectors except for ETOB and TTPK, which had few fish overall and highest mean densities for size class 3 (82 to 130 mm TL; Appendix 3 Table A3a; Figure 6a). As fish size increased, there was generally a decrease in density although INNH and OUTH showed a slight increase in density for fish that were between 82 and 130 mm TL and 130 and 250 mm TL, respectively.

Biomass results generally followed similar patterns as density, with INNH and OUTH having the highest biomass for non-schooling fish (Figure 5a). OUTH had the highest biomass for $TH_{(Schools)}$ and $TH_{(All)}$; however, it was once again comparable to INNH and OUTI when a single EDSU with a biomass of over 200 g/m^3 was excluded (same EDSU that was excluded for density; Figure 5a-c). Generally, mean biomass for schools by sector was still higher than for non-schooling fish, but in some sectors (e.g., INNH) non-schooling fish made a greater contribution to biomass (Figure 5a-b). Although the smallest fish made the greatest contribution to fish density, the larger fish (size classes 5 and 6 representing fish between 250 to 1200 mm TL) dominated the mean biomass estimates (Appendix 3 Table A3b; Figure 6b). This was particularly evident at INNH and OUTH.

Fish were detected in significantly more EDSU at INNH compared to the regional frequency for all datasets (Fisher's Exact, $p<0.001$) and in significantly more EDSU at TTPK for $TH_{(NoSchools)}$ and $TH_{(All)}$ (Fisher's Exact, $p<0.05$; Table 6; Figures 7a-c). Four sectors had significantly fewer EDSU with fish (BLUF, EHDL, ETOB, and ROGE) and, except for EHDL with fewer schools ($p<0.05$), this was largely driven by lower numbers of non-schooling fish ($TH_{(NoSchools)}$ and $TH_{(All)}$

Fisher's Exact <0.001, Figures 7a-c). When plotted spatially, similar patterns are evident with many EDSU in INNH having non-zero values for density and biomass compared to the BLUF, ETOB, and ROGE analysis sectors (Figures 8a-i). Patterns in fish distribution within analysis sectors are more challenging to interpret since they likely require repeated surveys to disentangle true patterns from random. Regardless, the overall results suggest an unequal distribution of fish detections across the Toronto and Region AOC with a large number of zeros (albeit true zeros) in the final dataset.

3.3.2 Vertical Distribution

The overall vertical distribution of echo integrated fish density (numbers per m^3, >2.9 cm TL) showed no consistent depth preference during the daytime surveys, although density differences by depth were apparent among sectors (Figure 9a and 9b). Schools of fish were detected throughout a wide range of depths between 4 and 43 m (Figure 9a). In most sectors, schools were found just below or above the thermocline, with the notable exception of TTPK where fish were only detected below thermocline. It is important to note that surveys in this sector were restricted to waters greater than 18 m deep. For both ETOB and HBNR the thermocline was close to the bottom, which likely precluded detections of fish below the thermocline at these sectors.

4.0 DISCUSSION

Within the Toronto and Region AOC the 2016 fish hydroacoustic surveys captured differences among analysis sectors for both pelagic fish density and biomass. There was a clear peak in both metrics within (i.e., INNH) and adjacent to (i.e., OUTH, OUTI) the central waterfront relative to sectors in the more open waters of Lake Ontario. Similarly, the majority of individuals captured during mid-water trawling came from these three analysis sectors. Collectively this suggests a non-random distribution of fish density and biomass within the AOC.

All surveys were undertaken during daylight hours; as such the vast majority of fish density and biomass occurred within schools. Daytime schooling behaviour is consistent with previous works that have found light conditions to be a major driver behind whether fish are schooling or dispersed (e.g., Luecke and Wurtsbaugh 1993). Schooling behaviour has been found to provide protection from predation (Landeau and Terborgh 1986; Turner and Pitcher 1986), increase foraging efficiency (Pitcher et al. 1982; Milne et al. 2005) and reduce energy costs for swimming (Couzin and Krause 2003). Schooling behaviour likely also partially contributed to the large number of zeros in our final dataset since schools were present in only a subset of EDSU (<9%). While this was a natural result of sampling during the daytime, it posed challenges for statistical comparisons of density and biomass among analysis sectors. An additional caveat is that estimates of density and biomass from day surveys have been found to consistently underestimate fish abundance by as much as 50% relative to night surveys (Appenzeller and Leggett 1992). This is largely driven by acoustic shadowing in schools wherein the top of the school hides its true depth and size. As such, night surveys are typically recommended (Guillard and Verges 2007); however, day work was maintained for the present survey to keep data collection consistent with previous surveys and also to ensure the safety of all boaters in the highly utilized waters of the Toronto and Region AOC.

The sole exception for complete dominance by schooling fish in our dataset was at INNH where although schools still contributed to most of the observed density, non-schooling fish drove the overall biomass estimate. This sector also had the highest mean density and biomass for non-schooling fish. On closer examination of the non-schooling fish dataset, while density estimates at INNH were driven by the smallest three size classes (<130 mm, TL), biomass estimates were driven by the largest two size classes (>500 mm, TL). This was also true for OUTH and to a lesser extent HBNR and EHDL (Figure 10). Unfortunately size classes within schools could not be evaluated and, in accordance with past surveys, they were assumed to be dominated by size class two individuals (58-82 mm TL). Collectively, results suggest that throughout the Toronto and Region AOC: 1) the majority of small-bodied individuals school during the day, 2) non-schooling small-bodied fishes are most abundant in or near the central waterfront, and 3) the majority of large-bodied fishes encountered during the survey are also found in or adjacent to the central waterfront.

4.1 MID-WATER TRAWLING

Mid-water trawling was undertaken to aid in the calibration of the hydroacoustics data, but also to provide an indication of the fishes that were present within each analysis sector. Consistent with the hydroacoustic results, catch was considerably lower to non-existent outside of the central waterfront. At BLUF, HBNR, and TTPK no fish were captured in the trawl net and at EHDL, ETOB, and ROGE five or fewer individuals were captured and all were Round Goby. Greater total catch rates and CPUE were observed in or adjacent to the central waterfront, with YOY Alewife dominating at INNH and Round Goby dominating catches at OUTH (followed by Alewife and Three Spine Stickleback) and OUTI (followed by Alewife). Overall CPUE estimates were low and daytime trawling may have contributed to these relatively low catches since fish were generally in schools that may have been missed by the comparatively small opening of the trawl net (relative to the volume of water available in each analysis sector). Furthermore, there is an increased likelihood of visual detection of the trawl by fish during daytime surveys.

The preponderance of Round Goby, a benthic fish with no swim bladder, in mid-water trawl data is surprising. While there are accounts of early juvenile Round Goby (size range 6 – 23 mm TL) captured in pelagic waters in Lake Erie (Hayden and Miner 2009), the bulk of the Round Goby captured in the present study were longer than 23 mm. Given their reliance on benthic habitat, it is likely that the remaining Round Goby were captured in the mid-water trawl when it inadvertently came close to or in contact with the bottom. Depth data from a logger attached to the trawl lead line verified contact with an undulating bottom during two trawls in OUTH that accounted for 885 of the Round Goby caught in this analysis sector. Their apparent dominance in the present pelagic fish community survey is therefore likely driven more by sampling issues than their actual presence outside of benthic habitats.

As noted, the majority of Alewife captured in the trawls were YOY, which typically remain near their spawning grounds until late larval stages before moving into more protected areas on their way to deeper waters (Scott and Crossman 1998). The abundance of this species at INNH and OUTH in the late summer suggests that the central waterfront of the Toronto and Region AOC provides important habitat for this species during their intermediate life stages. While their importance as prey for Lake Trout in Lake Ontario is well established, their abundance in the comparatively warmer waters of Toronto Harbour also likely support many nearshore piscivorous fishes (e.g., Northern Pike, Smallmouth Bass, Yellow Perch, and Walleye; Scott and Crossman 1998). An important caveat to our trawling efforts is that most trawls generally occurred in 10 m of water or less. Therefore, our surveys are biased towards depths and thermal regimes that do not favour adult Alewife and Rainbow Smelt, which are typically well below the thermocline during the late summer. These adults can be detected using hydroacoustics, but their presence or species-specific abundance cannot be determined.

The absence of large fish in the trawling data (largest fish was a 124 mm TL Round Goby) posed a challenge for determining the species driving the non-schooling fish biomass estimates at INNH and OUTH. Their absence, however, was not surprising given documented net avoidance by larger fishes (Binion et al. 2008). Alternative methods for sampling populations of larger fishes are already in place in the Toronto and Region AOC (i.e., electrofishing and trap netting; Hoyle et al. (2018), acoustic telemetry; Midwood unpublished data) and these methods will provide a more detailed assessment of the composition and distribution of larger-bodied fishes.

4.2 DEPTH DISTRIBUTION

Non-schooling fish and schools of fish were generally found just below or completely above the estimated thermocline. The sole exception was non-schooling fish at TTPK, where fish were detected at a depth of ~ 40 m, which was also the deepest occurrence in the present study. For the few other occurrences of fish just below the estimated thermocline (i.e., INNH and OUTH), the rate of change at this transition was comparatively low and temperatures just below the thermocline were generally still close to the lower range of cool water habitat (19 to 25 °C). For the small-bodied fishes that comprised the majority of the observed schools, daytime light intensity and water temperature were therefore likely driving factors behind their depth distribution such that they sought waters that were as deep as possible but still within their preferred temperature range (Appenzeller and Leggett 1995).

4.3 DIFFERENCES FROM PAST SURVEYS

In the future it would be prudent to merge results presented in the current report with past surveys of the Toronto and Region AOC. Additional information on the results of the 2009 and 2010 surveys can be found at DFO GLLFAS (2010) and DFO GLLFAS (2011), respectively. As such, it is important to identify differences in the sampling and analytical methodology employed in 2016 for both hydroacoustics and trawling. First, three new analysis sectors (Bluffers Park, Etobicoke Creek and Rouge River) were added to the surveys to capture conditions in open coastal areas and one sector, Humber Bay offshore, was not surveyed. Next, there were slight differences in the timing of surveys; the 2009 survey was completed between September 16 to October 2, and the 2010 survey from September 14 to 30. In 2016, scheduling conflicts for the CCGC Kelso resulted in the shifting of the first week of the survey to September 6 to 9. Finally, we changed the units of analysis for both density and biomass for the hydroacoustics analysis. In past surveys these estimates were presented as #/ha (abundance) and g/ha (biomass); however, for the present report we elected to apply a volumetric correction by shifting the denominator to m^3. Comparable corrections can be applied to the previous survey data to allow for comparison among years.

From a trawling perspective, a mid-water trawl was used to capture fish in 2016, rather than the bottom trawl that was used in both 2009 and 2010. Mid-water trawls will not damage or re-suspend bottom sediments and reduces the possibility of hanging-up the trawl on debris, which happened several times in the previous surveys. Another advantage of mid-water trawling was that the trawl area swept was completely ensonified by the acoustic beam, rather than partially enveloped by the acoustic dead-zone just above the bottom. Bottom trawls were run parallel to the depth contours in 2009 and 2010, while the 2016 mid-water trawls transects were generally run perpendicular to depth contours. Finally, the unit of effort for trawling was also shifted in 2016 to a time-based (20 minute transects) approach whereas in 2009 and 2010, trawl transects were distance-based. This shift was made due to high variability in the length of trawl transects when a distance-based standardization was used (target was 0.75 km, but in 2009 the mean length was 0.63 km ± 0.20 km and in 2010 it was 0.84 km ± 0.28 km, values are mean ± standard deviation). Collectively, these changes to the trawling protocol make comparisons with past data inappropriate.

4.4 FUTURE WORK

There are considerable opportunities to merge the results from the present survey with other existing datasets to provide a more complete picture of the status of the nearshore and coastal waters of the Toronto and Region AOC. Comparable surveys were completed in 2009 and 2010 for many of the analysis sectors surveyed for the present report and ultimately all these data should be combined to look at trends in the spatial distribution of fish density and biomass. A key step for this merging will be to ensure data are standardized in a consistent fashion. As noted in the previous section, while it will be possible to correct and compare the hydroacoustic results, trawling data cannot be compared through this time series.

Surveys of water chemistry and primary (phytoplankton) and secondary (zooplankton) production were undertaken by the Freshwater Ecosystem Research Lab at GLLFAS at a similar time as the present fish hydroacoustic work. Merging these two datasets would allow for an exploration of some potential drivers of the observed differences in fish density and biomass (i.e., limnological and biological habitat) as well as whether fish density and biomass may be driving lower than average densities of some zooplankton in a subset of analysis sectors (W. Currie unplublished data). Similarly, the present dataset could be merged with nearshore (<1.5 m) electrofishing surveys undertaken by GLLFAS and the Toronto and Region Conservation Authority to determine whether pelagic production estimates are correlated to nearshore production.

Finally, the results from the present hydroacoustic surveys and those from past hydroacoustic surveys could be used to develop a spatial layer of pelagic fish production for the central waterfront. This layer could then be linked with detailed spatial information on the movement and residency of larger fishes (e.g., Northern Pike, Largemouth Bass, Walleye, etc.) that has been collected using acoustic telemetry in this same region. This type of spatial layer would contribute to an overall assessment of the type of habitat available throughout the central waterfront, which can then be associated with some level of use by larger bodied fishes.

4.5 CONCLUSION

This report found that the central waterfront of the Toronto and Region AOC, which includes the inner and outer portions of Toronto Harbour and adjacent waters, had consistently higher density and biomass of fish than other pelagic waters within the AOC. While the entire region is affected by wind and wave action and upwellings of cold benthic water from Lake Ontario (Hlevca et al. 2015), it is likely that waters within the harbour provide some shelter and refuge for the predominantly small pelagic fishes captured in the present study. The relatively lower density and biomass of fish outside of the central waterfront does not necessarily suggest impairment of these pelagic habitats, but rather may be more indicative of the current background conditions within Lake Ontario. This therefore highlights the importance of the central waterfront both within the AOC as well as in western Lake Ontario as a habitat for forage fish that can in turn support the higher trophic species that are targets of the RAP and are of commercial, recreational, and aboriginal importance throughout Lake Ontario.

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Table 1. Summary of the dates and times of the 2016 Toronto and Region AOC hydroacoustic surveys. The total survey transect distance and survey duration are indicated.

Date	Time Start	Time End	Survey Distance (km)	Survey Duration (Hrs)	Average Speed (km/h)	Beam Sample Volume (m^3)	Num. Of EDSU's	Mean Depth (m)
September 6, 2016	17:14	18:44	4.64	1.50	3.09	444859.8	93	37.8
September 7, 2016	8:24	17:24	19.92	5.81	3.43	1171440.3	403	23.5
September 9, 2016	8:44	11:11	5.69	1.95	2.92	17238.5	117	9.0
September 19, 2016	15:35	18:49	5.42	1.70	3.19	135979.3	111	20.4
September 20, 2016	8:29	17:22	11.22	3.95	2.84	203125.0	232	16.2
September 21, 2016	8:12	18:24	15.20	5.10	2.98	402245.7	312	19.7
September 22, 2016	7:56	19:05	19.03	5.95	3.20	531279.0	392	21.0

Table 2. Summary of the total transect length, effective survey surface area, degree of coverage (Λ), estimated coefficient of variation (CV) and acoustic sample volume from the 2016 Toronto and Region AOC surveys. Note that the total sector volume was calculated from the 600 m survey point buffer area (>5 m depth). The expected surveys coefficient of variation (CV) is calculated from Aglen (1983).

Metric	BLUF	EHDL	ETOB	HBNR	INNH	OUTH	OUTI	ROGE	TTPK
Transect Length km (analysis transects only)	6.7	19.9	11.5	7.1	22.3	8.7	18.7	12.3	1.8
Effective Survey Area Ha (>**0** m Depth)	896	2511	1066	1152	502	396	1618	1593	514
Exp. Degree of Coverage Index	2.23	3.98	3.53	2.08	9.94	4.39	4.65	3.09	0.80
Exp. CV (b=0.5)	0.33	0.25	0.27	0.35	0.16	0.24	0.23	0.28	0.56
Beam Wedge Volume (m^3)	360629	9901415	784195	680370	136312	99631	6961924	1290558	5022749
Beam Wedge Volume (m^3) x 10^4	36	990	78	68	14	10	696	129	502
Lake or Sector Volume (m^3) x 10^4	9263	60548	13268	13259	1331	1964	30282	20792	23739
Prop^n Sample Volume (%)	0.39	1.64	0.59	0.51	1.02	0.51	2.30	0.62	2.12

Table 3. A summary and examples of species in each of the 6 fish size categories used to partition the observed integrated acoustic backscatter. The size partition limits are the total length (mm) and equivalent target strength (TS) estimated from Love's (1971a, 1971b) generalized fish length equation. ALWF = Alewife, SMLT = Rainbow Smelt, EMSH = Emerald Shiner, and LKWH = Lake Whitefish.

Size Class	Example Species	Min TLEN (mm)	Max TLEN (mm)	Min TS (dB)	Max TS (dB)
1	YOY UNKNOWN	29	58	-55.00	-49.43
2	ALWF, SMLT	58	82	-49.43	-46.56
3	ALWF, SMLT, EMSH	82	130	-46.56	-42.73
4	ALWF	130	250	-42.73	-37.31
5	LKWH	250	500	-37.31	-31.56
6	Large Fish	500	1200	-31.56	-24.12

Table 4. Summary of trawling effort and results by analysis sector for the 2016 Toronto Harbour survey. The depth of the mid-water trawls varied throughout the survey. An indication of the distribution of fish catches is included with the trawl depths where (‘) indicates catches > 30% and (*) > 50 % of the total fishes within each analysis sector. Catch per unit effort was calculated by dividing the total number of fish caught within the sector by the total trawl area swept (m^2), including those trawls where no fish were caught.

Analysis Sector	# of Trawls	# Trawls Without Fish	Approximate Trawl Depths (m)	# of Fish Caught	CPUE ($\#/m^2$)	Species Richness
BLUF	2	2	6, 10	0	0	0
EHDL	4	3	8, 8, 13*, 18	1	0.0001	1
ETOB	4	2	7, 10*, 10, 11	4	0.0005	1
HBNR	3	3	8, 10, 10	0	0	0
INNH	4	2	4, 6*, 6, 6	426	0.0469	4
OUTH	9	3	2, 2, 3, 3, 4, 5, 5, 6', 6	1459	0.0715	5
OUTI	6	4	2, 10, 11, 12*, 14, 26	145	0.0113	2
ROGE	8	7	6, 6, 6, 9*, 9, 9, 9, 12	5	0.0003	1
TTPK	1	1	24	0	0	0
Total	**41**	**27**		**2040**	**0.0225**	**5**

Table 5. Summary of the trawl catches in Toronto Harbour in 2016 by species, season and analysis sector. Included is the mean total length (mm) and standard deviation for up to 20 fishes of each species caught per trawl. Range of fish size includes all fishes caught; either from the individual fishes that were measured or fishes from the bulk counts as applicable. Two fish caught in the trawl could not be identified to species and were therefore excluded from this table.

Analysis Sector		Alewife	Brook Stickleback	Rainbow Smelt	Round Goby	Three Spine Stickleback
EHDL	Catch				1	
	TL (mm)				64	
ETOB	Catch				4	
	Mean TL (mm)				66 ± 21	
	Range (mm)				40 - 87	
INNH	Catch	317		23	83	1
	Mean TL (mm)	51 ± 6		39 ± 6	66 ± 14	63
	Range (mm)	33 - 68		29 - 55	30 - 94	
OUTH	Catch	197	93	3	984	182
	Mean TL (mm)	48 ± 8	42 ± 8	36 ± 2	60 ± 23	32 ± 5
	Range (mm)	32 - 84	25 - 64	35 - 39	22 - 124	24 - 60
OUTI	Catch	43			102	
	Mean TL (mm)	60 ± 5			66 ± 20	
	Range (mm)	44 - 66			30 - 109	
ROGE	Catch				5	
	Mean TL (mm)				64 ± 10	
	Range (mm)				53 - 78	
Total Catch		557	93	26	1179	183

Table 6. Summary of the effort within each analysis sector for the hydroacoustic surveys completed in the Toronto and Region AOC in 2016. The number of Elementary Distance Sampling Units (EDSUs) where fish were present or absent as schools, non-schooling fish or either are presented.

		Schools Only		Non-Schooling		Combined	
Analysis Sector	**Total EDSU**	**Present**	**Absent**	**Present**	**Absent**	**Present**	**Absent**
BLUF	104	7	97	11	93	18	86
EHDL	356	10	346	143	213	148	208
ETOB	168	12	156	28	140	37	131
HBNR	122	20	102	34	88	50	72
INNH	170	41	129	141	29	149	21
OUTH	180	18	162	69	111	75	105
OUTI	283	24	259	127	156	143	140
ROGE	211	8	203	35	176	41	170
TTPK	36	3	33	23	13	25	11
	1630	143	1487	611	1019	686	944

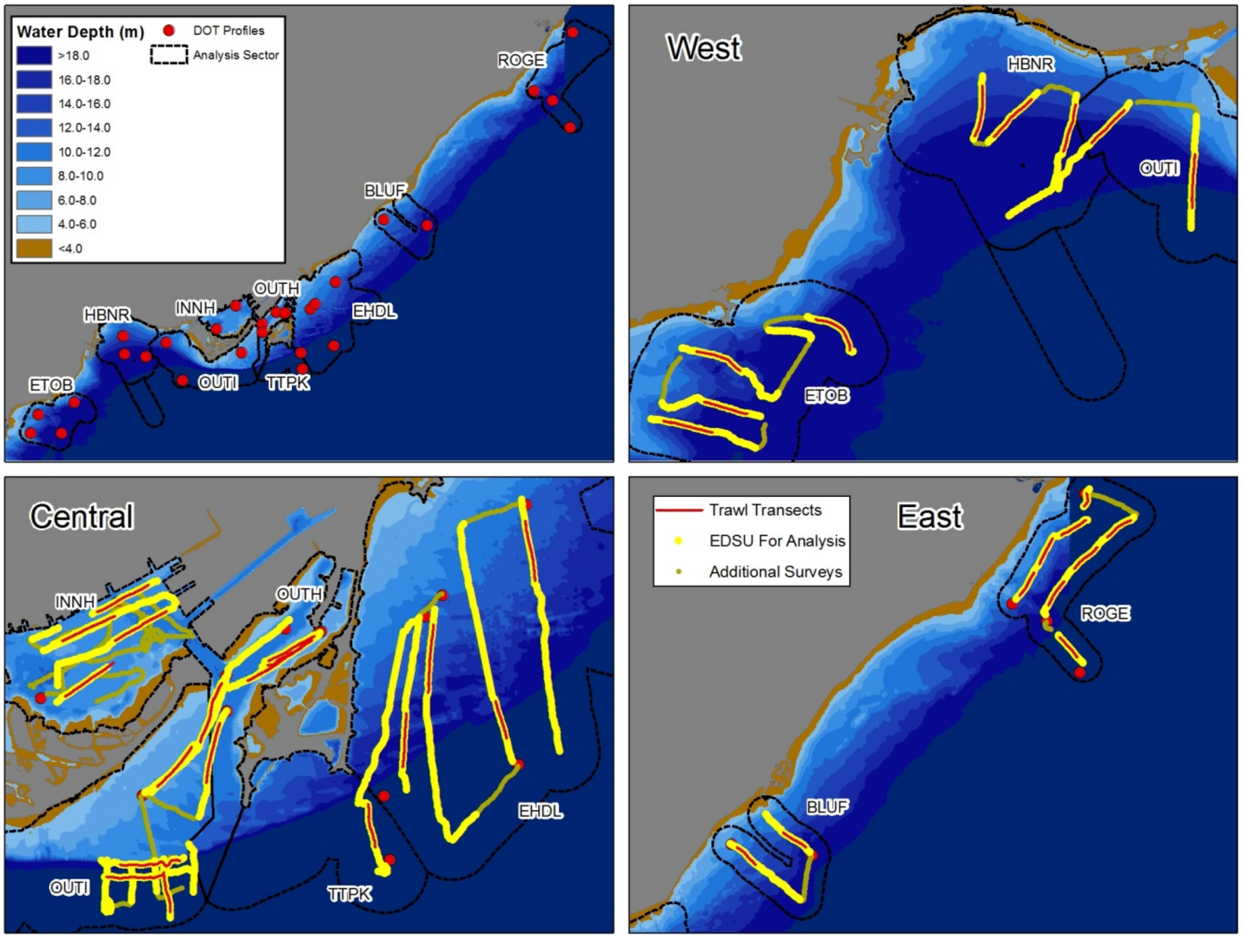

Figure 1. Map of the 2016 Toronto Harbour acoustic and trawling survey area extent. The Toronto survey area was divided into 10 analysis sectors where: ETOB – Etobicoke Creek mouth, HBNR – Humber Bay Nearshore, , OUTI – Outer Islands, INNH – Inner Harbour, OUTH – Outer Harbour, TTPK – Tommy Thompson Park, EHDL – Eastern Headlands to “The Beaches”, BLUF – Bluffers Park area and ROGE – Rouge River mouth area.

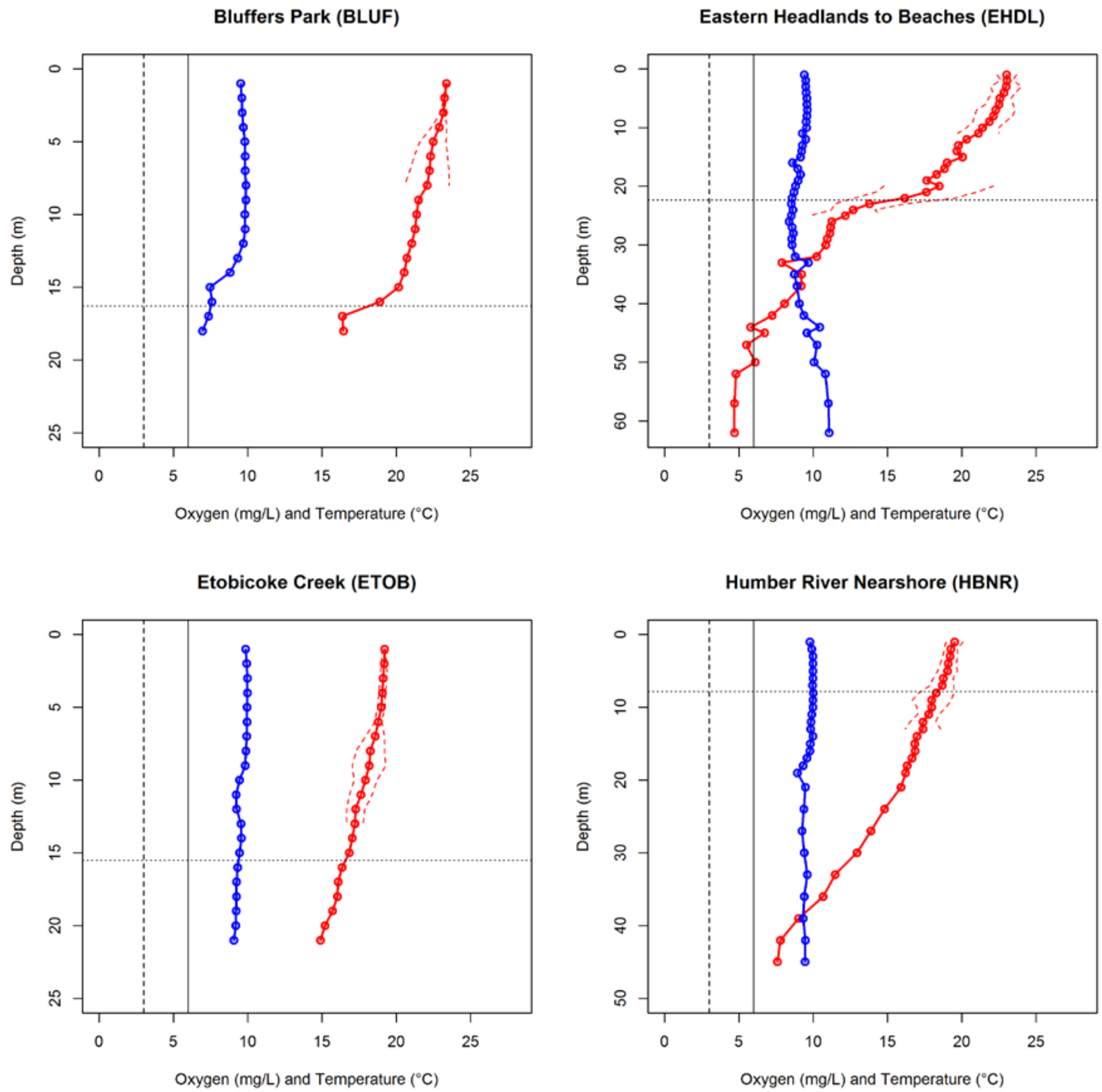

Figure 2a. Mean dissolved oxygen (blue) and temperature (red) profiles for the Toronto and Region AOC fish hydroacoustic transects. Where present, coloured dashed lines denote the standard deviation of the mean determined from multiple profiles. Horizontal dotted lines represent the estimated depth of the thermocline based on the *thermo.depth* function in the *rLakeAnalyzer* package. Vertical lines represent 6 mg/L (solid line) and 3 mg/L (dashed line) of dissolved oxygen to aid interpretation.

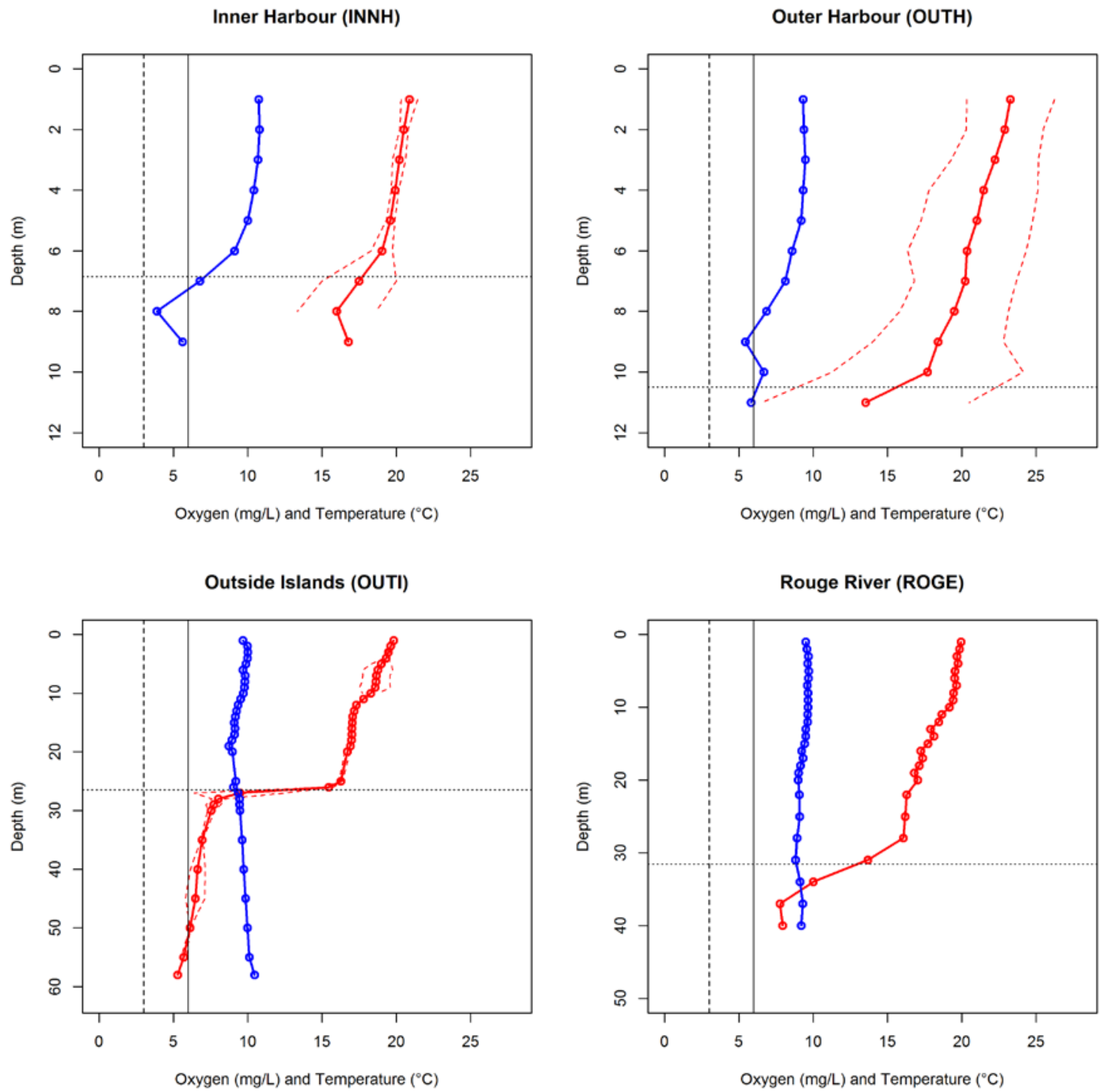

Figure 2b. Mean dissolved oxygen (blue) and temperature (red) profiles for the Toronto and Region AOC fish hydroacoustic transects. Where present, coloured dashed lines denote the standard deviation of the mean determined from multiple profiles. Horizontal dotted lines represent the estimated depth of the thermocline based on the *thermo.depth* function in the *rLakeAnalyzer* package. Vertical lines represent 6 mg/L (solid line) and 3 mg/L (dashed line) of dissolved oxygen to aid interpretation.

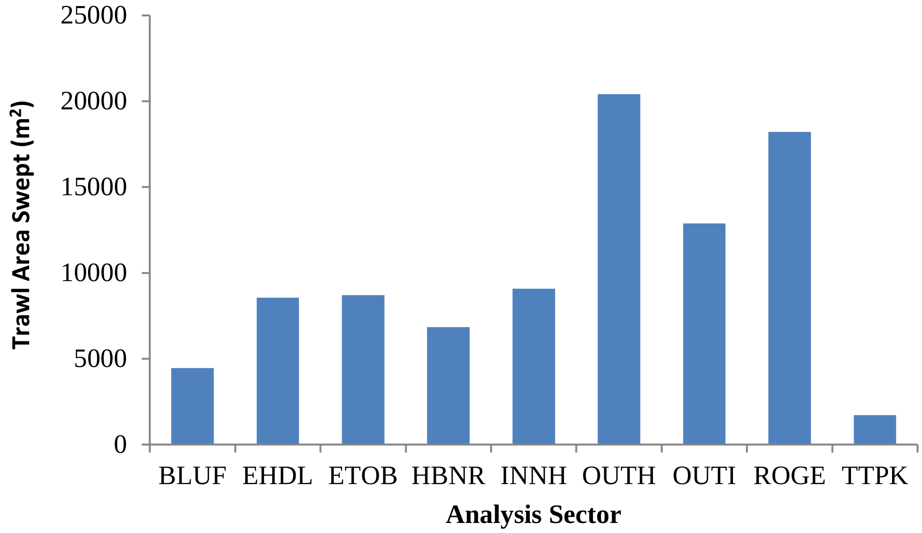

Figure 3. Variation in daytime trawl area swept by analysis sector for the 2016 Toronto Harbour hydroacoustic and trawling survey.

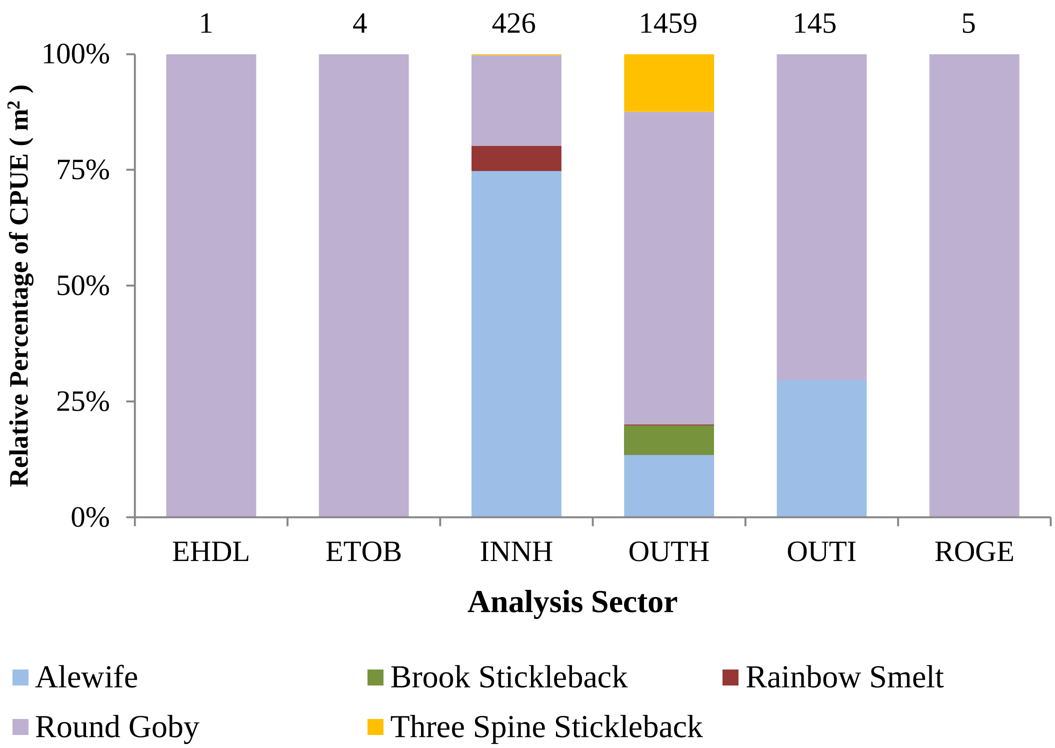

Figure 4. Relative percentage of CPUE by species and analysis sector from mid-water trawling in Toronto Harbour in 2016. The numbers above each bar represent the total catch by sector. No fish were captured in BLUF, HBNR, and TTPK.

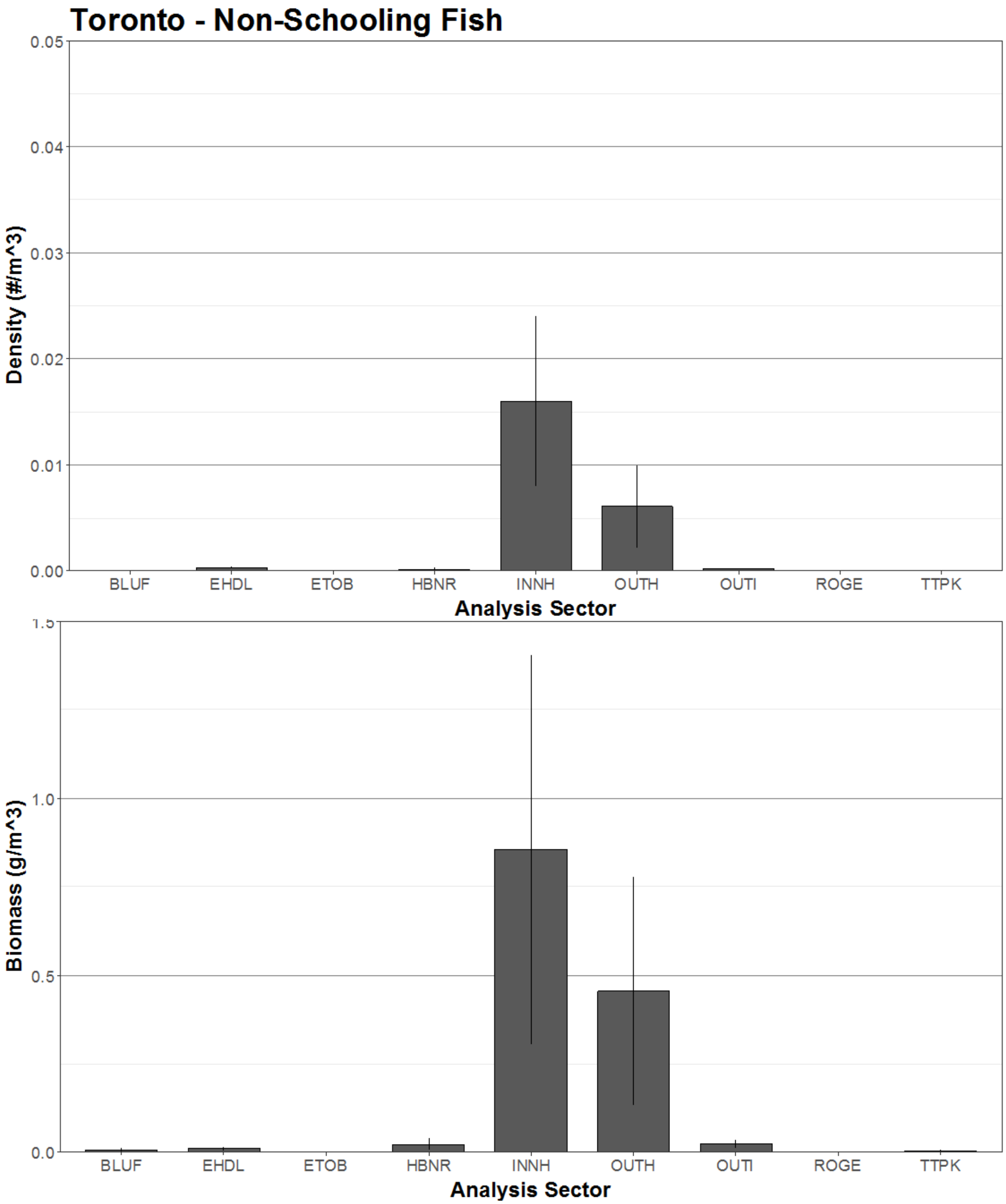

Figure 5a. Mean total density and biomass (with standard error) for non-schooling fish ($TH_{(NoSchools)}$) by analysis sector.

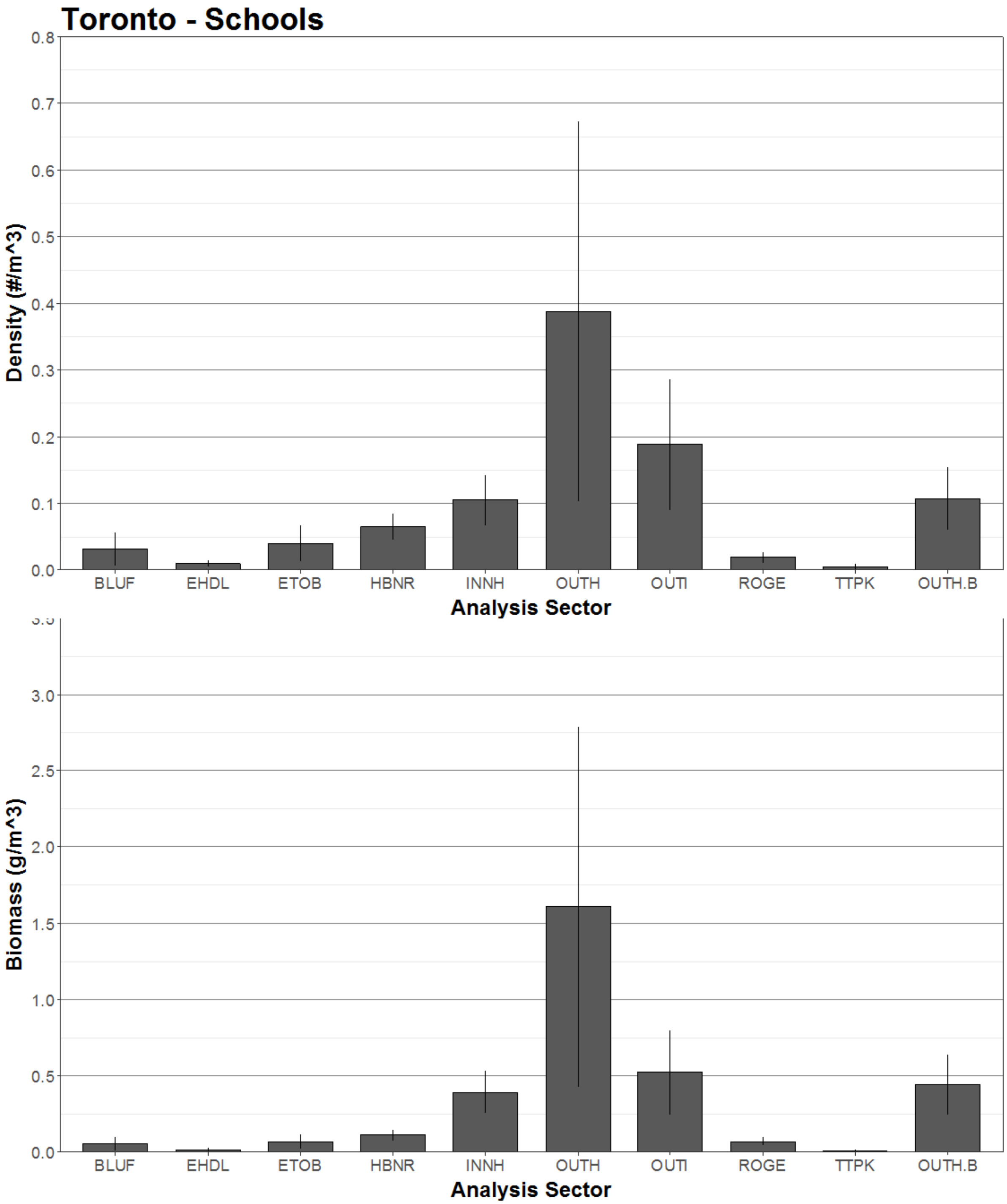

Figure 5b. Mean total density and biomass (with standard error) for schools ($TH_{(Schools)}$) by analysis sector. OUTH.B excludes the single EDSU with extremely high fish density.

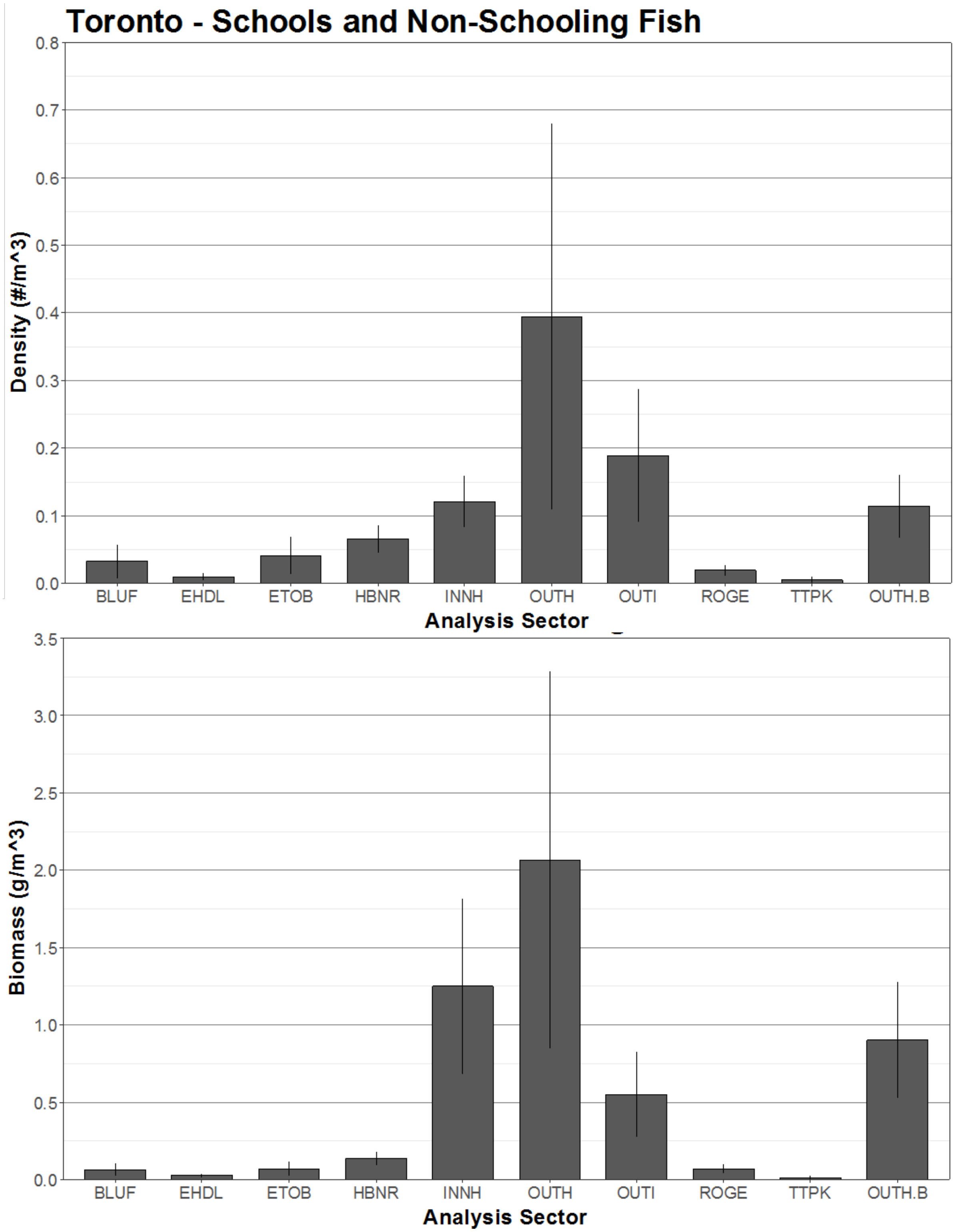

Figure 5c. Mean total density and biomass (with standard error) for non-schooling fish and schools ($TH_{(All)}$) by analysis sector.

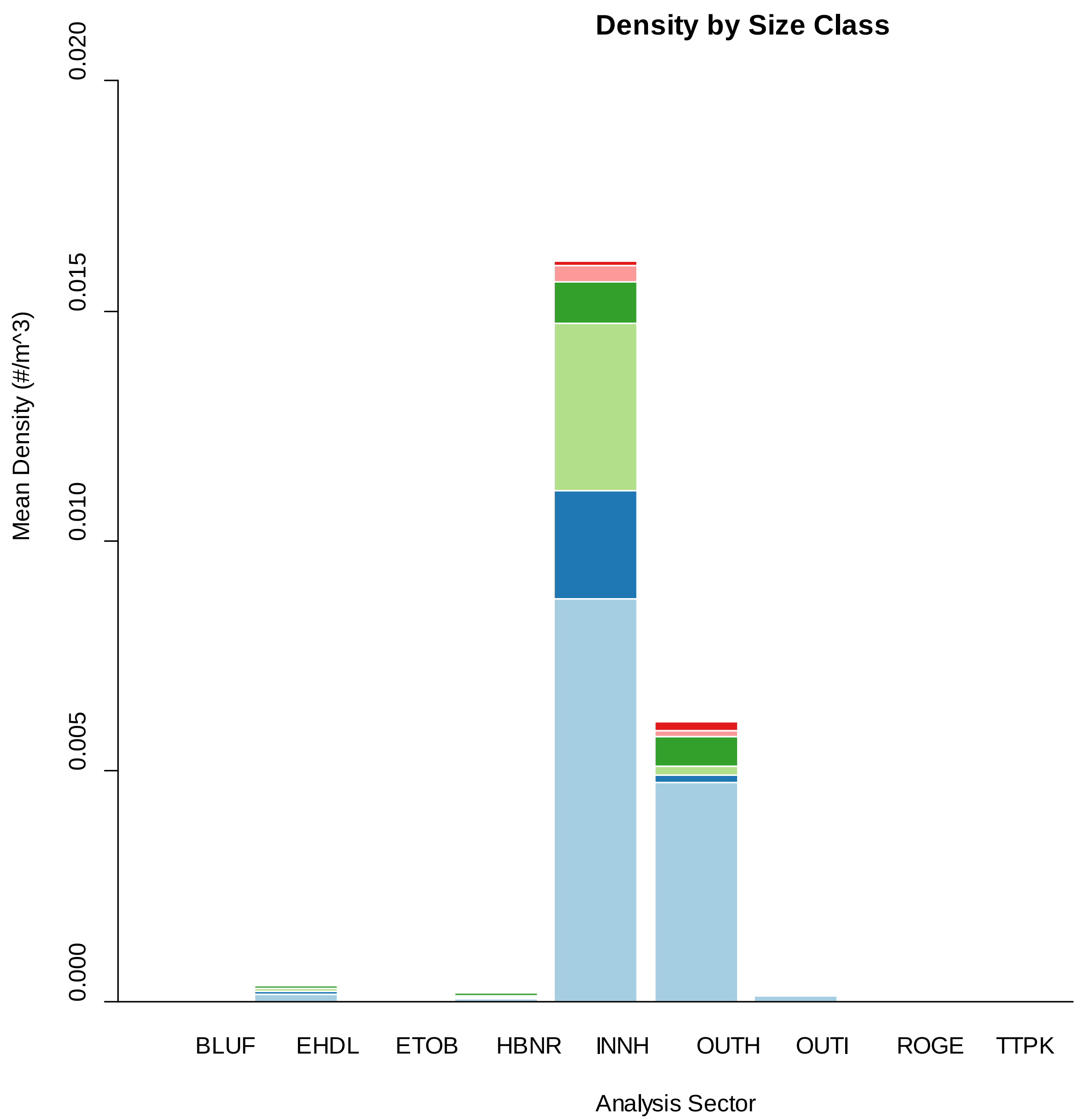

Figure 6a. Mean density (#/m^3) by size class for each analysis sector. Colours denote the mean values for each size class where: light blue = size class 1 (29-58 mm, TL), dark blue = size class 2 (58-82 mm, TL), light green = size class 3 (82-130 mm, TL), dark green = size class 4 (130-250 mm, TL), light red = size class 5 (250-500 mm, TL), and dark red = size class 6 (500-1200 mm, TL).

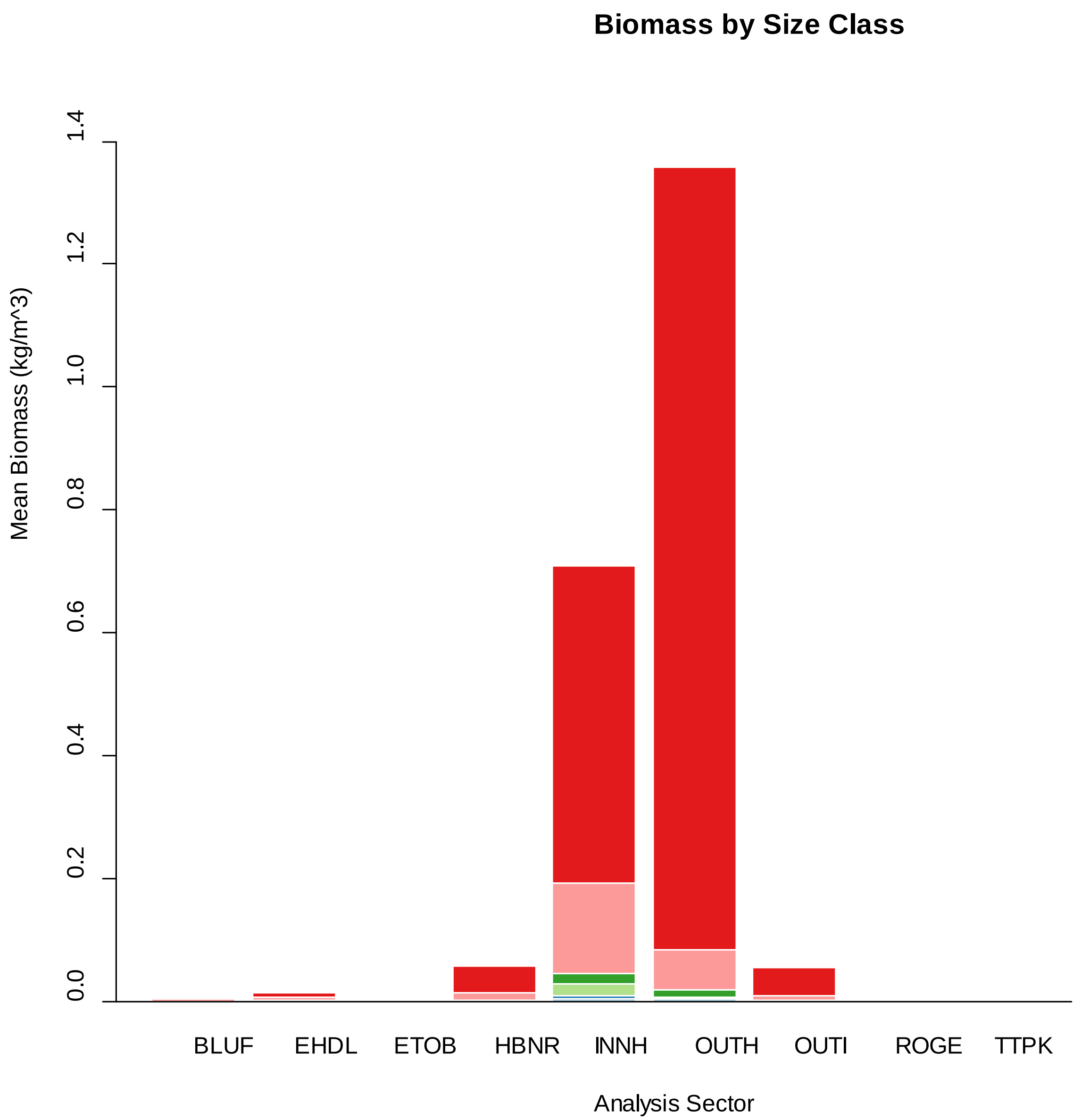

Figure 6b. Mean biomass (g/m^3) by size class for each analysis sector. Colours denote the mean values for each size class where: light blue = size class 1 (29-58 mm, TL), dark blue = size class 2 (58-82 mm, TL), light green = size class 3 (82-130 mm, TL), dark green = size class 4 (130-250 mm, TL), light red = size class 5 (250-500 mm, TL), and dark red = size class 6 (500-1200 mm, TL).

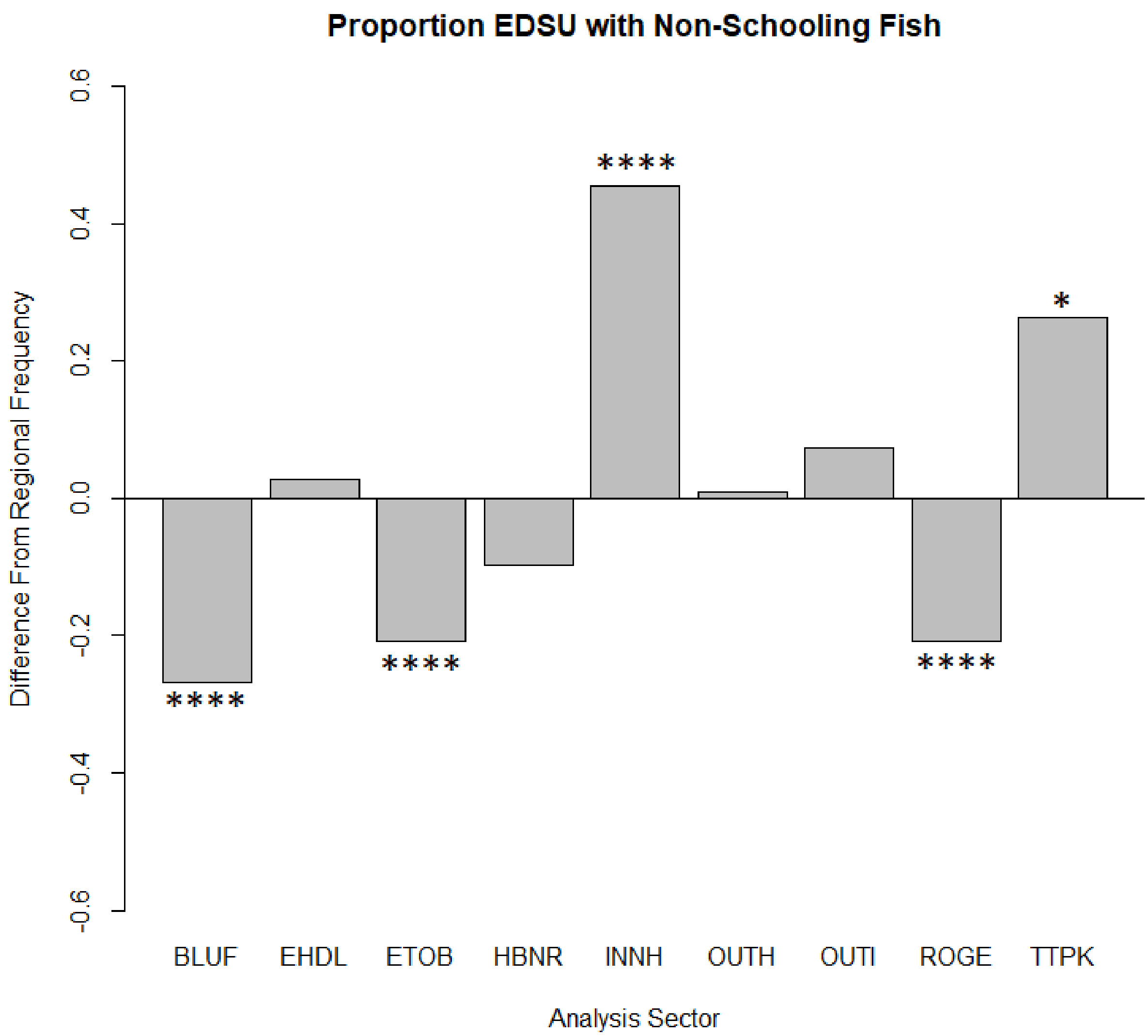

Figure 7a. Difference between the regional and sector-based proportion of EDSU where fish were detected. Asterixes denote deviations from the regional proportion (0.375 for $TH_{(NoSchools)}$) that were significantly different based on a Fisher's Exact test where *p<0.05, **p<0.01, *** p<0.001, ****p<0.0001.

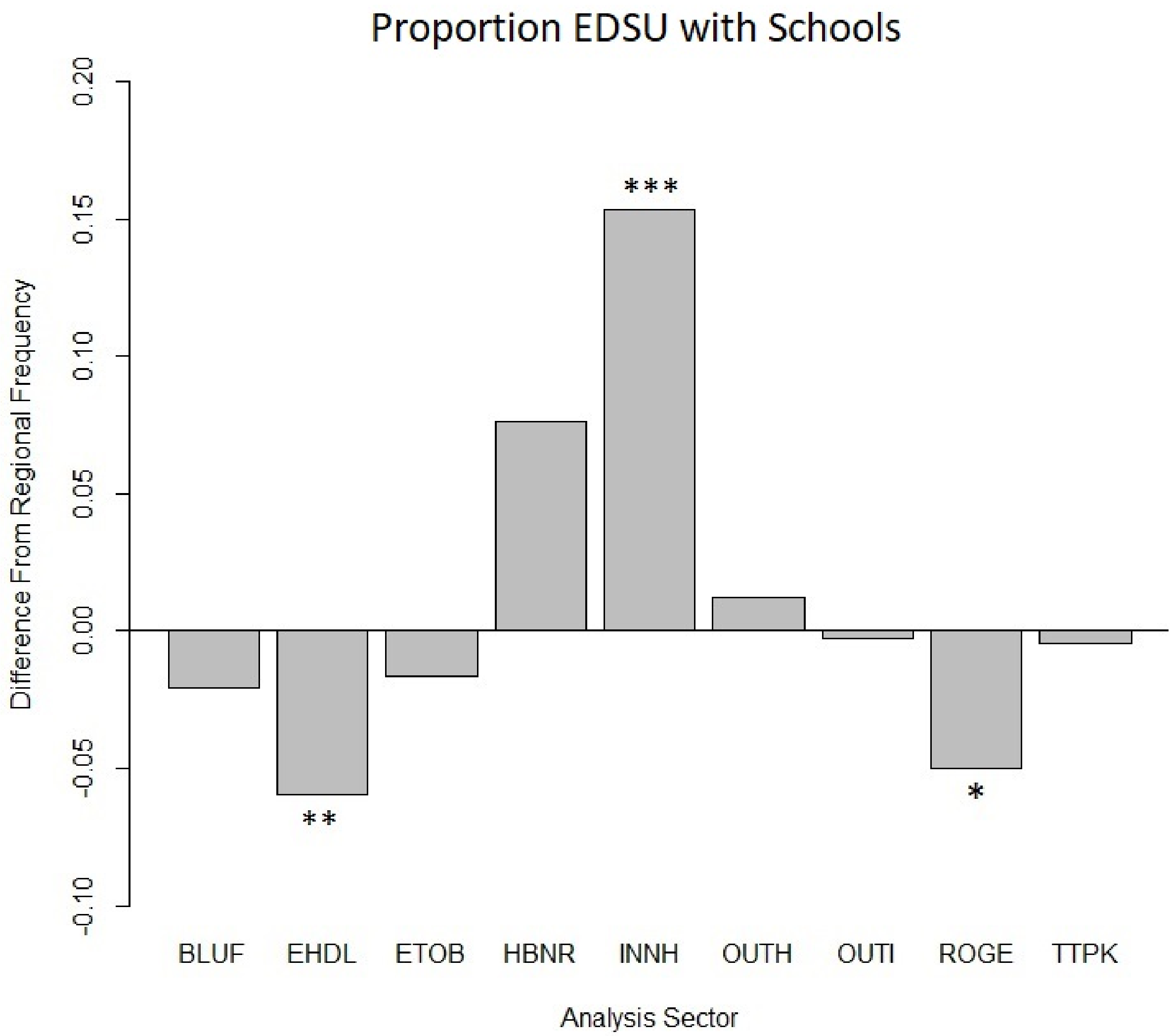

Figure 7b. Difference between the regional and sector-based proportion of EDSU where fish were detected. Asterixes denote deviations from the regional proportion (0.088 for $TH_{(Schools)}$) that were significantly different based on a Fisher's Exact test where *p<0.05, **p<0.01, *** p<0.001, ****p<0.0001.

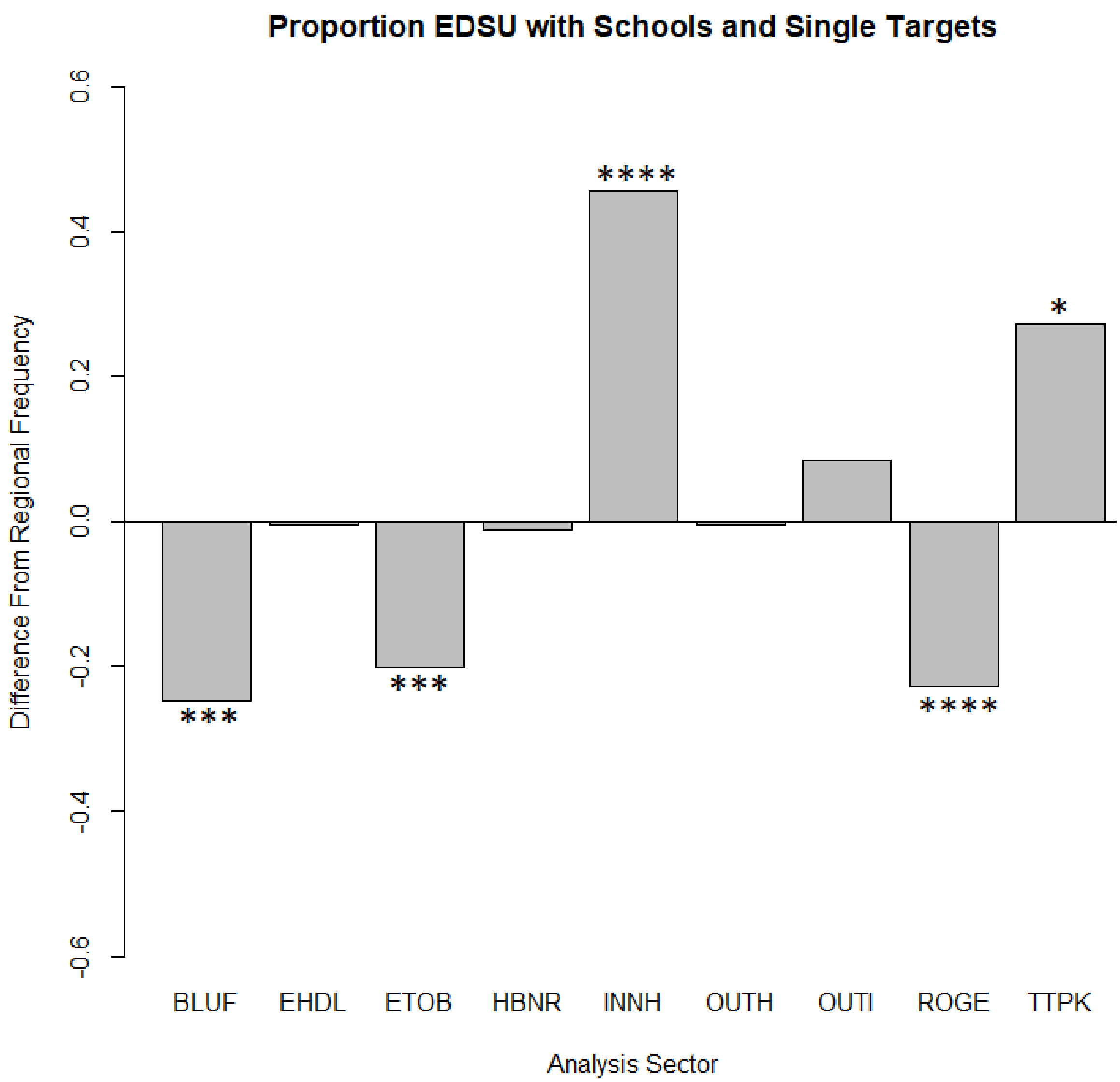

Figure 7c. Difference between the regional and sector-based proportion of EDSU where fish were detected. Asterixes denote deviations from the regional proportion (0.420 for $TH_{(All)}$) that were significantly different based on a Fisher's Exact test where *p<0.05, **p<0.01, *** p<0.001, ****p<0.0001.

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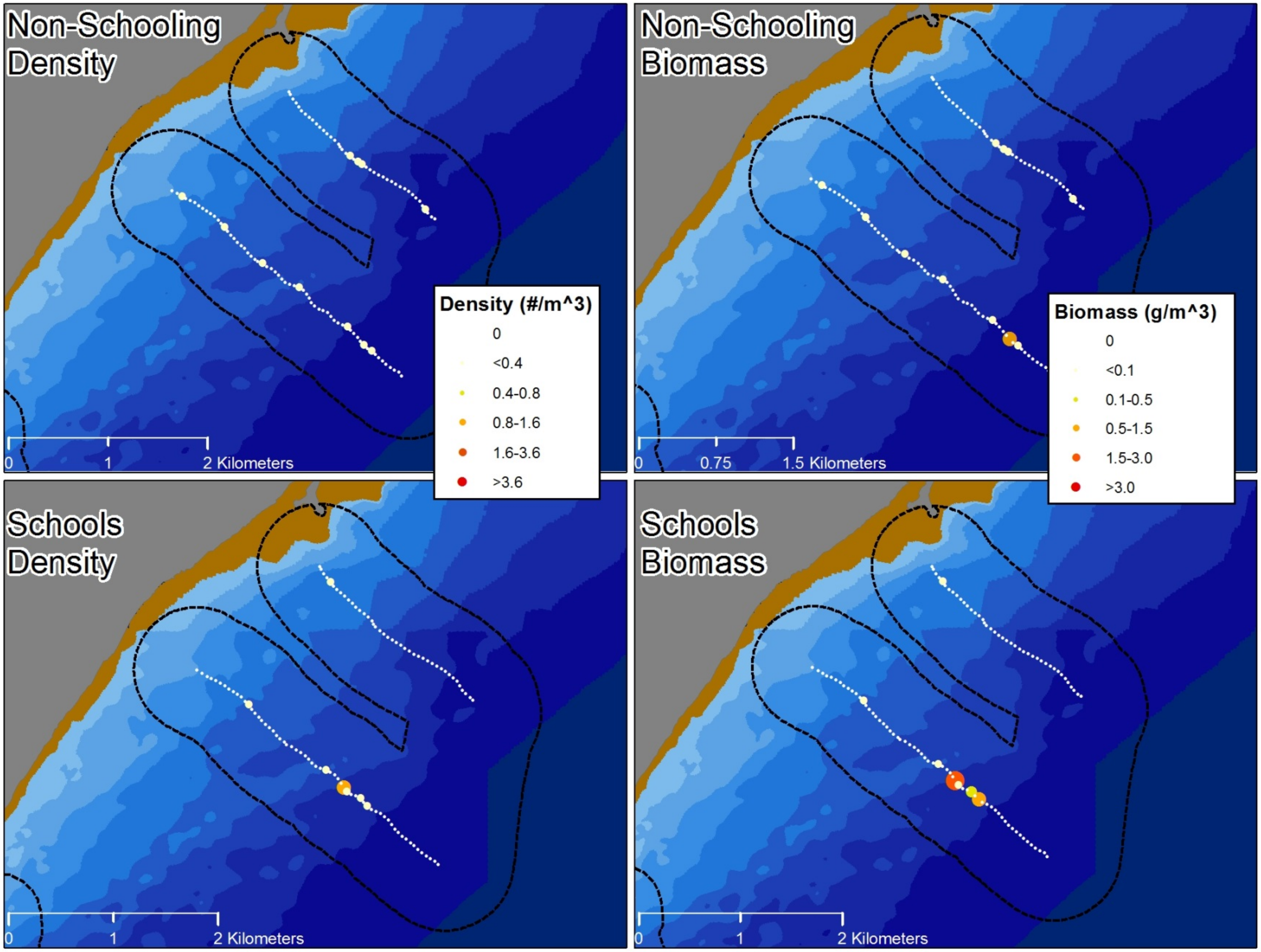

Figure 8a. Spatial distribution of non-schooling fish and school density and biomass at Bluffers Park (BLUF).

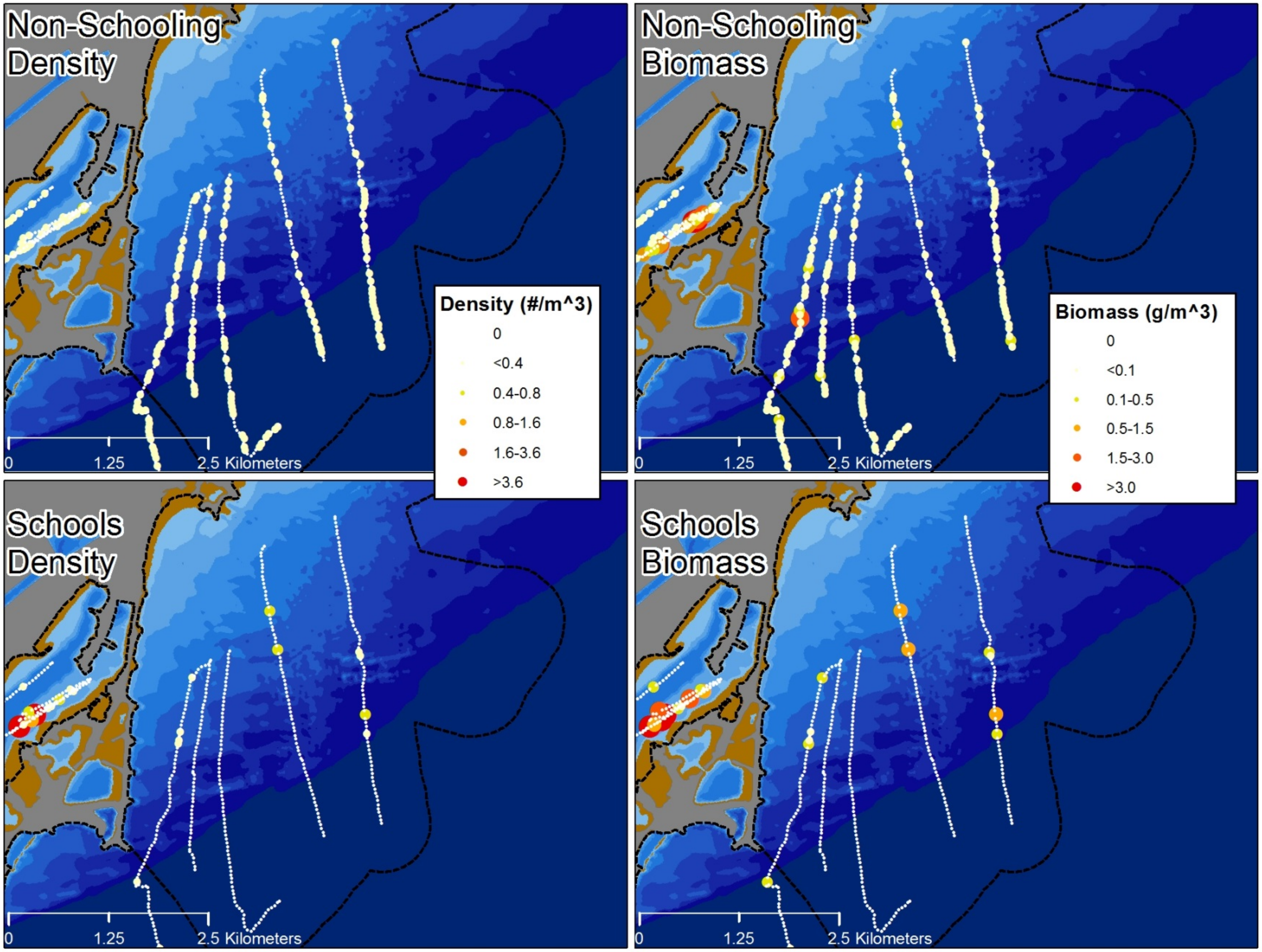

Figure 3b. Spatial distribution of non-schooling fish and school density and biomass at Eastern Headlands (EHDL).

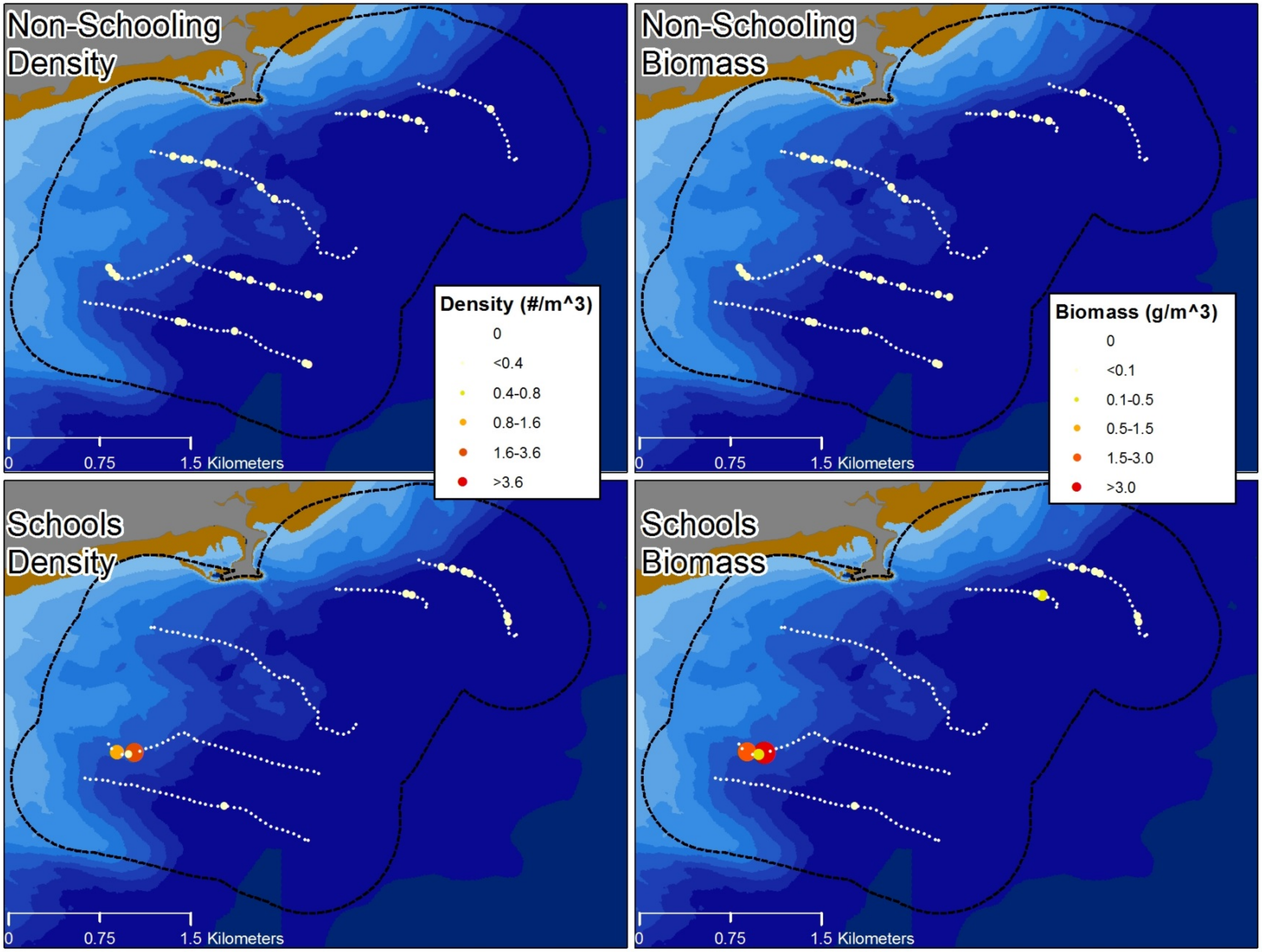

Figure 4c. Spatial distribution of non-schooling fish and school density and biomass at Etobicoke Creek (ETOB).

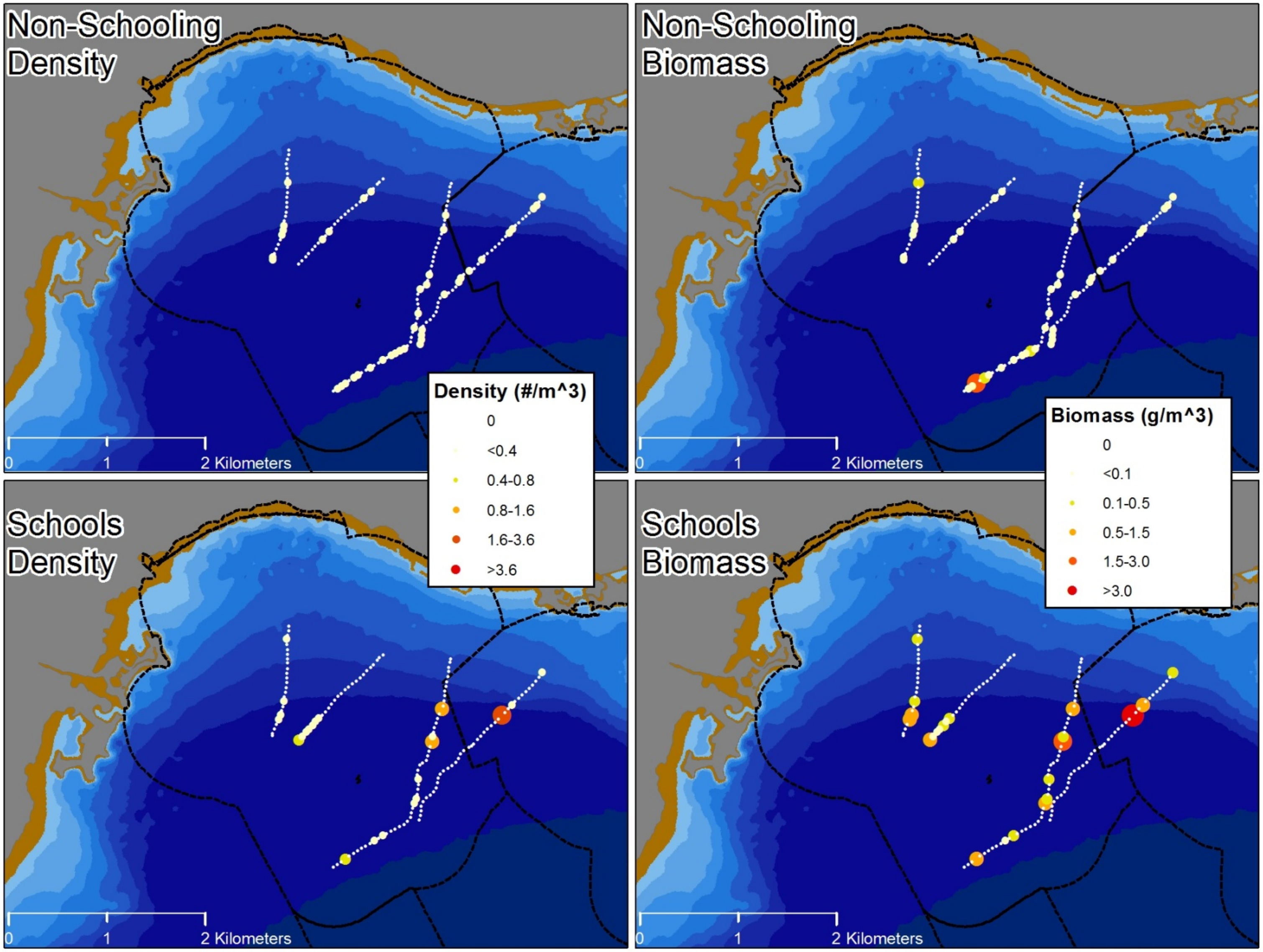

Figure 8d. Spatial distribution of non-schooling fish and school density and biomass at Humber Bay Nearshore (HBNR).

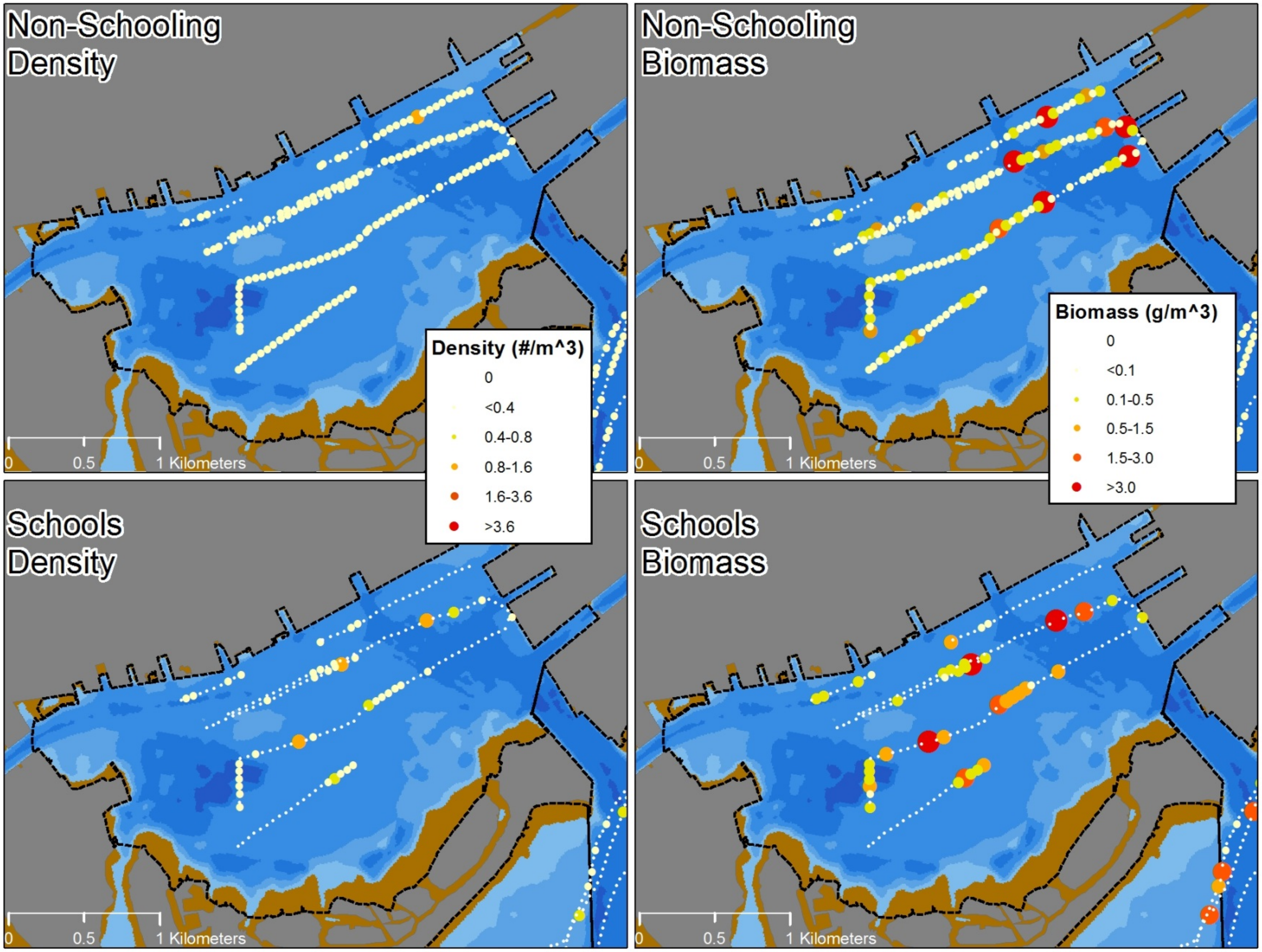

Figure 8e. Spatial distribution of non-schooling fish and school density and biomass at Inner Harbour (INNH).

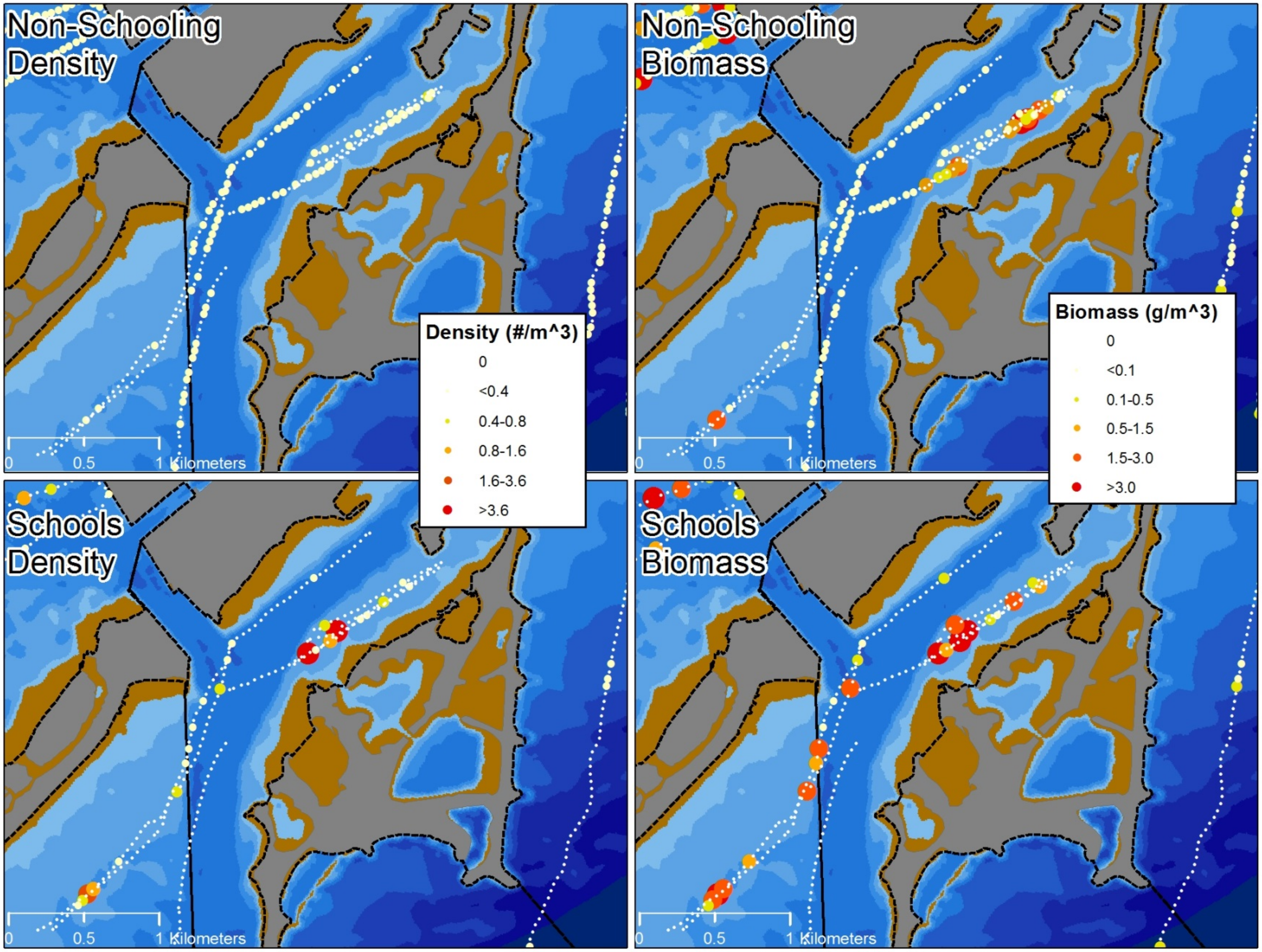

Figure 8f. Spatial distribution of non-schooling fish and school density and biomass at Outer Harbour (OUTH).

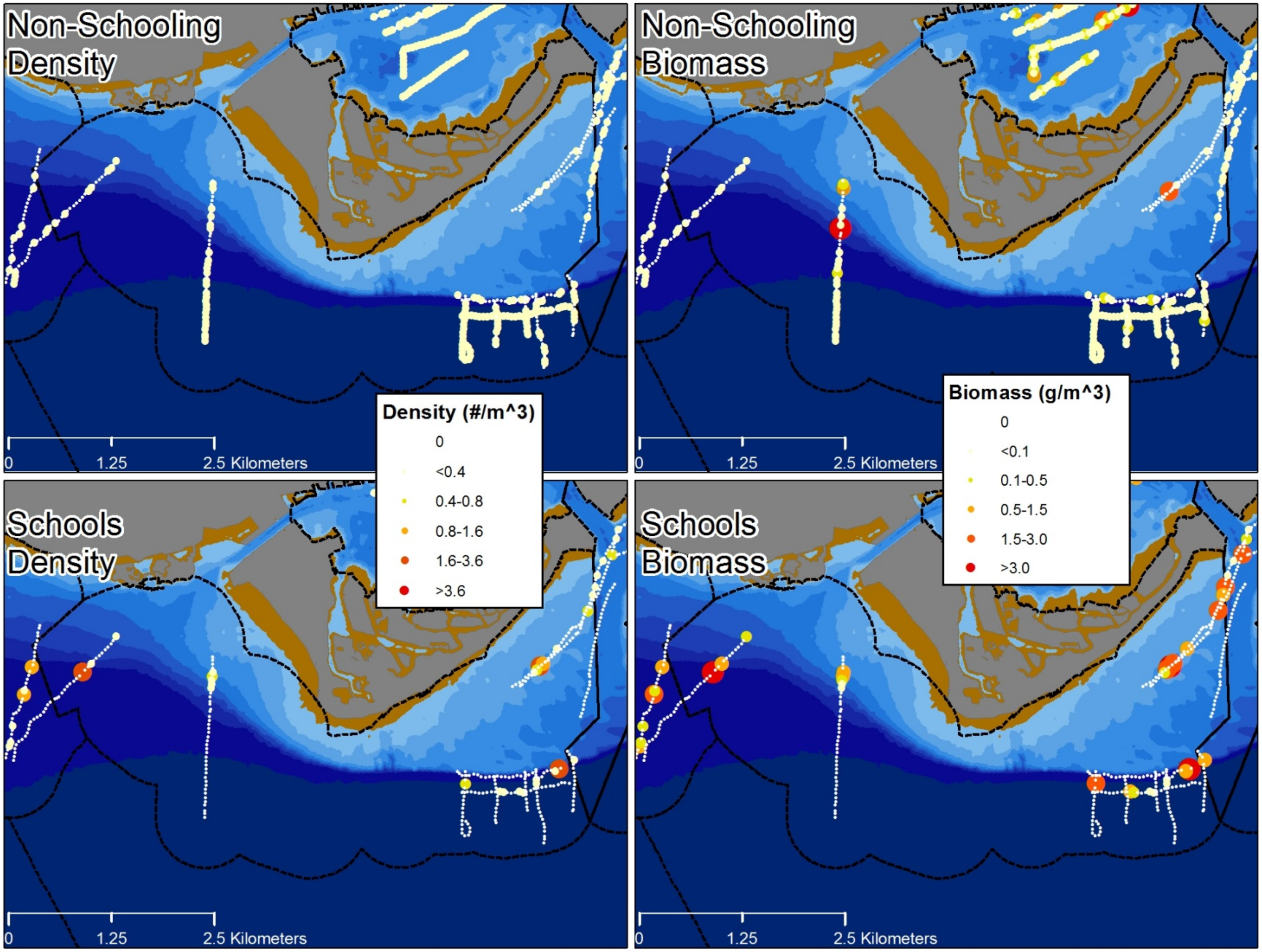

Figure 8g. Spatial distribution of non-schooling fish and school density and biomass at Outer Islands (OUTI).

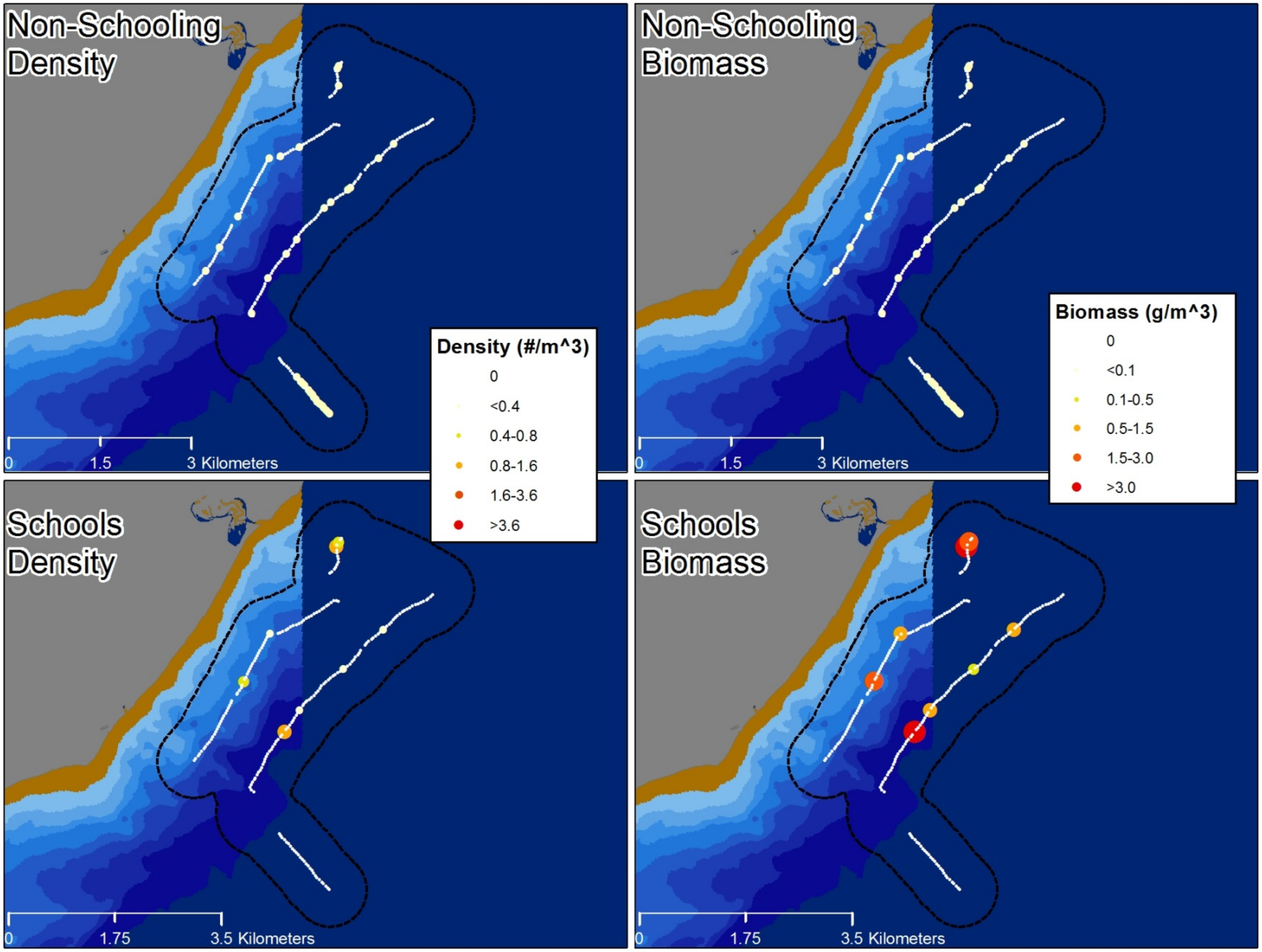

Figure 8h. Spatial distribution of non-schooling fish and school density and biomass at Rouge River mouth (ROGE). Rapid change in depth represents the boundary of the digital elevation model rather than a true rapid change.

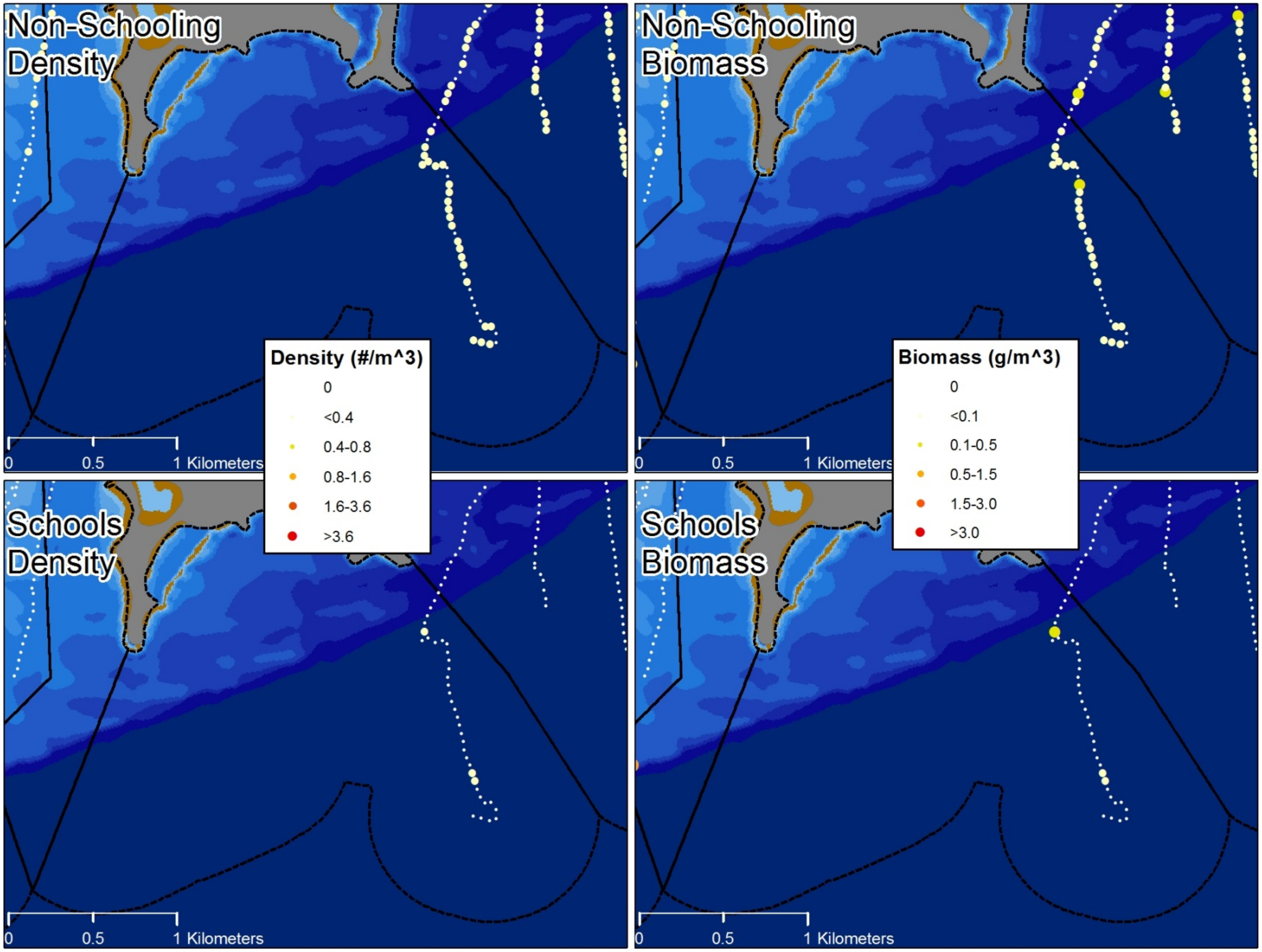

Figure 8i. Spatial distribution of non-schooling fish and school density and biomass at Tommy Thompson Park (TTPK).

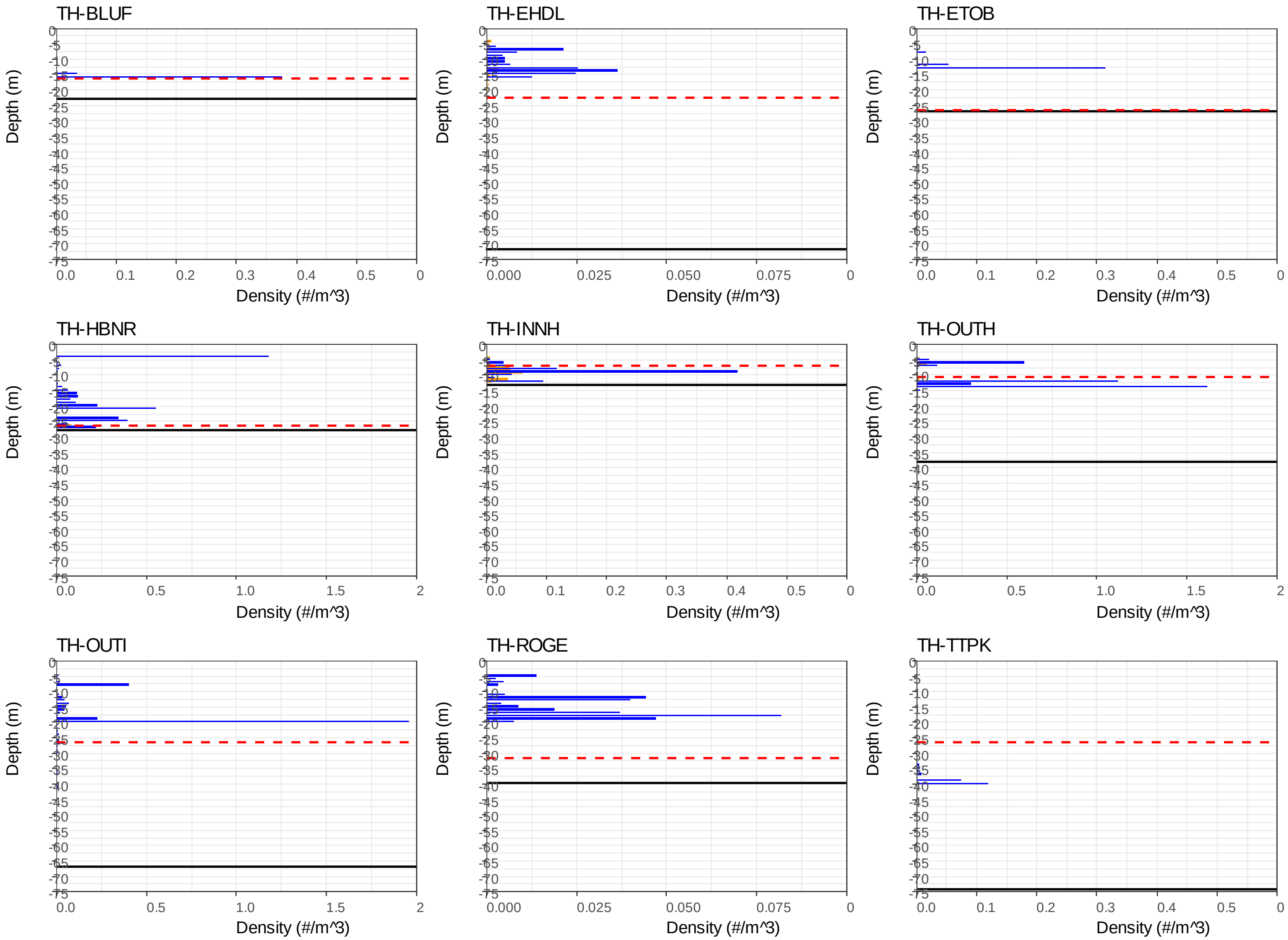

Figure 9a. Depth distribution of schools (blue) based on their density (#/m^3). Depth distributions of non-schooling fish are also present (orange), but are orders of magnitude lower than the schools such that they only appear at EHDL and INNH. More detailed assessment of non-schooling fish can be found in Figure 23b. The dashed red line indicates the mean estimated thermocline depth and the solid black line denotes the maximum water depth for surveys in each analysis sector.

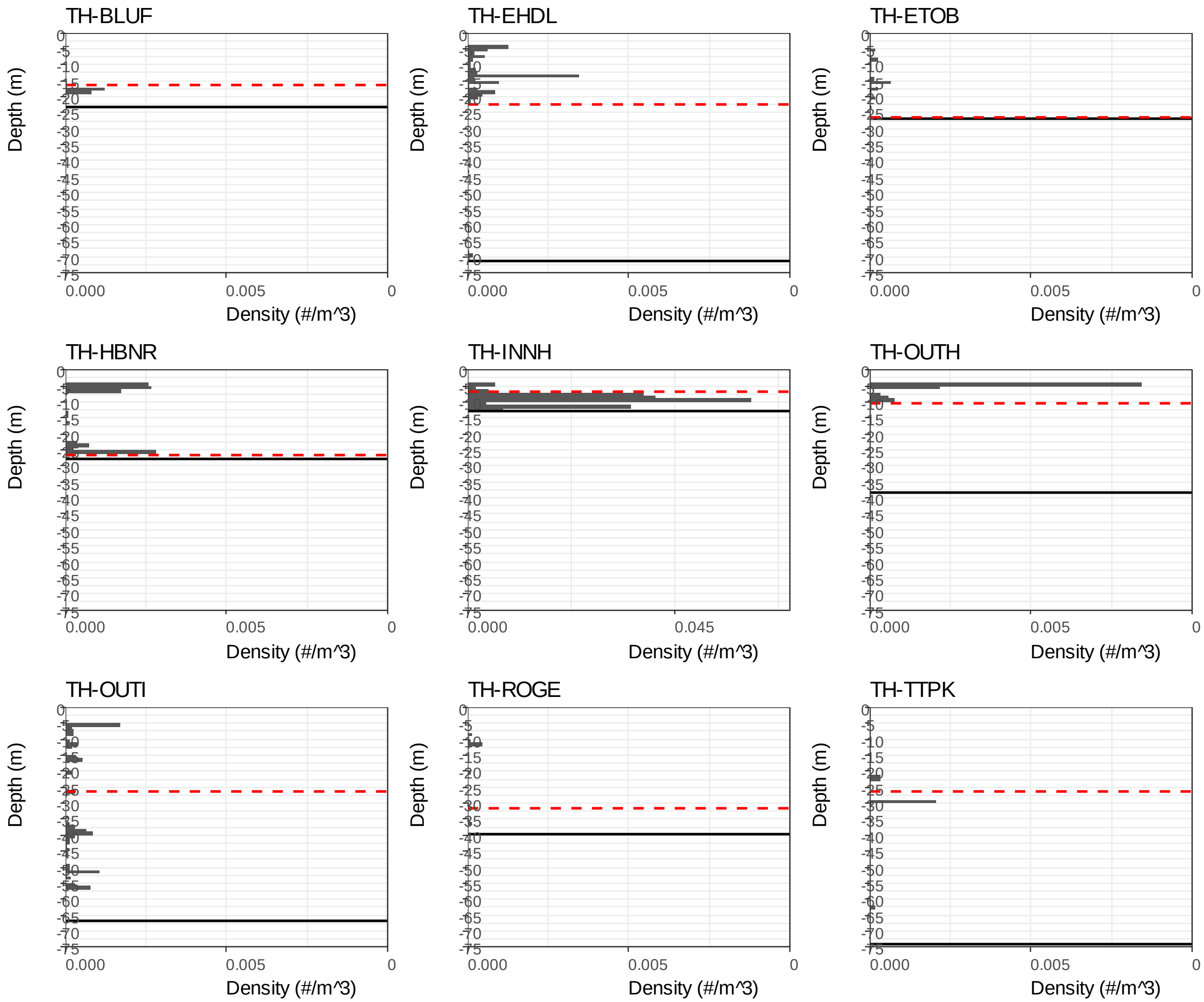

Figure 9b. Depth distribtuion of non-schooling fish (grey) based on their density (#/m^3). The dashed red line indicates the mean estimated thermocline depth and the solid black line denotes the maximum water depth for surveys in each analysis sector. Note order of magnitude difference in the x-axis relative to Figure 9a.

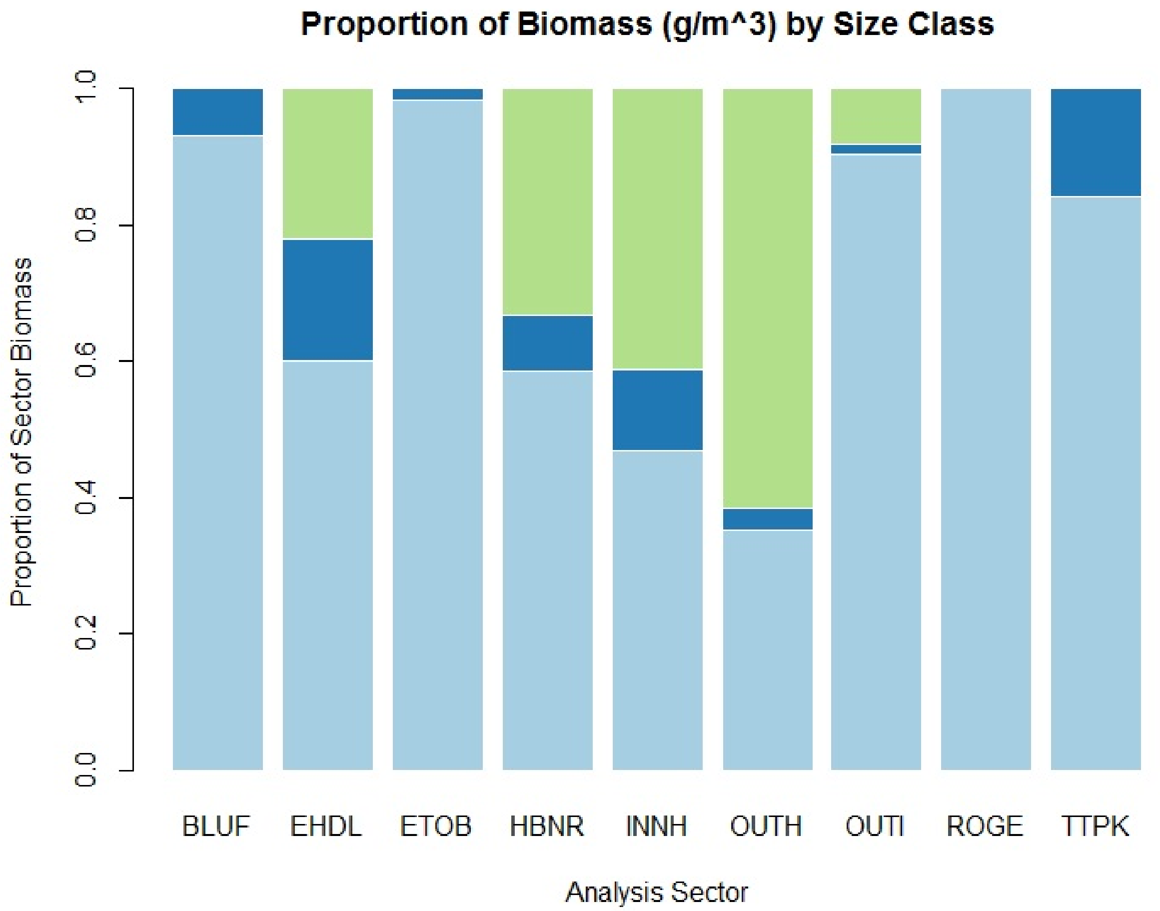

Figure 10. Propotion of biomass in each analysis sector that was accounted for by size classes 1-4 (29-250 mm, TL; lightblue), size class 5 (250-500 mm, TL; dark blue), and size class 6 (500-1200 mm, TL; green).

APPENDIX 1: GAS BUBBLES

Inspection of the 2016 Toronto and Region AOC acoustic surveys echograms revealed the presence of gas bubbles throughout the water column of several transects. The bubbles appear within the echograms as stacked columns of individual targets extending up from the acoustically detected bottom (Figure A1a). Gas bubbles are problematic for acoustics as they often share the same acoustic properties as small fish targets and therefore can bias fish density estimates (Ostrovsky 2009).

We used two methods for detecting and removing acoustic backscatter from gas bubbles:

1. For those echogram segments where the gas bubbles appear as vertical columns, we used the Echoview School Detection module to manually identify and remove regions of bubble stacks. These bubble regions were assigned as “Bad Data - Air Bubbles” in Echoview and set to Sv data below threshold. This method is described in DFO GLLFAS (2011) in section “3.1 GAS-BUBBLE EMISSIONS FROM THE SEDIMENT.”
2. For those segments where gas bubbles appear more random and/or isolated (i.e. not in vertical columns), we used the single target detection algorithm within Echoview to auto-detect “bubble track” regions using region properties such as target strength (dB) and target change in range rate (m/s). For most paired trawling transects the vessel speed was sufficiently slow and the ping rate was fast enough to provide multiple ensonifications, or “hits” on a single rising bubble. As the ascent rate of the bubbles was constant, they appeared on the echogram as individual single targets sloping up towards the surface (Figure A1a). Contiguous single targets were clustered to create track regions using the Echoview Fish Track Detection algorithm. Frequency histogram plots of the change in depth (m/s) of the exported bubble regions showed a bimodal distribution suggesting that detection regions with a change in depth <=-0.075 m/s are likely gas bubbles. All track regions that met these criteria were classified as “Bad Data - FT Bubbles” and set to “Bad Data”. Bubble track regions with a change in depth >-0.075 m/s were assumed to not be fish and deleted. Although there is the potential to erroneously remove upward swimming fish targets using this method, we feel this is unlikely given the evidence of fish schools diving in response to vessel noise. Positive identification of bubbles from those transects ([TRAN_TYPE] = “EV_Only”) where trawling was not completed was more uncertain because the increased vessel speeds did not produce long bubble tracks within the echogram. Our criteria required 3 or more single targets within a bubble track to calculate change in range.

An example of the spatial distribution of all bubble regions detected within the 2016 Toronto and Region AOC surveys is shown in Figure A1b.

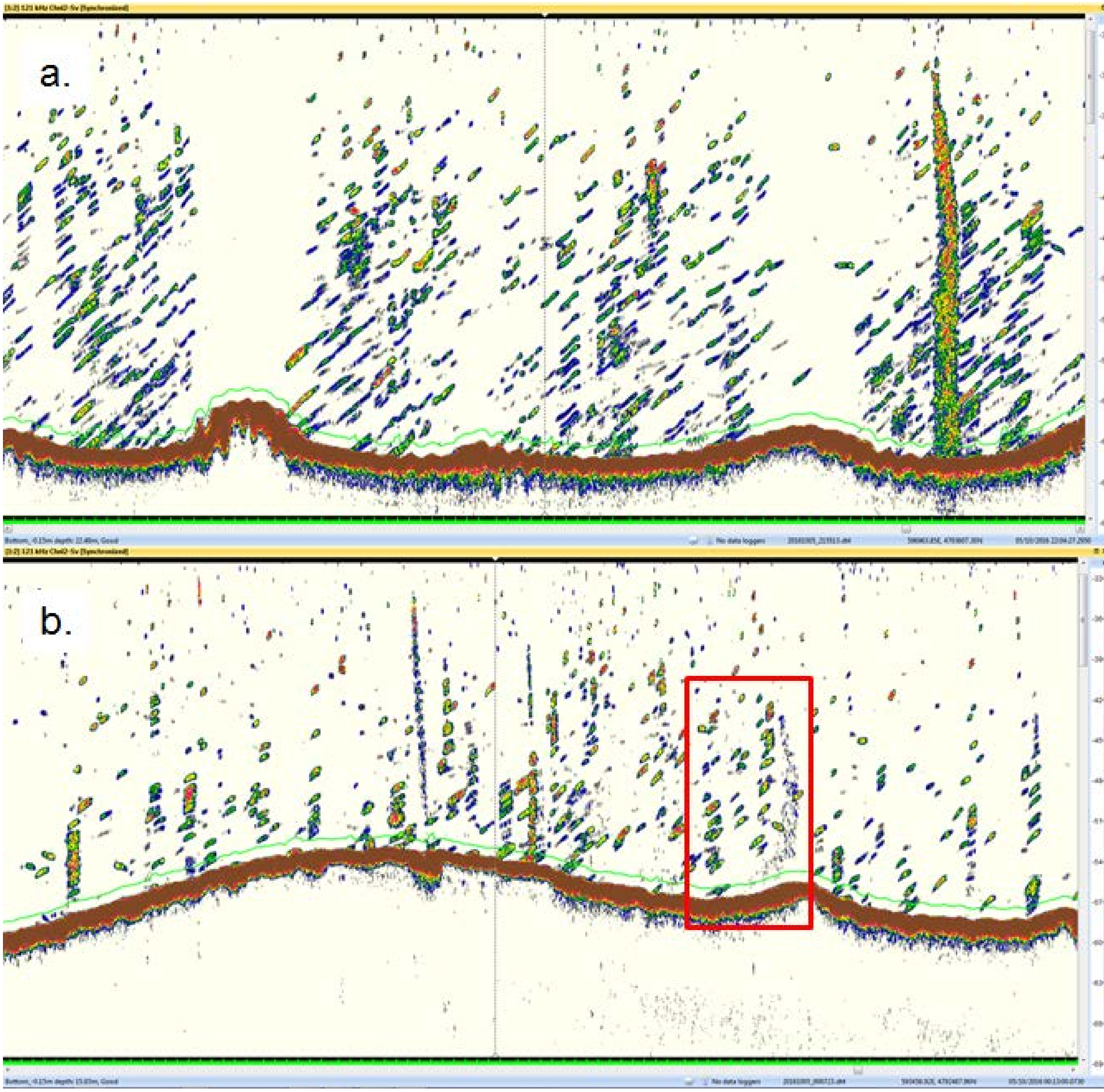

Figure A 1.1. Echogram (Sv) segment from the 2016 Hamilton Harbour hydroacoustic surveys (October 5, 2016 a. 22:04 and b. 00:13) where significant densities of gas-bubbles were identified. Gas bubble regions appeared on the echogram as either vertical columns and/or individual targets moving upwards towards the surface at a constant rate (highlighted within red box). Similar gas bubbles were detected during the Toronto and Region AOC surveys.

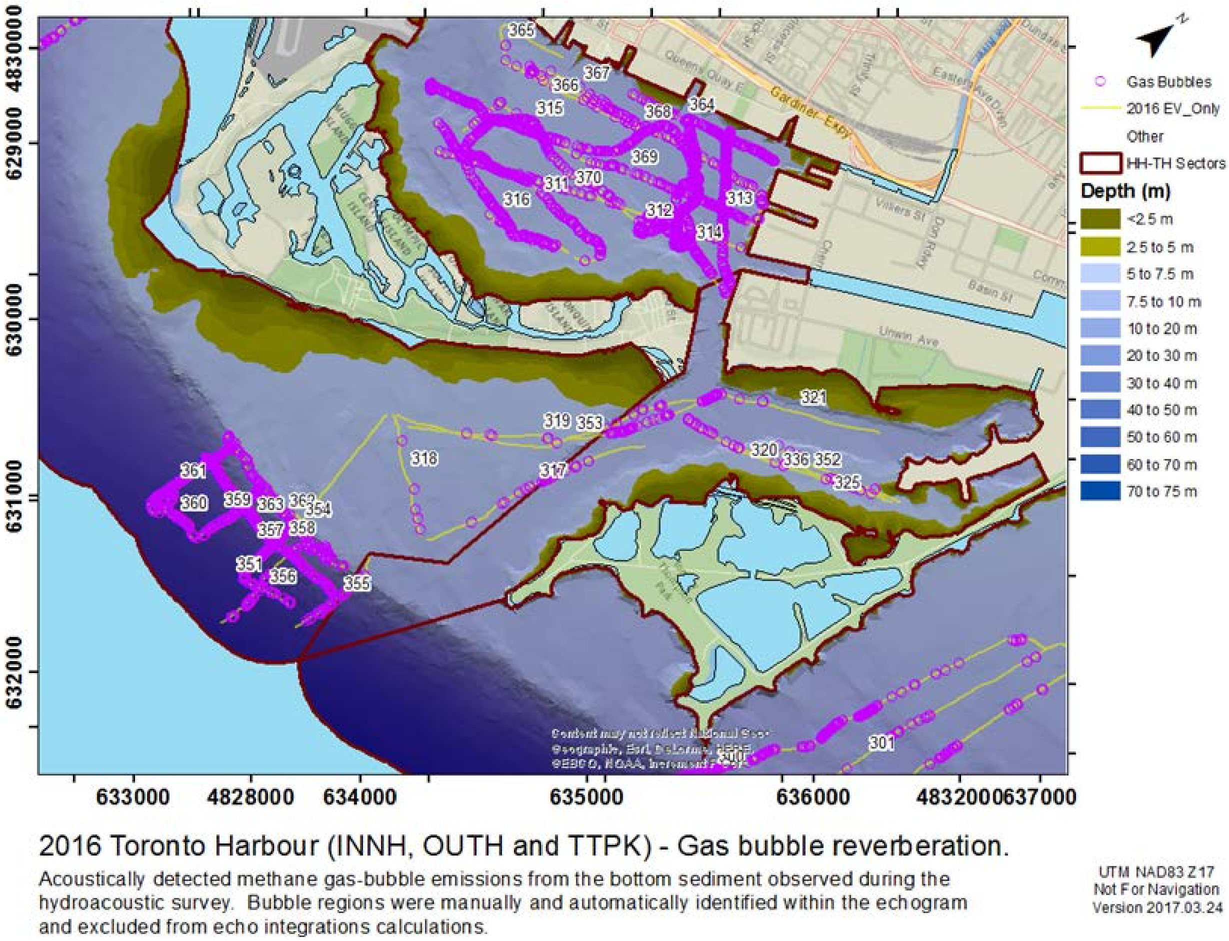

Figure A 1.2. The spatial distribution of regions identified as gas bubbles rising from the bottom sediments.

APPENDIX 2: DISSOLVED OXYGEN AND TEMPERATURE PROFILES BY TRANSECT

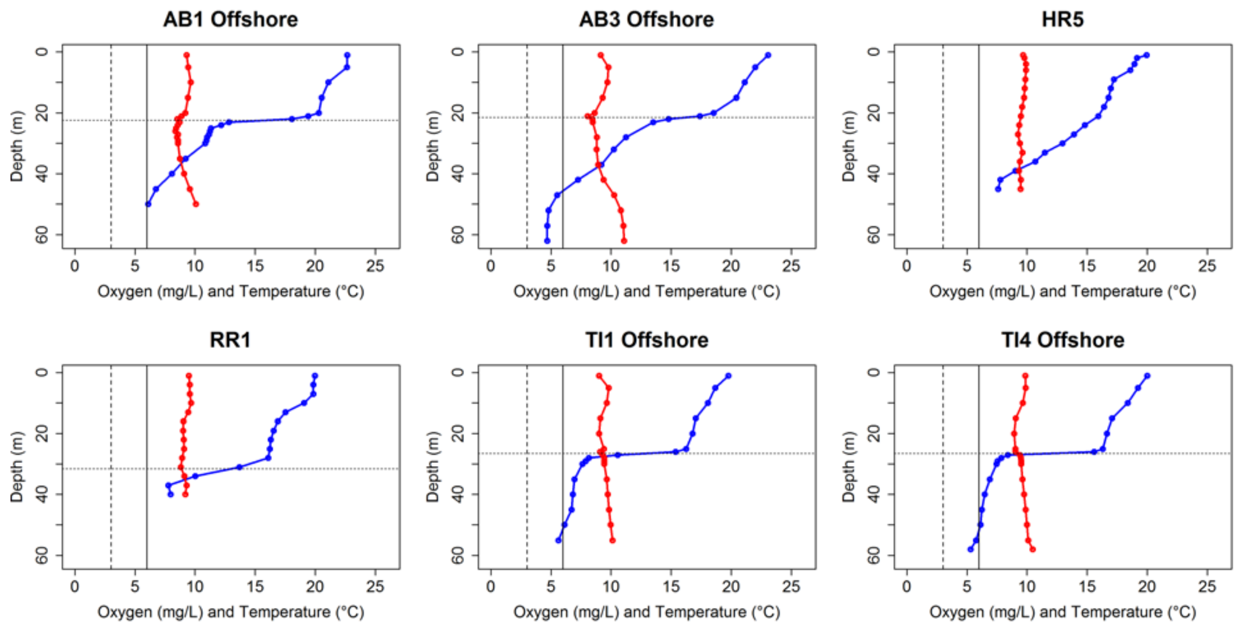

Figure A 2.1. Temperature (blue) and dissolved oxygen (red) profiles for the Toronto and Region AOC fish hydroacoustic transects. Horizontal dotted lines represent the estimated depth of the thermocline based on the *thermo.depth* function in the *rLakeAnalyzer* package. Vertical lines represent 6 mg/L (solid line) and 3 mg/L (dashed line) of dissolved oxygen to aid interpretation. Profiles were collected at the start of each transect and these sites represent the deepest locations surveyed in Toronto. Site codes: AB = Ashbridge's Bay; HR = Humber River; RR = Rouge River; and TI = Toronto Islands.

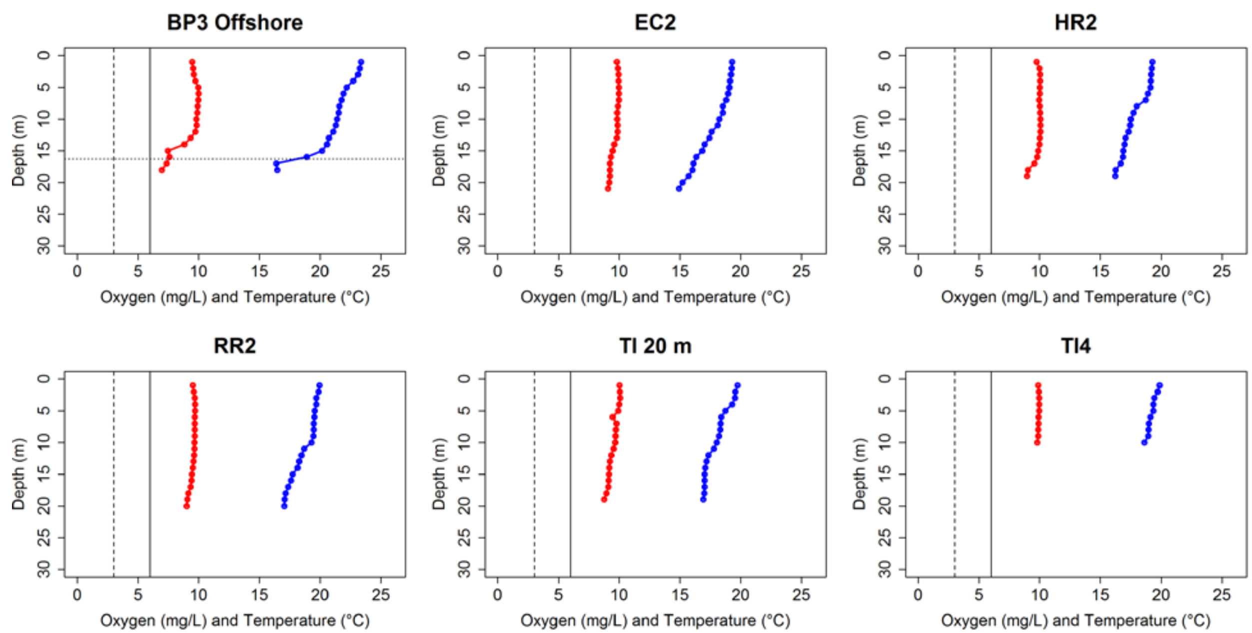

Figure A 2.2. Temperature (blue) and dissolved oxygen (red) profiles for the Toronto and Region AOC fish hydroacoustic transects. Horizontal dotted lines represent the estimated depth of the thermocline based on the *thermo.depth* function in the *rLakeAnalyzer* package. Vertical lines represent 6 mg/L (solid line) and 3 mg/L (dashed line) of dissolved oxygen to aid interpretation. Profiles were collected at the start of each transect and these sites represent locations with intermediate depths. Site codes: BP = Bluffer's Park; EC =Etobicoke Creek; HR = Humber River; RR = Rouge River; and TI = Toronto Islands.

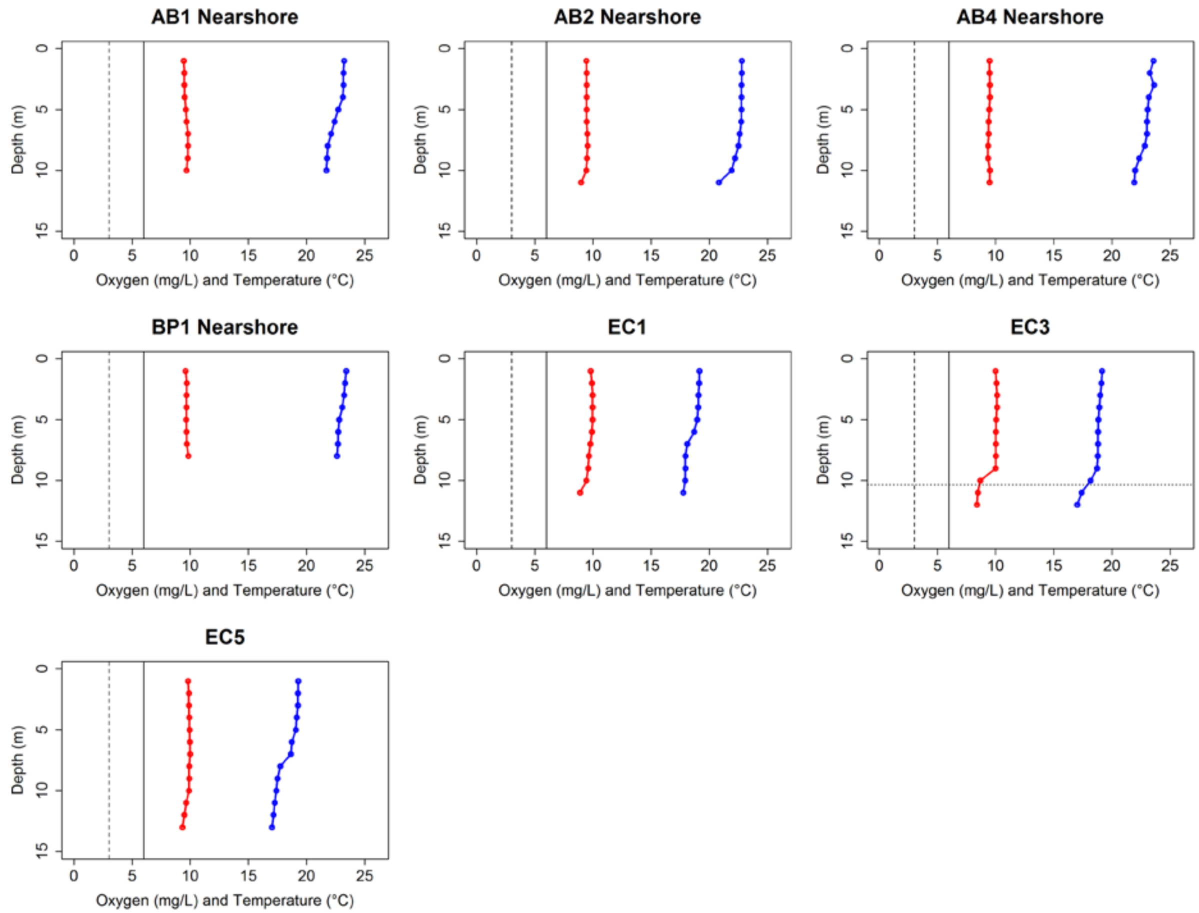

Figure A 2.3. Temperature (blue) and dissolved oxygen (red) profiles for the Toronto and Region AOC fish hydroacoustic transects. Horizontal dotted lines represent the estimated depth of the thermocline based on the *thermo.depth* function in the *rLakeAnalyzer* package. Vertical lines represent 6 mg/L (solid line) and 3 mg/L (dashed line) of dissolved oxygen to aid interpretation. Profiles were collected at the start of each transect and these sites represent locations with shallow depths. Site codes: AB = Ashbridge's Bay; BP = Bluffer's Park; and EC =Etobicoke Creek.

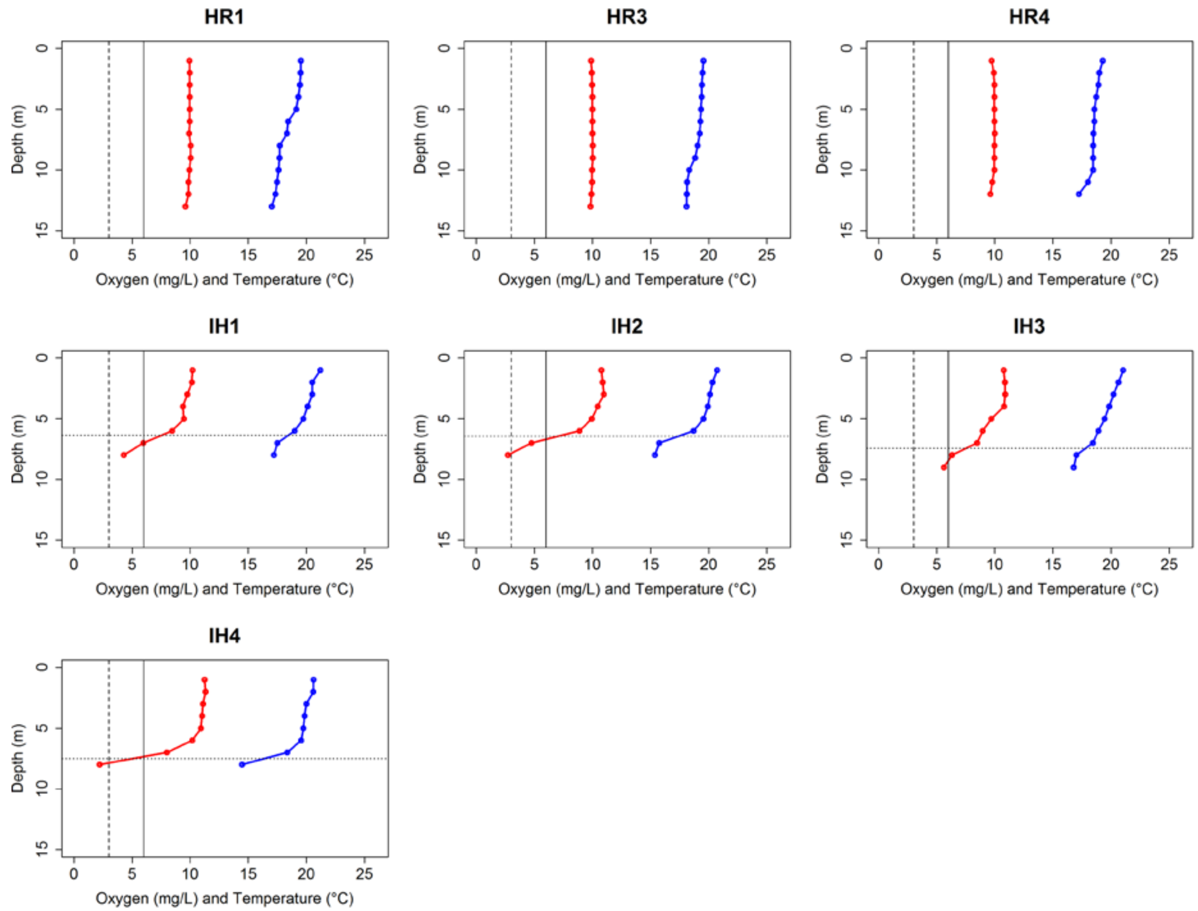

Figure A 2.4. Temperature (blue) and dissolved oxygen (red) profiles for the Toronto and Region AOC fish hydroacoustic transects. Horizontal dotted lines represent the estimated depth of the thermocline based on the *thermo.depth* function in the *rLakeAnalyzer* package. Vertical lines represent 6 mg/L (solid line) and 3 mg/L (dashed line) of dissolved oxygen to aid interpretation. Profiles were collected at the start of each transect and these sites represent locations with shallow depths. Site codes: HR = Humber River; and IH = Inner Harbour.

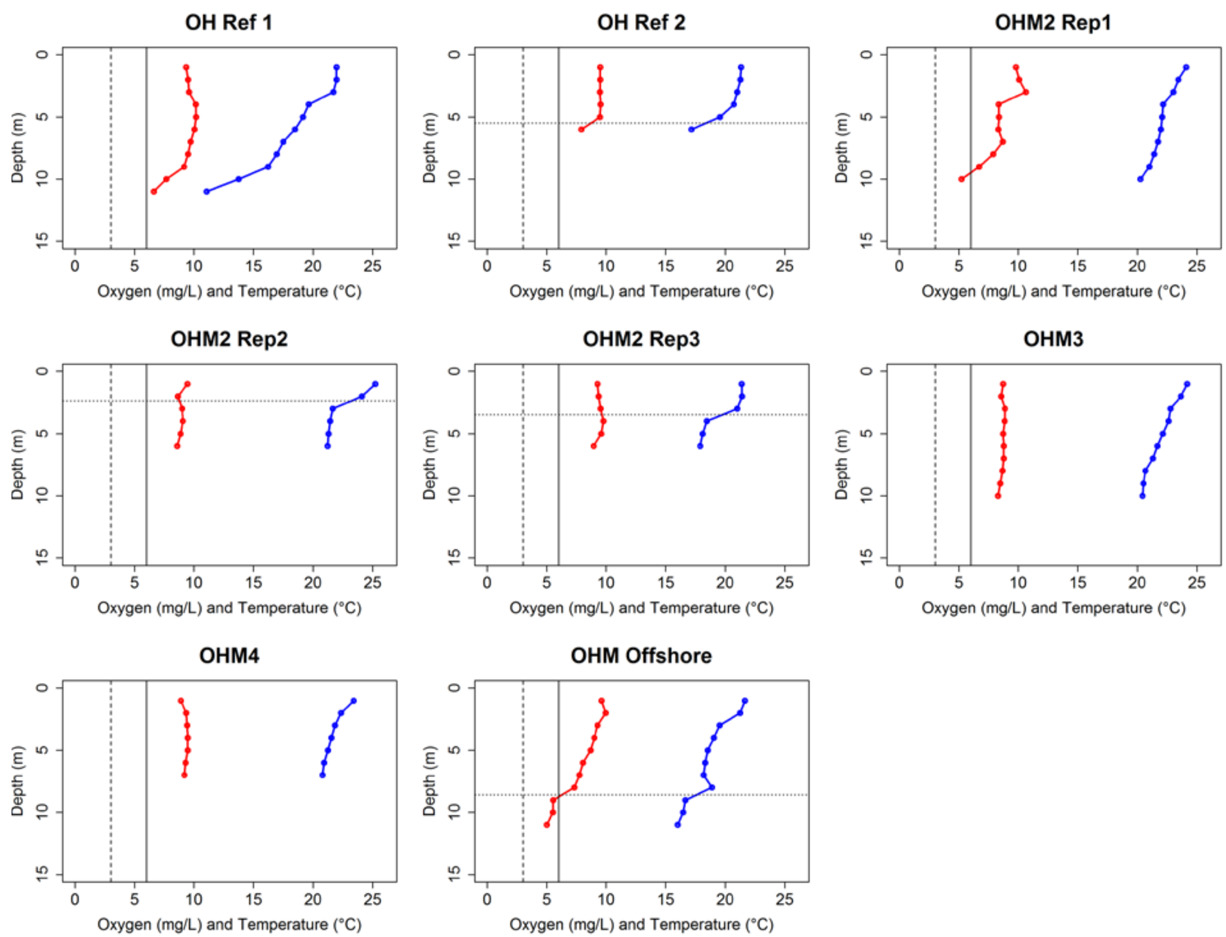

Figure A 2.5. Temperature (blue) and dissolved oxygen (red) profiles for the Toronto and Region AOC fish hydroacoustic transects. Horizontal dotted lines represent the estimated depth of the thermocline based on the *thermo.depth* function in the *rLakeAnalyzer* package. Vertical lines represent 6 mg/L (solid line) and 3 mg/L (dashed line) of dissolved oxygen to aid interpretation. Profiles were collected at the start of each transect and these sites represent locations with shallow depths. Site codes: OH = Outer Harbour; and OHM = Outer Harbour Marina.

APPENDIX 3: SUMMARY OF DENSITY AND BIOMASS ESTIMATES

Table A 3.1. Estimated mean fish density (numbers per m^3) from echo integration analysis by size class and analysis sector within the water column stratum (sum of 1m Bins) from the 2016 Toronto Harbour hydroacoustic surveys.

Analysis	Size Class 1		Size Class 2		Size Class 3		Size Class 4		Size Class 5		Size Class 6	
Sector	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
BLUF	2.05E-05	2.03E-05	0	0	0	0	5.21E-06	5.20E-06	1.02E-05	1.01E-05	0	0
EHDL	1.53E-04	4.62E-05	4.75E-05	2.70E-05	8.42E-05	2.38E-05	5.15E-05	1.99E-05	1.23E-05	7.26E-06	1.13E-06	5.25E-07
ETOB	1.50E-05	9.91E-06	2.78E-05	2.03E-05	4.05E-05	2.27E-05	0	0	2.68E-06	2.39E-06	0	0
HBNR	6.52E-05	3.54E-05	2.94E-05	1.73E-05	2.85E-05	1.37E-05	5.63E-05	3.04E-05	2.61E-05	1.64E-05	7.93E-06	6.40E-06
INNH	8.73E-03	4.35E-03	2.35E-03	7.74E-04	3.63E-03	2.43E-03	9.25E-04	5.96E-04	3.37E-04	1.12E-04	8.96E-05	4.87E-05
OUTH	4.75E-03	3.76E-03	1.67E-04	7.49E-05	1.80E-04	1.67E-04	6.36E-04	2.58E-04	1.44E-04	1.13E-04	1.86E-04	1.67E-04
OUTI	1.03E-04	4.25E-05	2.48E-05	1.45E-05	3.92E-06	1.70E-06	5.66E-05	3.72E-05	1.87E-05	8.23E-06	7.92E-06	6.14E-06
ROGE	2.30E-05	1.93E-05	1.95E-05	1.58E-05	1.79E-06	1.08E-06	8.79E-06	5.98E-06	0	0	0	0
TTPK	1.23E-05	1.11E-05	7.35E-06	6.66E-06	1.47E-05	1.33E-05	2.45E-06	2.22E-06	4.90E-06	4.44E-06	0	0

Table A 3.2. Estimated mean fish biomass (g per m^3) from echo integration analysis by size class and analysis sector within the water column stratum (sum of 1m Bins) from the 2016 Toronto Harbour hydroacoustic surveys.

Analysis	Size Class 1		Size Class 2		Size Class 3		Size Class 4		Size Class 5		Size Class 6	
Sector	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
BLUF	1.63E-05	1.62E-05	0	0	0	0	9.65E-05	9.62E-05	4.37E-03	4.33E-03	0	0
EHDL	1.27E-04	4.05E-05	6.65E-05	3.26E-05	3.89E-04	1.05E-04	8.90E-04	3.56E-04	5.17E-03	3.14E-03	6.31E-03	3.01E-03
ETOB	1.19E-05	7.88E-06	4.80E-05	3.50E-05	1.72E-04	9.17E-05	0	0	1.14E-03	1.01E-03	0	0
HBNR	5.29E-05	2.82E-05	5.07E-05	3.00E-05	1.42E-04	6.83E-05	9.98E-04	5.36E-04	1.11E-02	7.07E-03	4.56E-02	3.69E-02
INNH	4.92E-03	2.49E-03	4.01E-03	1.37E-03	1.84E-02	1.23E-02	1.87E-02	1.25E-02	1.47E-01	4.93E-02	5.16E-01	2.81E-01
OUTH	4.28E-03	3.42E-03	2.48E-04	1.03E-04	1.01E-03	9.46E-04	1.35E-02	5.73E-03	6.43E-02	5.12E-02	1.27E+00	1.17E+00
OUTI	1.02E-04	4.23E-05	4.38E-05	2.56E-05	1.96E-05	8.53E-06	1.26E-03	9.09E-04	7.83E-03	3.52E-03	4.53E-02	3.53E-02
ROGE	1.83E-05	1.54E-05	3.37E-05	2.74E-05	8.97E-06	5.38E-06	1.59E-04	1.04E-04	0	0	0	0
TTPK	9.77E-06	8.85E-06	1.27E-05	1.15E-05	7.35E-05	6.66E-05	4.93E-05	4.47E-05	1.86E-03	1.66E-03	0	0